INFRA-RED REFLECTANCE AND TRANSMITTANCE BY THIN FILM COATINGS OF SOME SELECTED METALS ON GLASS SUBSTRATE

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DECLARATION

I Kamwasir Hellena do hereby declare that this dissertation is my original piece of work and that it has never been previously submitted to any institution.

Signature of Candidate:.........................

Date:........14th Nov 2018........................

APPROVAL

This is to certify that this research dissertation by Kamwasir Hellena was produced under our supervision and is now ready for submission to the Board of Graduate School and senate of Kyambogo University with our approval.

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DEDICATION

This research dissertation is dedicated to my son, Daniel Namara whose fight against autism has inspired me to work hard against all odds.

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It has been a long and challenging journey to the completion of my dissertation and it would have been impossible for me to accomplish this goal if it wasn't for some people whose guidance, love, support and encouragement, gave me determination to take another step.

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God promised us that we are never alone in our journey of life. I give him all the credit for helping me reach my destination in this important journey of my academic life.

LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

Symbol	Description
A	Absorptance
δ	phase difference for light traversing a film
θ	light incident, refraction or reflected angle
λ	wavelength
k	extinction coefficient (imaginary part of refractive index)
n	refractive index
k	wave number
N	complex refractive index
θ_B	Brewster angle
α	absorption coefficient
P	gas pressure
ε	dielectric constant
ε_1	real part of dielectric constant
ε_2	imaginary part of dielectric constant
d	film thickness
c	velocity of light of light in vacuum
ω	angular frequency
t	time
D	electric displacement vector
B	magnetic flux density
H	magnetic field intensity

E	Electric flux density
μ	permeability of free space
$E^{i,r,t}$	incident, reflected and transmitted electric wave
E_j^+	forward travelling wave at j^{th} interface
E_j^-	back-travelling wave at j^{th} interface
J	current density vector
λ_m	mean free path
R	reflectance
r	deposition rate
r	reflection coefficient
r_{ij}	Fresnel's reflection coefficient
T	transmittance
t	transmission coefficient
t_{ij}	Fresnel's transmission coefficient

ABBREVIATIONS AND ACRONYMS

IR	infrared
NIR	near infrared
VIS	visible
UV	ultraviolet
XRD	x-ray diffraction
PUMA	Pointwise Unconstrained Minimization approach
mfp	mean free path
EMA	effective media approximation

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ABSTRACT

Reflection and transmission of light serve as key parameters in thin films coatings meant for temperature regulation in warm climates. In this study, the infrared reflectance and transmittance for three different thicknesses of thin films of palladium and platinum were determined. The thin films were made by thermally evaporating various masses of the platinum and palladium on glass substrates.

A Shimadzu UV-VIS-NIR Spectrophotometer was used to determine the reflectance and transmittance of the samples from which the spectra were determined. Ex situ measurements, using Pointwise Unconstrained Minimization Approach (PUMA) were made to determine the exact thicknesses of the films.

Reflectance was found to vary with film thickness. The results showed that the 60 nm film of palladium had a maximum reflectance of 33%, 140 nm film, a maximum reflectance of 39% and 230 nm film, a maximum reflectance of 72%. For platinum, the 140 nm film had a maximum reflectance of 28%, 146 nm film a maximum of 35% and 395 nm film a maximum reflectance of 42%. In all the cases, the reflectance in the infrared part of the spectra (800-2500 nm) was higher than in the visible region which suggests that palladium and platinum thin films may be used as heat mirrors. The transmittances of palladium and platinum thin films were high (over 80%) an indication that the thin films probably had voids. The study also showed that for the same thickness of palladium and platinum films (Palladium film of 140 nm and platinum film of 140 nm), palladium has greater reflectance than platinum showing dependence of reflectance of thin film on material used for its fabrication.

CHAPTER ONE: INTRODUCTION

1.1 Background of study:

The field of material science and the engineering community's ability to conceive the novel materials with extraordinary combination of chemical, physical and mechanical properties has changed modern society. Modern technology requires thin films for diverse applications among which are in semiconductor devices, wireless communications, intergrated circuits and multi functional emerging coatings. Thin film studies have directly or indirectly advanced many new areas of research in solid state Physics and Chemistry which are based on the phenomena uniquely characteristic of the thickness, geometry and structure of the film (West, 2003). The phenomenal rise in thin film researches have led to numerous inventions including super conduction films, interference filters, reflecting and anti-reflecting coatings (Maat et al, 2008)

Optical coating is done by depositing one or more thin layers of dielectric or metal on a substrate. The coating alters the way in which the component reflects and transmits light. One type is the anti-reflection coating which reduces unwanted reflections. Another is the high reflector coating. More complex coatings exhibit high reflection over some range of wavelength and anti-reflection over another range, allowing the production of dichroic thin film optical filters.

The solar radiation which falls on the earth's surface consists of various components that are characterized by different wavelengths like ultraviolet (300 nm - 400 nm), visible light (400 nm - 700 nm) and infrared (700 nm – 1 mm). The long wavelength part of the radiation (infrared radiation) causes heating. Optical coatings have been applied in the manufacture of energy efficient windows where glass is coated with metallic films to reduce indoor heating. The heating is a direct result of absorption of infrared radiation by carbon dioxide and water vapour.

A Country like Uganda which lies in the tropics has warm climate almost throughout the year. The importance and the necessity for energy saving have forced researchers to find a way to reduce the thermal load in hot climate regions in building resulting from solar radiation through the use of thin film coating on the glass windows. On the other hand, also to enhance its transmission for heating purposes in cold climate regions.

For a glass window to be effective in regulation of temperature in warm climates, it should have spectrally selective coatings such that it transmits the energy in the visible (VIS) and reflects all the energy in the infrared (NIR). In cases where the coating is opaque, the reflective metal film may be sandwiched between two dielectric layers that act as antireflective coatings to enhance the energy transmitted in the visible region. By varying the material and thickness of one or more of the layers, the optical behavior of the device can be tailored to suit different applications (Marta et al, 2003).

Noble metals are metals that are resistant to corrosion and oxidation in moist air. They include silver and gold, and the platinum group metals which include; ruthenium, rhodium, palladium, osmium, iridium and platinum. The optical, mechanical and chemical properties of noble metals are exploited in optical and protective coatings. In particular, noble metals have an intrinsic heat mirror function (Titta, 2004). If they are made sufficiently thin, approximately 10 nm, they transmit in the visible, but are still reflecting in the infrared. This function is critically dependent on the low refractive index-value in the relaxation region. Platinum and palladium metals are durable, resistant to oxidation and high temperature corrosion. However in practice, noble metal films are too soft and vulnerable to chemical attack to be used alone. This may therefore necessitate the use of dielectric layers which both protect the thin metal film from degradation and anti-reflect it to enhance transmission of visible light.

Cars usually get overheated when parked under sunshine, or when stuck in a jam in a busy city like Kampala, Uganda's capital city. Thermal energy may also be transmitted via conduction and convection and radiant barriers do not necessarily protect against these forms of heat transfer.

More alarming, is the fact that global climate change is increasing the average temperature and direct heat exposure in many places around the world. In countries with very hot seasons, workers are usually affected by working environments hotter than that with which human physiological mechanisms can cope (Lemke et al, 2009). Modern urban development as is the case in Kampala, adds several degrees to local temperature (Lemke et al, 2009). This implies higher exposure to heat which creates very unhealthy environments for people who are not able to protect themselves with air conditioning. Both living and working environments are affected, and this negatively impacts on people's health and on economic conditions. The potential health risks and worker productivity reductions due to increased temperatures are substantial (Lemke et al, 2009). The lack of attention may well be due to the fact that this is mostly a problem in the low and middle income countries like Uganda where climate change impacts are prominent and yet air conditioning is not widely available.

There is need therefore, to develop reasonably cheap reflective barriers which reflect significant amount of infrared radiation in an effort to reduce overheating in houses and vehicles. The researcher seeks to investigate the use of platinum group noble metals as radiant barriers. These metals are characterized by good corrosion resistance. The metallic elements to be investigated are palladium and platinum.

1.2 Problem Statement

The infrared part of the solar spectrum causes indoor heating and overheating in parked vehicles. The increasing heat exposure due to local climate is likely to create more cases of vehicle related hyperthermia, occupational health risks and, have a significant impact on productivity of many workers unless effective preventive measures (adaptation) reducing indoor and occupational heat stress are implemented. Normal glass which is used in most windows in houses and vehicles has significant transmittance in the infrared spectrum (Maynard, 2002). In a bid to minimize the risks mentioned above, there is need to explore a relatively cheap infrared reflective barriers which are corrosive resistant to be coated on the ordinary glass used in house windows and vehicle openings.

1.3 Purpose of the Study

The purpose of this study is to determine infrared reflection and transmittance by thin film coatings of some selected noble metals on glass substrate.

1.4 Objectives of the Study

To realize the above purpose, the researcher has set out the following objectives:

(i) To fabricate thin films of various thicknesses on glass using platinum and palladium of the platinum group of noble metals.

(ii) To determine reflectance of glass coated thin films.

(iii) To determine the transmittance of glass coated thin films.

(iv) To compare the reflectance and transmittance of glass coated thin films.

1.5 Scope of the study

In this study, thin films of two metals were fabricated. These metals were platinum and palladium of the platinum group of noble metals. For each of the metal films, three different thicknesses were considered. The thicknesses were varied by evaporating 0.02 g, 0.04 g and 0.06 g of the metals on a glass substrate. Ex situ measurements yielded 60 nm, 140 nm, 230 nm respectively for palladium and 140 nm, 146 nm, 395 nm respectively for platinum. The thicknesses were determined using Pointwise Unconstrained Minimisation Approach (PUMA).

These metal films were then tested to determine their infra-red reflectance and transmittance. In order for a coating to be used as a heat mirror, it should have high reflectance in the infra-red spectrum as well as high transmittance in the visible spectrum.

1.6 Significance of the study

The research avails data which can be used by industrialists to develop and produce infra-red reflective glasses. The adoption of the infra-red reflective glass windows reduces indoor ambient temperatures and thus reducing cases of heat stroke. Reducing indoor temperatures, makes the work environment more conducive and thus eliminates cases of slowing down of work hence improving economic productivity. A thermally conducive environment also reduces incidences of diminished mental task ability and hence, accident risk. Moreover, cars will be cooler and therefore comfortable when parked under sunshine or caught in a jam; hence, eliminating cases of vehicle related hyperthermia.

In addition, scientists can use it as base-line data for further research in development of more specialized glass type for use in optical and, electronic components.

The data can also be useful to the Uganda Bureau of Standards in setting the minimum standard of window glass in vehicles, school and hospital buildings, so as to minimize risks of hyperthermia.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1 Propagation of electromagnetic waves

There exist a number of phenomena related to the propagation of light and its interaction with material media. Application of Maxwell's equations and the associated boundary conditions is helpful in tracing the progress of radiant energy through any system. The laws of reflection and refraction of light can be deduced by many approaches like the Huygen's principle, theory of Malus and Dupin, Fermats principle and the electromagnetic principle. The more powerful approach is provided by the electromagnetic theory of light and Maxwell's equations which provide us with all the information that can be drawn from classical theory of electric and magnetic fields.

The definition of a "thin film" in this context includes cases where more than one boundary is considered to obtain the resulting optical behavior. In principle, the determination of the amplitudes and intensities of beams of light reflected or transmitted by a thin film or a system of several films can be done by setting up Maxwell's equations and applying the appropriate boundary conditions. In practice however, the resulting equations are depressingly complicated and the evaluation of the properties of a given combination of films involves monstrously tedious computation.

Consider an optically homogenous, isotropic medium of dielectric constant ε, magnetic permiabillity μ, and electric conductivity σ. The electric displacement vector **D** and current density vector **J**; the amount of electric current flowing through a unit cross-sectional area, are related to the electric field E, magnetic field intensity **H** and the magnetic flux density **B** through the material as per the equations (1) (2) and (3).

$$\mathbf{J} = \sigma\mathbf{E} \tag{1}$$

$$\mathbf{D} = \varepsilon\mathbf{E} \tag{2}$$

$$\mathbf{H} = \frac{1}{\mu}\mathbf{B} \tag{3}$$

In regions of space where there is no charge or current, Maxwell's equations read

$$\nabla \bullet \mathbf{D} = \rho \quad (4)$$

$$\nabla \bullet \mathbf{B} = 0 \quad (5)$$

$$\nabla x\mathbf{E} + \frac{\partial \mathbf{B}}{\partial t} = 0 \quad (6)$$

$$\nabla x\mathbf{H} = J + \frac{\partial \mathbf{D}}{\partial t} \quad (7)$$

Using equations (1) and (2) Maxwell's equations reduce to

$$\nabla \bullet \mathbf{D} = \frac{1}{\varepsilon}\rho \quad (8)$$

where, ρ is the total charge density

$$\nabla \bullet \mathbf{B} = 0 \quad (9)$$

$$\nabla x\mathbf{E} + \mu\frac{\partial \mathbf{H}}{\partial t}=0 \quad (10)$$

$$\nabla x\mathbf{H} = \sigma\mathbf{E} + \varepsilon\frac{\partial \mathbf{E}}{\partial t} \quad (11)$$

The curl of equation (10) gives us

$$\nabla x(\nabla x\mathbf{E}) = -\mu\frac{\partial}{\partial t}(\nabla x\mathbf{H}) = -\nabla x\frac{\partial \mathbf{B}}{\partial t}$$

Maxwell's' equations describe how electric and magnetic fields are generated by charges and changes of fields and how they physically propagate through space. The electric and magnetic fields are perpendicular to the direction of propagation of the electromagnetic waves. The curl describes a swirl of the magnetic and electric vectors which describes cycloid motion, a characteristic of electromagnetic waves.

Substituting (11) into (12) and using vector identities we get

$$\nabla(\nabla \bullet \mathbf{E}) - \nabla^2\mathbf{E} = -\mu\frac{\partial J}{\partial t}-\mu\varepsilon\frac{\partial^2 \mathbf{E}}{\partial t^2}.$$

i.e

$$\nabla^2\mathbf{E} - \mu\varepsilon\frac{\partial^2\mathbf{E}}{\partial t^2} - \mu\sigma\frac{\partial\mathbf{E}}{\partial t} = \nabla(\frac{\rho}{\varepsilon_o}) \quad (13)$$

This is a very useful equation and many other equations can be derived from it. In the absence of space charges, (ρ=0) equation (12) transforms to

$$\nabla^2\mathbf{E} - \mu\varepsilon\frac{\partial^2\mathbf{E}}{\partial t^2} - \mu\sigma\frac{\partial\mathbf{E}}{\partial t} = 0 \quad (14)$$

This equation may be simplified further depending on whether a medium is conducting or non-conducting. For a conducting medium, the third term from the left of (14) is dominant and we write it as

$$\nabla^2\mathbf{E} - \mu\sigma\frac{\partial\mathbf{E}}{\partial t} = 0 \quad (15)$$

This is known as the diffusion equation.

For a non-conducting medium the term involving σ in equation (14) can be neglected and we have

$$\nabla^2\mathbf{E} - \mu\varepsilon\frac{\partial^2\mathbf{E}}{\partial t^2} = 0 \quad (16)$$

Similarly, equations can be obtained for the magnetic field intensity **H**

$$\nabla^2\mathbf{H} - \mu\varepsilon\frac{\partial^2\mathbf{H}}{\partial t^2} - \mu\sigma\frac{\partial\mathbf{H}}{\partial t} = 0 \quad (17)$$

and thus an equivalent of (15) would be given by

$$\nabla^2\mathbf{H} - \mu\varepsilon\frac{\partial^2\mathbf{H}}{\partial t^2} = 0 \quad (18)$$

If the field is time harmonic then **E** and **H** have a phase actor of the form exp(-iωt) where w is the angular frequency, then we can rewrite (11) and (10) of as (12)

$$\nabla\mathrm{x}\mathbf{H} + i\omega\left(\varepsilon + i\frac{\sigma}{\omega}\right)=0 \quad (19)$$

$$\nabla x\mathbf{E} - i\omega\mu\mathbf{H} = 0 \tag{20}$$

respectively and (14) becomes

$$\nabla^2\mathbf{E} + k^2\mathbf{E} = 0 \tag{21}$$

where k is the complex wave number, ω the angular frequency and ε is the dielectric constant and are respectively defined as

$$k^2=\omega^2\mu\varepsilon \tag{22}$$

$$\varepsilon=\varepsilon+i\frac{\sigma}{\omega} \tag{23}$$

Equation (23) can be rewritten as

$$\varepsilon=\varepsilon_1+i\varepsilon_2 \tag{24}$$

Where, ε_1 and $\varepsilon_2$are real and imaginary parts of the dielectric constant respectively.

Introducing a complex phase velocity v and complex refractive index N we have

$$v=c\mu\varepsilon^{\frac{1}{2}} \tag{25}$$

$$\text{and} \quad N = \mu\varepsilon^{\frac{1}{2}} = \frac{c}{\omega}k \tag{26}$$

$$\text{or} \qquad N=n+ik \tag{27}$$

where c is the velocity of light in vacuum, n is the refractive index and *k* the extinction coefficient. To characterize the interaction process between the electromagnetic waves and media we use ε_1 and ε_2 or n and *k*. Squaring (26) and (27) using (23) and (24) then equating real and imaginary parts yields the Drude's relations

$$n^2\text{-}k^2 =\varepsilon=\varepsilon_1 \tag{28}$$

$$2nk=\frac{\sigma}{\omega}= \varepsilon_2 \tag{29}$$

where u≈1 at optical frequencies. The optical constants of a medium are thus frequency dependent. Solving (28) and (29) gives

$$n^2 = \frac{1}{2}\{\varepsilon_1 + (\varepsilon_1^2 + \varepsilon_2^2)^{\frac{1}{2}}\} \quad (30)$$

$$k^2 = \frac{1}{2}\{-\varepsilon_1 + (\varepsilon_1^2 + \varepsilon_2^2)^{\frac{1}{2}}\} \quad (31)$$

Since n and *k* must be real the positive sign of the square root is then taken. If ε_1 andε_2 are known then n, *k* calculations can be possible. Use of Fresnel's equations can help obtain reflectance and transmittance. For non-conducting media σ=0 thus from (28) and (29)

$$k=o \quad (32)$$

$$n^2= \varepsilon \quad (33)$$

We now return equations (15) and (18).The simplest type of wave that is a solution to these equations is a plane wave and is a good approximation to actual waves in many situations. A plane wave is one in which the wave amplitude and the field vectors are constant over all points of a plane normal to the direction of propagation. This plane constitutes a wave front which advances with velocity, v, in a direction normal to itself. We may choose the coordinate system in such a way that the direction of propagation coincides with say z-axis and since the wave equation takes a one dimensional form such as

$$\frac{\partial^2\omega}{\partial z^2} - \frac{1}{v^2}\frac{\partial^2\omega}{\partial t^2} = 0 \quad (34)$$

Comparing (10) and (12),

$$v = (\varepsilon\mu)^{-\frac{1}{2}} \quad (35)$$

is the velocity of propagation and in vacuum

$$v = (\varepsilon_o\mu_o)^{-\frac{1}{2}} \quad (36)$$

Equation (34) has a general solution

$$\psi(x,t)=A\exp i(kz-\omega t)+B\exp -i(kz-\omega t)=f(z-vt)+g(x+vt) \quad (37)$$

where A and B are generally complex constants and k=$\frac{\omega}{v}$ where v is the phase velocity of the wave. The equation (37) represents waves travelling to the right and to the left with velocity v. We may assume that the plane wave fields are of the form

$$\mathbf{E}(z,t)=E_o \exp i(kz-\omega t) \tag{38}$$

$$\mathbf{H}(z,t)=H_o \exp i(kz-\omega t) \tag{39}$$

For the propagation of the wave in any arbitrary direction, we have

$$\mathbf{E}(r,t)=E_o \exp i(k.r\pm\omega t), \tag{40}$$

$$\mathbf{H}(r,t)=H_o \exp i(k.r\pm\omega t) \tag{41}$$

Where E_o and H_o are constants in time. Substituting k in accordance with (26) and (27) into (38) we get

$$\mathbf{E}=E_o \exp\left(-\omega \frac{kz}{c}\right) \exp i \frac{\omega}{c}(nz-t) \tag{42}$$

The real part of this expression can be expressed as:-

$$\mathbf{E} = E_o \exp\left(-\omega \frac{kz}{c}\right) \cos\{\frac{\omega}{c}(nz-t)\} \tag{43}$$

This represents the electric vector and is a plane wave with wavelength $\lambda=\frac{2\pi c}{\omega n}$ and with attenuation given by the exponential term. The significance of the extinction coefficient *k* can be seen clearly from (43) as a measure of the attenuation with distance as the wave propagates through the medium. An electromagnetic wave entering an absorbing medium is thus damped to 1/e of its amplitude in a distance

$$d = \frac{\lambda_o}{2\pi k} \tag{44}$$

where λ_o is the wavelength in the vacuum. The distance d is referred to as the skin depth or penetration depth.

2.1.1 Reflection and transmission of electromagnetic waves at a plane interface

The application of appropriate boundary conditions to Maxwell's equations solves the problem of determining the light reflected and transmitted at a boundary separating two media. These boundary conditions require that the tangential components of both electric and magnetic vectors be continuous at the boundary.

Consider a plane wave E_i on the surface of z=0, the plane of incidence being the plane xOz, the angle of incidence θ_0 and the angle of refraction θ_1 ,as shown in Figure 2.1.

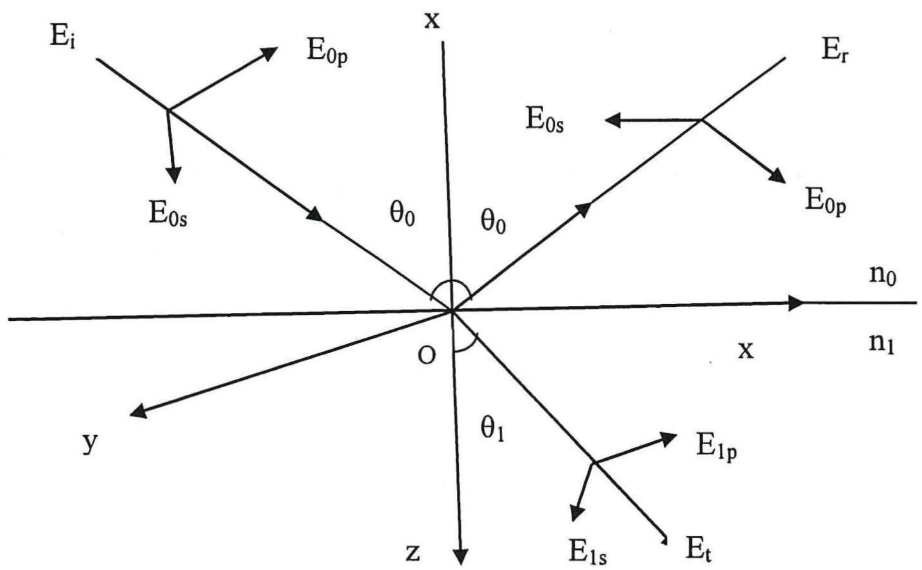

Figure 2. 1 : Reflection and transmission of an electromagnetic wave at a plane interface

We denote E'_{np} as the amplitude of the electric vector of a wave travelling in the positive direction in the n^th layer, or medium, in the system and polarized with the electric vector parallel to the plane of incidence and E'_{ns} for the component of electric vector perpendicular to the plane of incidence. Thus we denote the amplitudes of the electric vectors of the wave approaching the surface by, E'_{op}, E'_{os} for the two components and E^-_{op}, E^-_{os} for the reflected waves, while E^+_{1p}, E^+_{1s}, are for the transmitted waves

The phase factors associated with the incident, reflected and transmitted waves are of the form

$$E_i = \exp\{i\{\omega t - \frac{2\pi n_o}{\lambda}(x\sin\theta_o + z\cos\theta_o)\}\} \quad (45)$$

$$E_r = \exp\{i\{\omega t - \frac{2\pi n_o}{\lambda}(x\sin\theta_o - z\cos\theta_o)\}\} \quad (46)$$

$$E_t = \exp\{i\{\omega t - \frac{2\pi n_1(x\sin\theta_1 + z\cos\theta_1)\}\}}{\lambda} \quad (47)$$

Respectively, where λ is the wavelength in vacuum. At the boundary, which we take as z=0, the point of incidence being the origin of coordinates, we have for the total components of the electric and magnetic vectors in the x- and y-directions

$$E_{ox} = (E_{op}^{+} + E_{op}^{-})\cos\theta_o,\ E_{oy} = (E_{os}^{+} + E_{os}^{-}) \quad (48)$$

$$H_{ox} = n_o(-E_{os}^{+} + E_{os}^{-})\cos\theta_o,\ H_{oy} = n_o(E_{op}^{+} - E_{op}^{-}) \quad (49)$$

for the first medium and

$$E_{1x} = (E_{1p}^{+})\cos\theta_o,\ E_{1y} = E_{1s}^{+} \quad (50)$$

$$H_{1x} = -n_1 E_{1s}^{+}\cos\theta_1 H_{1y} = -n_1 E_{1p}^{+} \quad (51)$$

Applying the relation $H=\frac{n}{\mu}E$ from Maxwell's equation together with the boundary conditions of the continuity of the tangential components of the magnetic vector across the interface to equation (48-49) and (50-51) we can get Snell's law

$$n_o\sin\theta_o = n_1\sin\theta_1 \quad (52)$$

and the amplitude ratios of the reflected and transmitted waves commonly referred to as Fresnel's coefficients given by

$$r_{1p} = \frac{E_{op}^{-}}{E_{op}^{+}} = \frac{n_o\cos\theta_1 - n_1\cos\theta_o}{n_o\cos\theta_1 + n_1\cos\theta_o} = -\frac{\tan(\theta_o - \theta_1)}{\tan(\theta_o + \theta_1)} \quad (53)$$

$$r_{1s} = \frac{E_{os}^{-}}{E_{os}^{+}} = \frac{n_o\cos\theta_o - n_1\cos\theta_1}{n_o\cos\theta_o + n_1\cos\theta_1} = \frac{\sin(\theta_o - \theta_1)}{\sin(\theta_o + \theta_1)} \quad (54)$$

$$t_{1p} = \frac{E_{1p}^{+}}{E_{op}^{+}} = \frac{2n_o\cos\theta_o}{n_o\cos\theta_1+n_1\cos\theta_o} = \frac{2\sin\theta_1\cos\theta_o)}{\sin(\theta_o+\theta_1)\cos(\theta_1-\theta_o)} \tag{55}$$

$$t_{1s} = \frac{E_{1s}^{+}}{E_{os}^{+}} = \frac{2n_o\cos\theta_o}{n_o\cos\theta_o + n_1\cos\theta_1} = \frac{2\sin\theta_1\cos\theta_o)}{\sin(\theta_o + \theta_1)} \tag{56}$$

where r_{1p} and r_{1s} are known as Fresnel's reflection coefficients and, t_{1p}, t_{1s} are the Fresnel's transmission coefficients.

For equations above , t_{1p}=1+ r_{1p} and t_{1s}=1+ r_{1s} so that for the case n_o>n_l the values of t_{1p} and t_{1s} exceed unity. If n_l>n_o the ratio is negative indicating that the reflection of the wave results in a phase shift or change of π i.e the electric vector of the electric wave oscillates 180° out of phase with that of the incident wave. In the reverse case, the phase shift is zero. The two split beams formed by reflection at the top and at the bottom of a film can interfere destructively or constructively. The first is when the resultant amplitude is the difference of the amplitudes of the two components and when the relative phase shift is 180°. When reflection occurs in a medium of lower refractive index than the adjoining one, there is a phase shift of 180°. Constructive interference occurs when the relative phase shift is zero or a multiple of 180°.

The energy flux is given by the pointing vector **S** given by

$$\mathbf{S} = \frac{1}{\mu_o}(\mathbf{ExB}) \tag{57}$$

Reflectance is defined as the ratio of the reflected to the incident energy. Thus

$$R_p = \frac{(E_{op}^{-})^2}{(E_{op}^{+})^2} = r_{1p}^2 \tag{58}$$

$$R_s = \frac{(E_{os}^{-})^2}{(E_{os}^{+})^2} = r_{1s}^2 \tag{59}$$

And the average of the two can give the resulting reflectance of the material thus

$$R = \frac{1}{2}(R_s + R_p) \tag{60}$$

Transmittance is defined as the ratio of the transmitted to the incident energy, thus

$$T_p = \frac{n_1(E_{1p}^{+})^2}{n_o(E_{op}^{+})^2} = \frac{n_1}{n_o}t_{1p}^2 \quad (61)$$

$$T_s = \frac{n_1(E_{1s}^{+})^2}{n_o(E_{os}^{+})^2} = \frac{n_1}{n_o}t_{1s}^2 \quad (62)$$

It is noted that for glass, the reflectance in the parallel (p) direction vanishes at a particular angle known as the Brewster angle. At the Brewster angle the reflected energy is entirely in the direction perpendicular (s) to the plane of incidence. The Brewster angle is significant in the determination of transmission axes of polarizers. It is shown that at Brewster angle, θ_B sometimes called polarizing angle is given by

$$\theta_B = \arctan(\frac{n_1}{n_o}) \quad (63)$$

For normal incidence on an isotropic medium the incident plane become unidentified and any distinction between the parallel and perpendicular components of R and T vanishes thus the reflection and transmission coefficients, expressed in terms of refractive indices become

$$R_p = (\frac{n_o-n_1}{n_o+n_1})^2 \quad (64)$$

$$T_p = T_s = \frac{4n_o n_1}{(n_o+n_1)^2} \quad (65)$$

Thus 4% of the light incident normally in air-glass interface will be reflected back, whether internally no>n1 or externally $n_o<n_l$

2.1.2 Reflection at the surface of an absorbing medium

The equations of propagation of light in a transparent medium may be used to describe propagation in an absorbing medium by replacing the refractive index n with a complex quantity

$$N=n+ik \quad (66)$$

The imaginary part is the extinction coefficient related to the absorption of energy in the medium. The optical properties of a transparent medium can be conveniently characterized by two constants namely the complex refractive index k and the absorption coefficient $\propto$ given by

$$k = \frac{\propto\lambda}{4\pi} \tag{67}$$

where λ is the wavelength measured outside the medium

The refractive index N may be defined by Snell's law of refraction thus substituting equation (58) into equation (44) to give

$$\sin\theta_1 = \frac{n_o \sin\theta_o}{n_1 + ik_1} \tag{68}$$

So that θ_l is complex and thus does not represent the angle of refraction except for the special case $\theta_o=\theta_l=0$. For this case only, the Fresnel's reflection coefficients (which are same for both components of polarization) may be easily found thus

$$r_{1p} = r_{1s} = \frac{n_o-(n_1+ik_1)}{n_o+n_1+ik_1} \tag{69}$$

which gives the reflectance of the surface as

$$R_p = R_s = \left(\frac{n_o - N_1}{n_o + N_1}\right)\left(\frac{n_o - N_1}{n_o + N_1}\right)^* = \frac{(n_o - n_1)^2 + k_1^2}{(n_o + n_1)^2 + k_1^2} \tag{70}$$

It can be clearly seen that if the conductivity of metals goes to zero, k=0 equation (62) reduces to equation (56).

For other than normal incidence, the exact expressions for the reflectance are cumbersome and approximations are used. For many absorbing materials, particularly metals in the visible region $n^2+k^2>>1$. To this approximation the reflectances reduce to

$$R_p = \frac{(n^2 + k^2)\cos^2\theta_o - 2n\cos\theta_o + 1}{(n^2 + k^2)\cos^2\theta_o + 2n\cos\theta_o + 1} \tag{71}$$

$$R_s = \frac{(n^2 + k^2) - 2n\cos\theta_o + \cos^2\theta_o}{(n^2 + k^2)\cos^2\theta_o + 2n\cos\theta_o + \cos^2\theta_o} \quad (72)$$

The Fresnel's transmission coefficients have no direct significance for the wave entering an absorbing medium since the attenuation of the wave depends on the distance travelled in the medium.

The absorption coefficient $\propto$ in the exponent of Lambert-Bonguers' law which describes the attenuation of radiation in an absorbing medium as a function of distance x in the medium is given by

$$I = I_o \exp(-\propto x) \quad (73)$$

$$T = \frac{I}{I_o} = \exp(-\propto x) \quad (74)$$

Where I_0 denotes the intensity of the incident radiation on a boundary and I the radiation at the distance x in the medium and T is the transmittance. Actually n and $\propto$ are not constants as in some region they strongly depend on the wavelength λ (Pulkner, 1984)

Thin films generally have properties which are somewhat different from the bulk starting materials. As regard optical properties, the observed values of the refractive index and the absorption coefficients are often lower and higher respectively compared with those of the same bulk materials. Very thin films ($d \leq 10$ nm) can have strong variations that the term optical constants become problematic. This behavior demonstrates, however, the dependence of n and k on film thickness and to some extent on the substrate condition. For thicker films ($d \geq 40$ nm) the thickness dependence rapidly decreases and the resulting film properties are influenced by the production method (Pulkner, 1984)

2.1.3 Reflection and transmission on thin film interfaces

Thin films can either be made up of a single film or multilayer films. Since we are only fabricating single films in this research, we will only consider reflection and transmission on single film interface with the substrate.

2.1.3.1 Reflection and transmission at a single film interface

Consider a parallel beam of unit amplitude and wavelength λ incident on a plane parallel-sided homogenous isotropic, absorbing or non-absorbing film of refractive index n_1 and thickness d_1

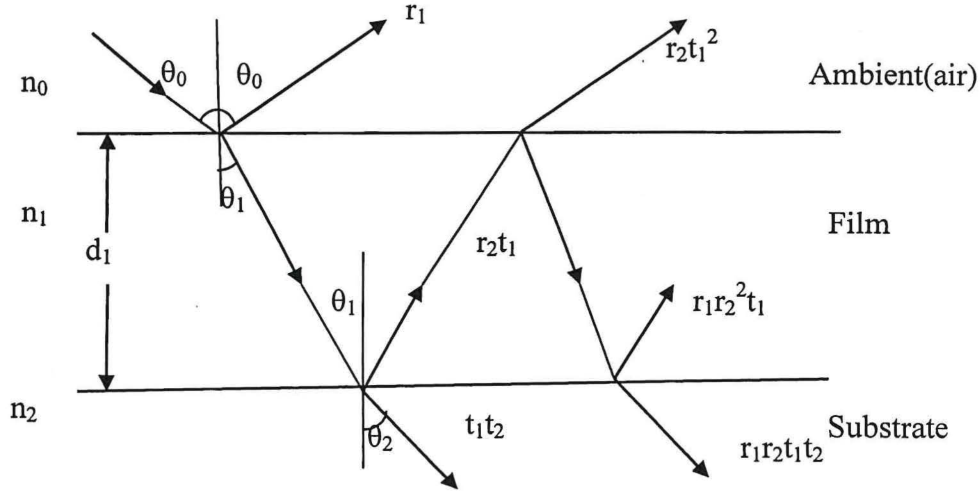

Figure 2. 2 : Multiple reflection in a film covered substrate

that is formed on a homogenous isotropic medium of refractive index n_2 as shown in Figure 2.2. The amplitude of the successively reflected and transmitted beams can be written down in terms of Fresnel's coefficients (Pulkner, 1984). The values of r and t for a given boundary depend on the direction of propagation of light across the boundary. For propagation of light from n_o to n_1 we have

$$r_1 = \frac{n_o - n_1}{n_o + n_1} t_1 = \frac{2n_o}{n_o + n_1} \quad (75)$$

and for propagation of light from n_1 to n_o we have

$$r_1' = \frac{n_1 - n_o}{n_o + n_1} t_1' = \frac{2n_1}{n_o + n_1} \quad (76)$$

The primed quantities refer to a boundary passage opposite to the main travelling direction (Karllson, 1994). Some workers have not taken into account this difference and defined a single transmission coefficient however by compensating errors in applying the conservation of energy, the correct result has been obtained.

For normal incidence and for a single layer r_1'=-r_1-, r_2'=-r_2. Both components of the amplitude of reflected light have the same magnitude but differ in sign. This means that one component is shifted by π with respect to the other that is to say it has opposite phase. We confine ourselves to one component with the indices p and s omitted since for normal incidence of light the plane of incidence has no meaning anyway. The amplitudes of the successive beams reflected into medium n_o are given by r_1,$t_1^2r_2$, $t_1^2r_2^2$,….and the transmitted amplitudes by $t_1t_2, -t_1t_2r_1r_2$, $t_1t_2r_1^2r_2^2$,……., the phase difference of the beam on traversing the film is given by

$$\delta_1 = \frac{2\pi}{\lambda} n_1 1\cos\theta_1 \tag{77}$$

where $n_1 d_1 = D_1$ is the path difference

The reflected amplitude is thus given by

$$r = r_1 + t_1 t_1' r_2 \exp(-2i\delta_1) - t_1 t_1' r_1 r_1^2 \exp(-4i\delta_1) + \cdots = r_1 + \frac{t_1 t_1' r_2 \exp(-2i\delta_1)}{1 + r_1 r_2 \exp(-2i\delta_1)} \tag{78}$$

where the time-dependent factor has been omitted

For a non-absorbing media this may be further simplified by writing the Fresnel coefficients n terms of r_1, r_2. From conservation of energy we have $t_1 t_1' = 1 - r_1^2$

thus equation (78) becomes

$$r = \frac{r_1 r_2 \exp(-2i\delta_1)}{1 + r_1 r_2 \exp(-2i\delta_1)} \tag{79}$$

We consider a case for normal incidence since r_{1p}=r_{1s}=r_1 and r_{2p}=r_{2s}=r_2 the transmitted amplitude is given by

$$r = t_1 t_2 \exp(-i\delta_1) - t_1 t_2 r_1 r_2 \exp(-3i\delta_1) + t_1 t_2 r_1^2 r_2^2 \exp(-5i\delta_1) + \cdots$$

thus

$$r = \frac{t_1 t_2 \exp(-i\delta_1)}{1 + r_1 r_2 \exp(-2i\delta_1)} \tag{80}$$

and for non-normal incidence we get

$$r_p = \frac{r_{1p} + r_{2p}\exp(-2i\delta_1)}{1 + r_{1p}r_{2p}\exp(-2i\delta_1)} r_s = \frac{r_{1s} + r_{2s}\exp(-2i\delta_1)}{1 + r_{1s}r_{2s}\exp(-2i\delta_1)} \tag{81}$$

$$t_p = \frac{t_{1p}t_{2p}\exp(-2i\delta_1)}{1 + r_{1p}r_{2p}\exp(-2i\delta_1)} t_s = \frac{t_{1s}t_{2s}\exp(-2i\delta_1)}{1 + r_{1s}r_{2s}\exp(-2i\delta_1)} \tag{82}$$

meaning that each takes two possible forms depending on the state of polarization of the incident light.

For cases in which the Fresnel's reflection coefficients are small enough for their products to be negligible compared to unity the expressions reduce to

$$r \approx r_1 + r_2 \exp(-2i\delta_1), \qquad t = (1 + r_1 + r_2)\exp(-2i\delta_1) \tag{83}$$

For an absorbing film or film bounded by absorbing media, the values of n_o, n_l and n_2 are replaced by the corresponding complex quantities. The Fresnel's coefficients then become complex and the values of r and t can be calculated. To get the expression for the energies of the beams corresponding to the amplitudes of waves in the media bounding the film we use

$$n_o rr^* = \frac{n_o(r_1^2+r_2^2+2r_1r_2\cos 2\delta_1)}{(1+r_1^2r_2^2+2r_1r_2\cos 2\delta_1)} \tag{84}$$

$$n_2 tt^* = \frac{n_2 t_1^2 t_2^2}{1 + r_1^2 r_2^2 + 2r_1r_2\cos 2\delta_1} \tag{85}$$

The reflectances and transmittances defined as the ratio of the reflected and transmitted energy to the incident energy are thus

$$R = \frac{(r_1^2 + r_2^2 + 2r_1r_2\cos 2\delta_1)}{(1 + r_1^2r_2^2 + 2r_1r_2\cos 2\delta_1)} \tag{86}$$

$$T = \frac{n_2\cos\theta_2}{n_1\cos\theta_o}\frac{t_2^2t_1^2}{(1+r_1^2r_2^2+2r_1r_2\cos 2\delta_1)} \tag{87}$$

For normal incidence $\theta_o = \theta_2 = 0$ thus equation (87) reduce to

$$T = \frac{n_2t_1^2t_2^2}{n_1(1 + r_1^2r_2^2 + 2r_1r_2\cos 2\delta_1)} \tag{88}$$

And for the special case represented by equation (79)

$$R = (r_1^2 + r_2^2 + 2r_1r_2\cos 2\delta_1) \tag{89}$$

$$T = \frac{n_2}{n_1}(1 + r_1 + r_2)^2 \tag{90}$$

Where r_1, r_2, t_1, t_2 are given by equations (75) and (76) which on substituting into equation (79) and (80) we have

$$r = \frac{(n_o - n_1)(n_1 + n_2)\exp(i\delta_1) + (n_o + n_1)(n_1 - n_2)\exp(-i\delta_1)}{(n_o + n_1)(n_1 + n_2)\exp(i\delta_1) + (n_o - n_1)(n_1 - n_2)\exp(-i\delta_1)} \tag{91}$$

$$t = \frac{4n_on_1}{(n_o + n_1)(n_1 + n_2)\exp(i\delta_1) + (n_o - n_1)(n_1 - n_2)\exp(-i\delta_1)} \tag{92}$$

The expressions for reflectance and transmittance are now written as

$$R = \frac{(n_o^2+n_1^2)(n_1^2+n_2^2)-4n_on_2n_1^2+(n_o^2-n_1^2)(n_1^2-n_2^2)\cos^2\delta_1}{(n_o^2+n_1^2)(n_1^2+n_2^2)+4n_on_2n_1^2+(n_o^2-n_1^2)(n_1^2-n_2^2)\cos^2\delta_1} \tag{93}$$

$$T = \frac{8n_on_2n_1^2}{(n_o^2+n_1^2)(n_1^2+n_2^2)+4n_on_2n_1^2+(n_o^2-n_1^2)(n_1^2-n_2^2)\cos^2\delta_1} \tag{94}$$

We also express (88) by making the substitution

$\cos2\delta_1 = 1 - 2\sin^2\delta_1$ to get

$$R = \frac{r_1^2 + r_2^2 - 4r_1r_2\sin^2\delta_1}{(1 + r_1r_2)^2 - 4r_1r_2\sin^2\delta_1} \tag{95}$$

$$= \frac{(r_1 + r_2)^2\cos^2\delta_1 + (r_1 - r_2)^2\sin^2\delta_1}{(1 + r_1r_2)^2\cos^2\delta_1 + (1 - r_1r_2)\sin^2\delta_1} \tag{96}$$

$$= \frac{n_1^2(n_2-n_o)^2-(n_2^2-n_1^2)(n_1^2-n_o^2)\sin^2\delta_1}{n_1^2(n_2+n_o)^2-(n_2^2-n_1^2)(n_1^2-n_o^2)\sin^2\delta_1} \tag{97}$$

thus

$$R = 1 - \frac{4n_on_2n_1^2}{n_1^2(n_2 + n_o)^2 - (n_2^2 - n_1^2)(n_1^2 - n_o^2)\sin^2\delta_1} = 1 - T \tag{98}$$

where

$$T = \frac{4n_on_2n_1^2}{n_1^2(n_2 + n_o)^2 - (n_2^2 - n_1^2)(n_1^2 - n_o^2)\sin^2\delta_1} \tag{99}$$

alternatively from equation (95) we get

$$R = \frac{n_1^2(n_2-n_o)^2\cos^2+(n_2^2-n_on_1)^2\sin^2\delta_1}{n_1^2(n_2+n_o)^2\cos^2+(n_2^2-n_on_1)^2\sin^2\delta_1} \quad (100)$$

Thus equations (93), (97) and (100) are identical but expressed differently. By use of suitable programs the reflectances and transmittances of absorbing and non-absorbing media can be evaluated.

From equation (77) in case the phase change of $m\pi$ this causes an increment Δd_1 in d_1 thus (77) becomes

$$(\delta_1 + m\pi) = \frac{2\pi}{\lambda} n_1(d_1 + \Delta d_1)\cos\theta_1 \quad (101)$$

solving gives

$$\Delta d_1 = \frac{m\lambda}{2n_1\cos\theta_1}, \text{m interger} \quad (102)$$

The reflectances and transmittances of non-absorbing films that differ in thickness by an integral multiple of $1/2n_1 cos\theta_1$ are thus the same. The condition for the maxima and minima is given by,

$$\frac{dR}{dD_1} = 0 \quad (103)$$

Differentiating (98) gives $\sin 2\delta_1=0$;thus

$$2\delta_1=\sin^{-1}0=m\pi \quad (104)$$

Substitute equation (104) into (77); then $2.\frac{2\pi}{\lambda}n_1d_1\cos\theta_1 = m\pi$

Therefore

$$D_1 = n_1d_1 = \frac{m\pi}{4\cos\theta_1}, m = 0,1,2,\dots\dots \quad (105)$$

For normal incidence

$$D_1 = \frac{1}{4} m\lambda \tag{106}$$

Thus non-absorbing films that differ in optical thickness by an integral multiple of a quarter of the wavelength of the incident light have the same reflectance and transmittances that are extremas. Two cases can be considered for m odd and even

Case i: when m is odd, $\cos 2\delta_1$=-1;

Thus equation (88) becomes

$$R = (\frac{r_1^2+r_2^2-2r_1r_2}{1+r_1^2r_2^2-2r_1r_2}) = (\frac{r_1+r_2}{1+r_1r_2})^2 \tag{107}$$

substituting for r_1, r_2 from equation (75) and (76) we have

$$R = (\frac{n_o n_2 - n_1^2}{n_o n_2 + n_1^2})^2 \tag{108}$$

Case ii: when m is even, $2\cos\delta_1$=1

Thus equation (15) becomes

$$R = \frac{r_1^2 + r_2^2 + 2r_1r_2}{1 + r_1^2r_2^2 - 2r_1r_2} = (\frac{r_1 + r_2}{1 + r_1r_2})^2 \tag{109}$$

Substituting for r_1 and r_2 we have

$$R = (\frac{n_o - n_2}{n_o + n_2})^2 \tag{110}$$

Equation (110) is independent of n_1. This implies that when m is even the reflectance is similar to that of clean substrate. For oblique incidence we substitute $n_i = n_i cos\theta_i$ in all the formulae

Hence a film whose thickness is $m\lambda/4\cos\theta_1$ m=2,4,6,........has no influence on the intensity of the reflected or transmitted radiation.

To find the nature of these extrema we need to find $\frac{d^2R}{dD_1^2}$ hence for normal incidence the maximum of R is when

$$(-1)^m(n_o-n_1)(n_1-n_2)>0 \quad (111)$$

and minimum when

$$(-1)^m(n_o-n_1)(n_1-n_2)<0 \quad (112)$$

Since the first medium, the ambient, is always air $n_o=1$, relations (111) and (112) depend on whether $n_1>n_2$ or $n_1<n_2$

For a film with optical thickness $m\lambda/4$, m=1,3,5,...........the reflectance is a minimum according to whether the refractive index of the substrate is greater or less than that of the film. If $n_1<n_2$, R is minimum; such films are required when a decrease in reflectivity of glass is needed. If $n_1>n_2$, R is maximum, such films are required when an increase in reflectivity is needed.

For a film with optical thickness $m\lambda/4$, m=2,4,6,..........the opposite applies although the maximum or minimum are the same as the reflectances of the substrate itself as for the case (111) above.

Here the effects in light transmitted by a film are complementary to the effects in the reflected light; in other words the minimum in transmitted light corresponds to the maximum in reflected light and vice versa

For $n_1<n_2$ when $D_1=0$ the initial reflectance is given by equation (110)

With growing path difference or thickness of the film the reflectivity decreases to the minimum at $D_1=\lambda/4$ as in equation (108)

With growing path difference it again increases to a maximum at $\lambda/2$, decreases to a minimum at $3\lambda/4$ etc. Thus for $n_1<n_2$ undesirable reflectivity of the surface of glass with a film can be

completely eliminated. Materials like MgF_2 with n_l=1.38 and Cryolite with n_l=1.35 are used for this purpose.

For $n_l>n_2$ the minimum and maximum of the reflectivity are opposite to those for $n_l<n_2$. The initial state for $D_l=0$ corresponds to the reflectivity of clean glass without a surface film and is the minimum of reflectance as in equation (110)

With growing path difference D we get the maximum reflectance (108) which goes on decreasing and increasing at multiples of $\lambda/4$. Hence the reflectivity of glass with a thin film is increased. The increase in the reflectivity does not depend on whether the first or second order is used with growing thickness of the film the reflectivity is periodically repeated. It is clear that the greatest decrease or increase in reflectivity is obtained for path differences of $D_l=\lambda/4$, $\lambda/2$, $3\lambda/4$, λ, $5\lambda/4$,...

2.2 Techniques for film preparation

Any coating process can be divided into three steps and this can be summarized as the passage of the coating material from the solid phase to a suitable transport phase, the transport of coating material from the source to the vicinity of the substrate, and the passage of coating material from the transport phase back into the solid phase on the substrate surface (Venables, 2000). There are two preferred methods for the production of thin films and these are chemical vapour deposition (CVD) and physical vapour deposition (PVD). The three major technologies of the latter are evaporation, sputtering and ion plating. The two methods differ from each other primarily in the mechanism by which the coating material is passed into the vapour phase. This mechanism determines the range of coating materials for which the method is applicable and to a large extent the deposition rates can be achieved. Only evaporation technique which will be used in this work will be discussed.

2.2.1 Vacuum evaporation

The basic principle is that if a solid is heated to a sufficiently high temperature in vacuum it will evaporate and the evaporating atoms or molecules will travel in straight lines in the directions defined by a cosine distribution with thermal energies of 0.02 eV to 0.05 eV. In this technique therefore the coating material is passed into the transport phase by sublimation or evaporation. Heating is typically done by electrical resistance, eddy currents, thermal radiation, electron beam bombardment, laser beam or electric discharge methods. To ensure that the atoms undergo transport to the substrates with no collision with air molecules, the process is carried out under vacuum. If the pressure is high the atoms of the ambient gas would collide with vapour atoms and cause scattering which in turn leads to a smaller fraction of vapour atoms reaching the substrate which is placed in their path. Yet another condition has to be met for deposition of films to have a small distance between the vapour source and target compared to the mean free path of the vapour molecules. The mean free path of a metal atom is the average distance travelled by all atoms between collisions and is said to be inversely proportional to the gas pressure. The relationship between the gas pressure, P and the mean free path λ_m is given by

$$\lambda_m = \frac{6.25x10^{-3}}{P(mb)} \tag{113}$$

and Table 2.1 gives the mean free paths at room temperature and different pressures (Kivaisi, 1989)

Table 2. 1 : The mean free path of atoms at various pressures

Pressure (mb)	mfp λ_m (m)
$1x10^{3}$	$6.25x10^{-8}$
$1x10^{-3}$	$6.25x10^{-2}$
$1x10^{-4}$	$6.25x10^{-1}$
$1x10^{-5}$	6.25
$1x10^{-7}$	625

If the source to target distance is sufficiently small compared to the mean free path of the vapour molecules in the atmosphere of the deposition system a large fraction of the molecules will reach the target without suffering collision with molecules of the residual gas in the system. The only fundamental requirement on the target is that it should be maintained at low temperature so that the coating flux constitutes a super saturated vapour over their surfaces.

An evaporating coating unit consists typically of a vacuum chamber, pumping system, pressure measuring instrumentation, evaporating source and power supplies, substrate fixturing and deposition rate detector. Figure 2.3 shows the major components of a typical evaporation unit.

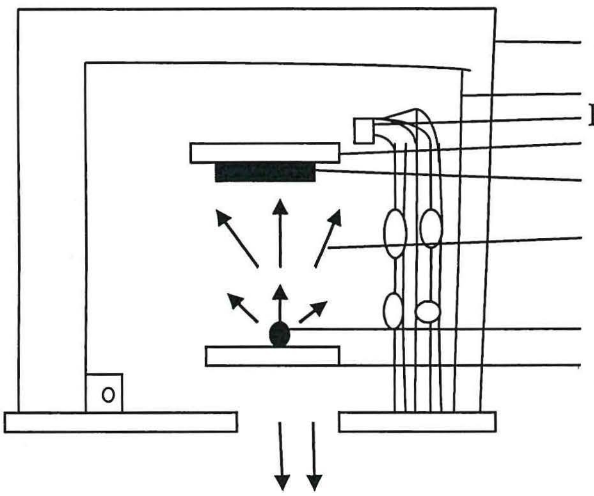

Figure 2. 3 : Schematic diagram of an evaporation Unit

A glass or metal bell jar is evacuated usually with two vacuum pumps in series. The pumping systems combine high vacuum pumps with mechanical backing and roughing pumps. The high vacuum pumps are generally of the conventional diffusion type, although oil free getterion, turbo molecular or cryogenic pumps are sometimes used. The evaporant is placed in a crucible, boat or tungsten helical filament which is heated using a large electric current.

At pressures of about $1x10^{-6}$ mb which are easily attainable about 99% of the evaporant leaving the source in the right direction would reach a substrate 10 cm away without collision. The substrate may be heated or cooled in order to give the film particular properties.

2.3 Evaporation materials

Apart from the elements, only a relatively small number of inorganic compounds can be evaporated to produce a coating with the same composition as the starting material. Suitable compounds are found mostly among the halides and Chalcogenides. In some cases, it is necessary to change the evaporation process (eg reactive evaporation, evaporation from different sources or flash evaporation) in order to ensure that the resulting thin film has the desired stoichiometry (Friz et al, 2009)

Evaporation materials have to fulfill a series of requirements in order to meet the demands of the coating process and to achieve required film properties (Pulkner, 1984).

2.3.1 Chemical purity

The chemical purity of vapour deposition materials influences not only the coating properties but also the way the material behaves during evaporation. Chemical purity of at least 99.99% is required to avoid effect of impurities on the optical properties of the thin film. Even minute concentrations of transition elements can have a marked effect on the transmission properties of dielectric layers (Erwin et al, 2002). Accounts of specific losses can be found in literature on optical waveguides made of Silicon dioxide (Ohring, 2002).

2.3.2 Physical properties

Testing of dimensions, particle sizes and weights is a vital part of quality control. X-ray diffraction (powder diffraction) is used to check the phase purity of the end product. Also differences in the stoichiometry of a compound may negatively affect evaporation characteristics and coating properties (Andrade et al, 1935)

2.3.3 Process suitability

Decades of experience in the manufacture of evaporation materials have shown that factors affecting process suitability are so complex that they do not allow quality to be defined simply by physical and chemical properties. Therefore, substance testing under actual conditions of use continues to be a major feature of quality control. It is also necessary to record the evaporation data (pressure and rate fluctuations).

CHAPTER THREE

METHODOLOGY

This chapter gives an overview of the research design, sample cleaning procedures, fabrication of the films, measurement of infrared reflectance and transmittance of the fabricated samples, determination of thin film thickness refractive indices of the thin films and their absorption coefficients.

3.0 Research Design

Since there is sufficient knowledge to indicate the causes of overheating in houses and cars, the researcher sought to develop and assess intervention measures in order to alleviate the effects of overheating. In that case, the experimental approach was used, whereby, one variable (thickness of thin film) was manipulated and its effect on reflectance and transmittance measured.

3.1 Fabrication of thin films of different thicknesses on glass substrates

The evaporation target elements used for fabricating the samples were palladium and platinum. The thicknesses of the thin films were varied by evaporating three different masses; 0.02 g, 0.04 g, and 0.06 g of the metals. The actual thicknesses were thereafter determined by carrying out ex situ measurements. Before evaporating the metal films on the substrates, the substrates (glass slides) had to be cleaned.

A warm bath was prepared using industrial soap (Teepol) and distilled water. The subtrates were washed in the bath using a lint-free and cotton swab, gently rubbing off dirt and residues. Acetone was then poured into a glass container and the glass slides placed inside for ten minutes in order to clean off oils and organic residues. Thereafter, the slides were removed and placed in methanol for five minutes to remove any remaining contaminants that may have stuck on glass surface. Two solvent method was used because some solvents like acetone leave their own residues. Lastly, the glass substrates were stored in tightly sealed slide holders.

To prepare a film, a glass slide was first mounted on a substrate holder which can be rotated about the horizontal axis. The rotation was done in a bid to produce uniform deposits; the material to be evaporated was filled into powder and a specific mass weighed and placed in a boat 20 cm away from the substrate vertically below it. The whole set up was inside a vacuum chamber.

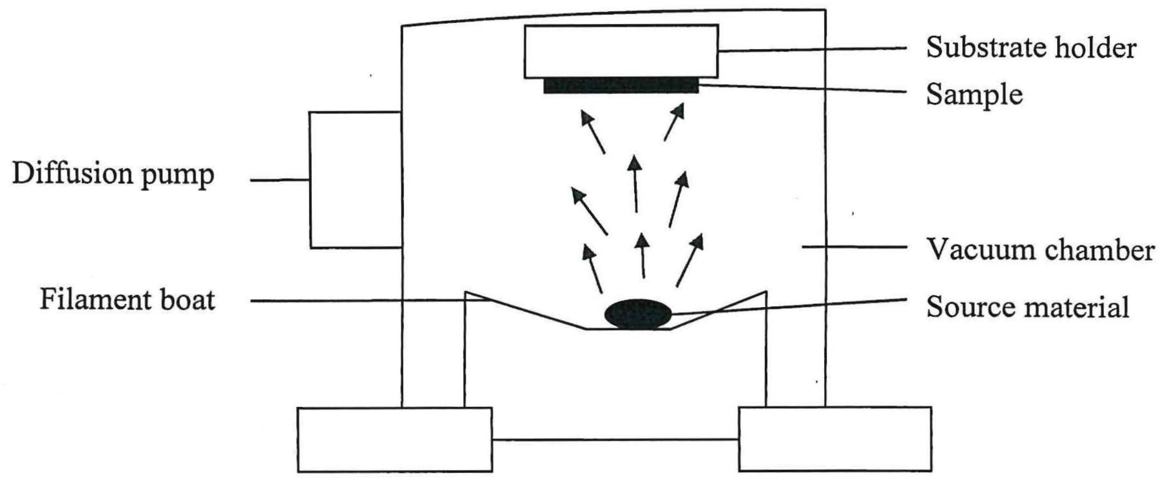

Figure 3. 1 : Schematic diagram for fabrication of thin films

Before raising the temperature of the source material by passing current through it, the chamber had to be pumped to base pressure of $3x10^{-5}$ mb using a conventional oil diffusion pump system. The pump down process (cycle time) was ranging between 50 minutes to 1 hour.

The schematic diagram for fabrication of the thin films is shown in Figure 3.1. Palladium and platinum thin films were prepared by evaporating the respective source material at an average of 1 nm/s. Mechanical rotation of the substrate holder was done during deposition in an attempt to produce homogenous films.

After each of the coating sessions, the samples were retained in the vacuum chamber for fifteen minutes, by which time the samples would have cooled enough to avoid oxidation of the hot metallic elements on exposure to the atmosphere.

The samples were labeled as indicated below:

i) For a coating of 0.02g of palladium(P); P1
ii) For a coating of 0.04g of palladium; P2
iii) For a coating of 0.06g of palladium;P3
iv) For a coating of 0.02g of Platinum(T); T1
v) For a coating of 0.04g of platinum; T2
vi) For a coating of 0.06g of Platinum; T3

3.2 Measurement of Reflectance and Transmittance of the fabricated samples

The optical transmittance T and reflectance R measurements of the samples were taken and recorded over 200-2500nm wavelength range using a double beam spectrophotometer (Shimadzu UV-3101PC: UV-VIS-NIR). The set up for measuring reflectance and transmittance is shown in Figure 3.2.

Figure 3. 2 : The set up for measuring reflectance and transmittance

The spectrophotometer takes in light, breaks it into spectral components, digitize the signal as a function of time and read it out and display it through a computer.

A schematic of the spectrophotometer is shown in Figure 3.3.

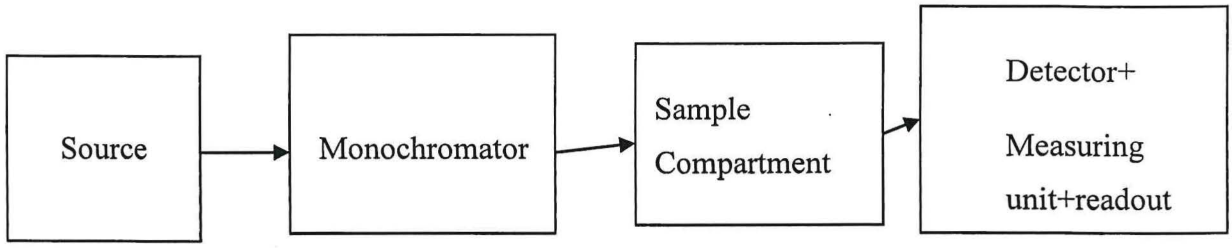

Figure 3. 3 : Schematic of the spectrophotometer

Tungsten filament is used as a source of light. The function of the monochromator is to produce a beam of single wavelength. A monochromator contains the following component parts; entrance slit, collimating lens, a dispersing device, a focusing lens and an exit slit. Polychromatic radiation enters the monochromator through the entrance slit. The beam is collimated, and then strikes the dispersing element at an angle. The light is collimated by a concave mirror onto a prism which disperses the spectral components of the light at slightly varying angles and these are focused by a second concave mirror. The beam is split into its component wavelengths and this leaves the monochromator through the exit slit and reflected or transmitted off the sample.

The samples are placed on the sample stage in the sample compartment, with the coated surface facing the light source for reflectance measurement, and off the light source for transmittance measurement respectively. The reflected/transmitted light then enters the detector. In the detector, the photons are converted into electrons which are digitized and read out through a Universal Serial Bus (USB) to a computer. The computer then interpolates the signal based on the number of pixels in the detector and the linear dispersion of the diffraction grating to create a calibration that enables the data to be plotted as a function of wavelength over the given spectral range.

Before reflection data is collected, the spectrometer is first calibrated by taking a reference scan. This reference scan is taken by placing a white light reflectance standard at the same geometry from the probe as was to be used in actual measurement. This allows the spectrometer to measure the ratio between a "perfect" white light reflector and the sample of interest in order to determine which wavelengths of light are reflected or transmitted as per the equations (86) and (87).

3.3 Determination of thickness of thin film, refractive indices and absorption coefficients

The optical properties of most thin films depend on deposition techniques and deposition conditions. As many advanced electronic and optical devices require the knowledge of these properties, it is important to extract, with a high degree of precision, the real properties of a deposited film as well as its thickness. For such purpose, the easiest available optical data are the transmittance (T) and/or the reflectance (R) spectra. Proposed approaches consist in imposing constraints that restrict the variability of the absorption coefficients and of refractive index of the film. That is, the approaches are subject to physical constraints.

The optical parameters (refractive index of the film and absorption coefficient) in this research were determined using Pointwise Unconstrained Minimization Approach (PUMA). PUMA implements an unconstrained formulation of the nonlinear programming model, which solves the estimation problem using a method based on repeated iterative calls to an unconstrained minimization algorithm. In PUMA, the constraints are handled in such a way that the final problem turns out to be unconstrained and solved by means of an efficient large scale minimization method. Unlike Swanepoel method, the retrieval of correct thickness and the optical constants in PUMA does not rely on the existence of interference fringes. What is required is the reflectance and/or the transmittance data which is put in one file with the PUMA program and thus creating a binary file. It is in this file that a command window is opened and the commands (Bergin, 1999) input. When the commands are correctly input, the program runs itself and retrieves the optical parameters in an output file. The retrieved parameters can again be input to minimize the error and the process repeated until the retrieved thickness indicates zero, which implies that there is no better estimation and thus the previous retrieved values are considered.

3.4 Comparing the reflectance and transmittance of glass coated thin films

The effect of thickness of thin film on reflection and transmission was investigated by first measuring the reflectance and transmittance of samples of other thicknesses using UV-VIS spectrophotometer. The spectra for the three different thicknesses of a particular metal film were put on the same graph to analyze how thickness variation affects reflectance of infrared and transmission of visible part of the spectrum.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.0 Introduction

This chapter gives the results obtained from optical measurements of thermally deposited films of Platinum and Palladium using a UV/VIS/NIR spectrophotometer in the wavelength range of 200-2500 nm. Section 4.1 gives the results of reflectance and transmittance measurements of palladium metal films on glass substrate for the various thicknesses basing on the mass of the palladium metal evaporated. Section 4.2 gives the results of reflectance and transmittance measurements of platinum metal films on glass substrate for the various thicknesses basing on the mass of the platinum metal evaporated. Section 4.3 gives the retrieved thicknesses of the fabricated samples and their respective refractive indices and absorption coefficients. In section 4.4 the combined graphs for the various thicknesses are displayed and henceforth the effect of film thickness on reflectance and transmittance of the metal films on glass substrate analysed. It is important to note that for a coating meant for a warm climate, it should have a high transmittance in the visible range (400 - 700 nm) and high reflectance in the near infrared range(700 nm - 1 mm) while for a cold climate the reverse is true.

4.1 Reflectance and transmittance of palladium films

In this section we shall analyze the reflectance and transmittance of palladium thin films thermally deposited on glass substrate.

4.1.1 Reflectance of Palladium film

The reflectance characteristics of palladium are presented in the figures 4.2, 4.3 and 4.4.

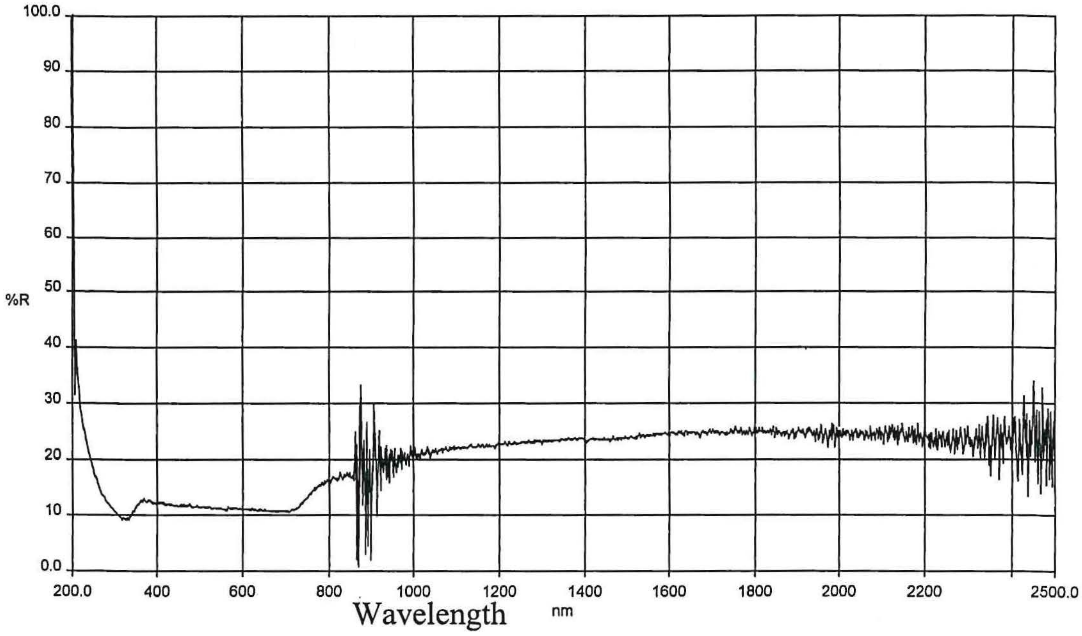

Figure 4. 1 : Reflectance of 0.02 g of palladium against wavelength

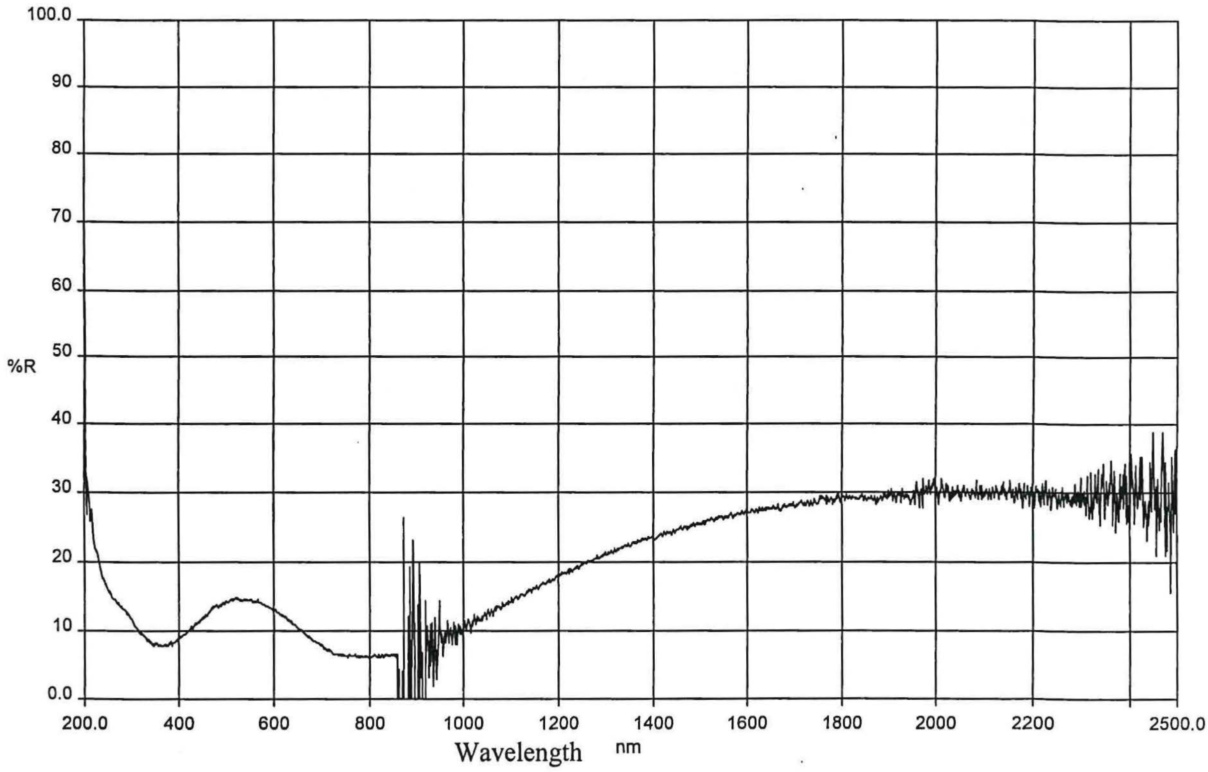

Figure 4. 2 : Reflectance for 0.04 g film of palladium against wavelength

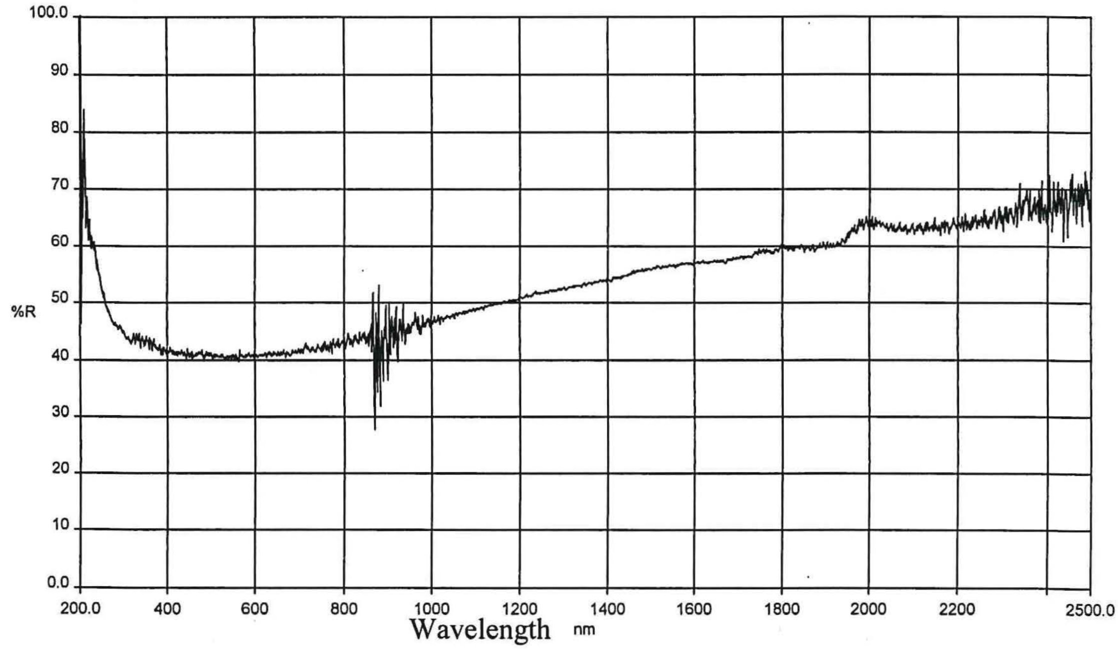

Figure 4. 3 : Reflectance of 0.06 g film of palladium against wavelength

The flat reference line at 100% is a good indicator that the system has sufficient light and sensitivity to yield low noise measurements (even at the wavelength extremes of the spectrophotometer).

As shown in Figure 4.1, the maximum reflectance of 0.02 g of palladium coating is 33%. There are pronounced interference effects between 800-1000 nm and between 2300-2500 nm. The pronounced interference effect is due to absorption (Yamamoto et al, 1994). The absorption enlarges the phase shift in the film, leading to pronounced interference effect near the absorption peak. It is also evident that the reflectance is higher in the infra red region (800- 2500 nm) compared to the visible region (400-800 nm). This may be attributed to the intrinsic heat mirror function of noble metals (Titta, 2005). In this case, the film selectively reflects or transmits radiation depending on the wavelength.

In Figure 4.2, the maximum reflectance for 0.04 g coating of palladium is 39%. The spectra is also characterized by pronounced interference fringes between 800-1000 nm and between 2300-2500 nm near the absorption peaks for the thin film. The peaks result from interband transitions leading to high absorptance.

For the 0.06 g coating as visualized in Figure 4.3, the maximum reflectance is 72%. The increase in reflectance with increase in film thickness may be due to uniformity in the film as the fraction of the voids in the film decrease leading to increased reflectance (Ida et al, 2002).

As seen in the Figures 4.1, 4.2 and 4.3, there is an increase in reflectance with increase in film thickness. However, with increasing thickness, the optical constants like refractive index change tending to that of the bulk, in which case an increase in film thickness would have no effect on the reflectance of the thin film. The peak intensity and the position change as a consequence of continous transformation of a spectral dip towards the constant value of bulk reflectance (i.e the shape of restsrahlen bands) (Marta et al, 2006). The transformation may also cause additional peaks to arise. When the film thickness is increased, the bulk spectral region increases.

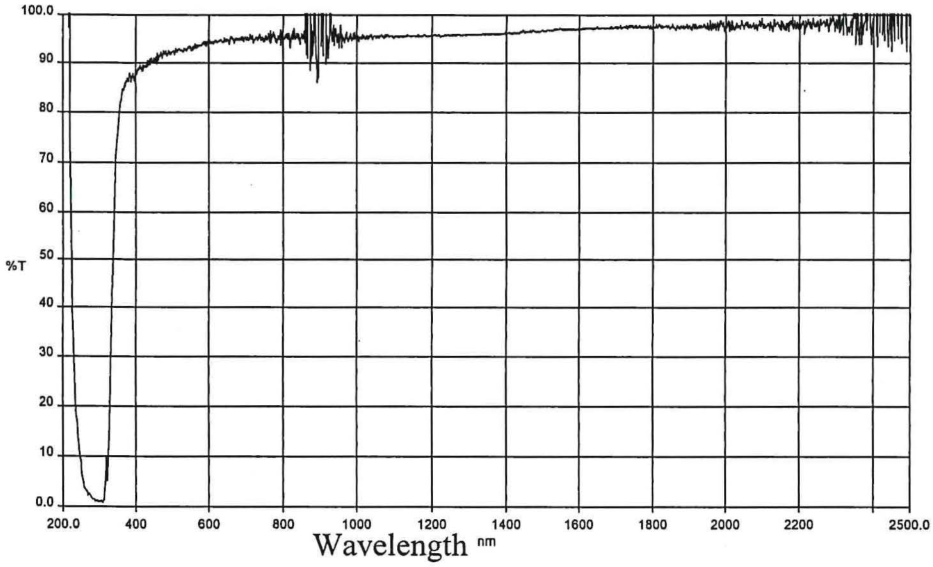

Figure 4. 4 : Transmittance of 0.02 g of Palladium against wavelength

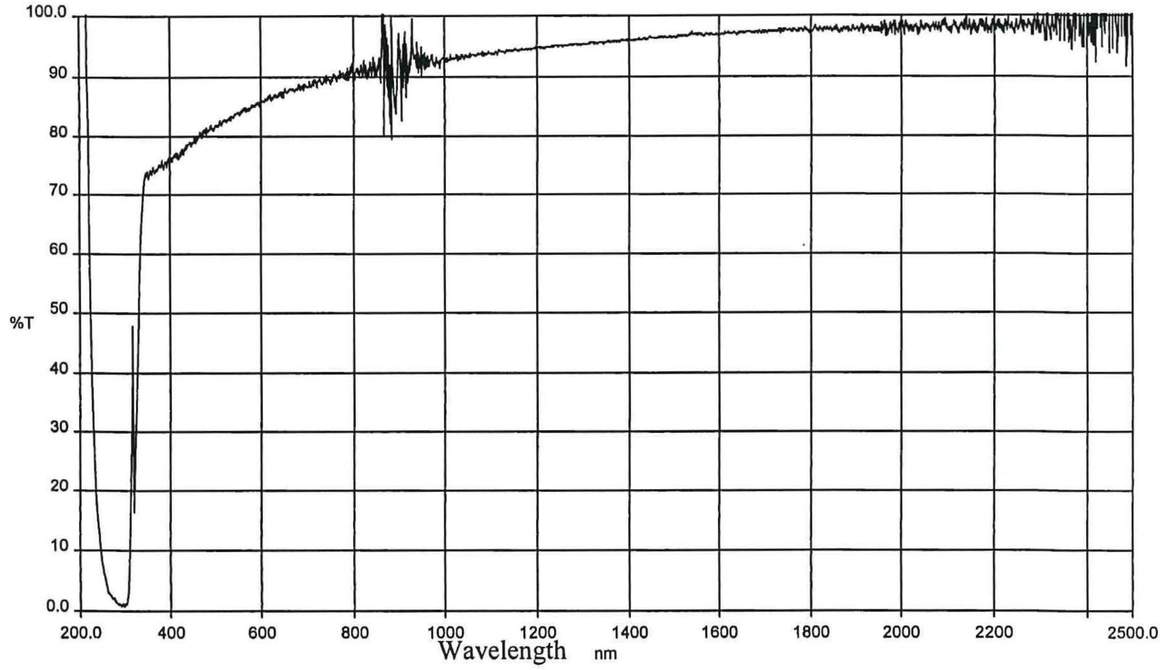

Figure 4. 5 : Transmittance of 0.04 g of palladium against wavelength

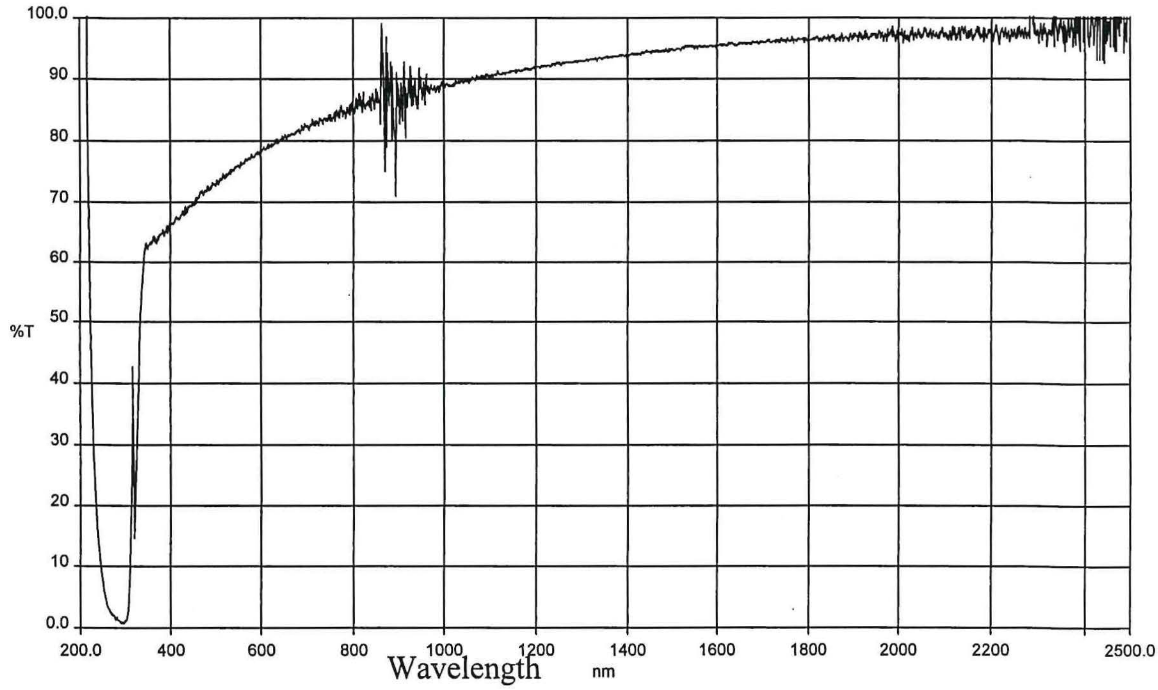

Figure 4. 6 : Transmittance of 0.06 g of palladium against wavelength

As observed in Figures 4.4, 4.5 and 4.6, the transmittances are generally above 90%. This may be an indication of voids in the films. With increase in film thickness however, the void density reduces and hence the transmittance reduces as observed by comparing the transmittances for the three masses. The voids are a result of islands growing to become separate grains in the final film (Lloyds et al, 1977). The separate grains are caused by faster rates of deposition which make deposited atoms to bond before they stabilize. The voids may also result due to residual gas pressure, especially given the fact that the vacuum pressure could not be reduced beyond $3.0x10^{-5}$ mb of pressure.

4.2 Reflectance and transmittance of Platinum thin films

In this section, the reflectance and transmittance of platinum films on glass for masses corresponding to 0.02g, 0.04g and 0.06g of platinum evaporated on glass are presented and analyzed.

4.2.1: Reflectance of platinum thin films

The reflectance characteristics of platinum thin films are visualized in Figures 4.7, 4.8 and 4.9 below.

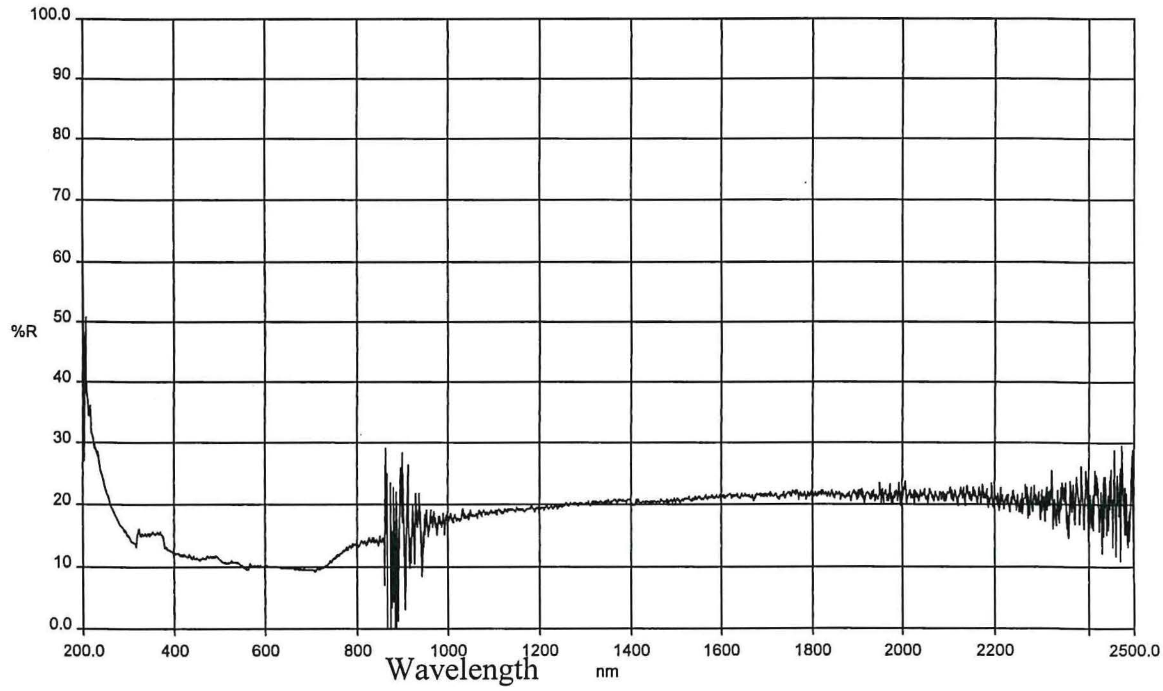

Figure 4. 7 : Reflectance of 0.02 g of Platinum against wavelength

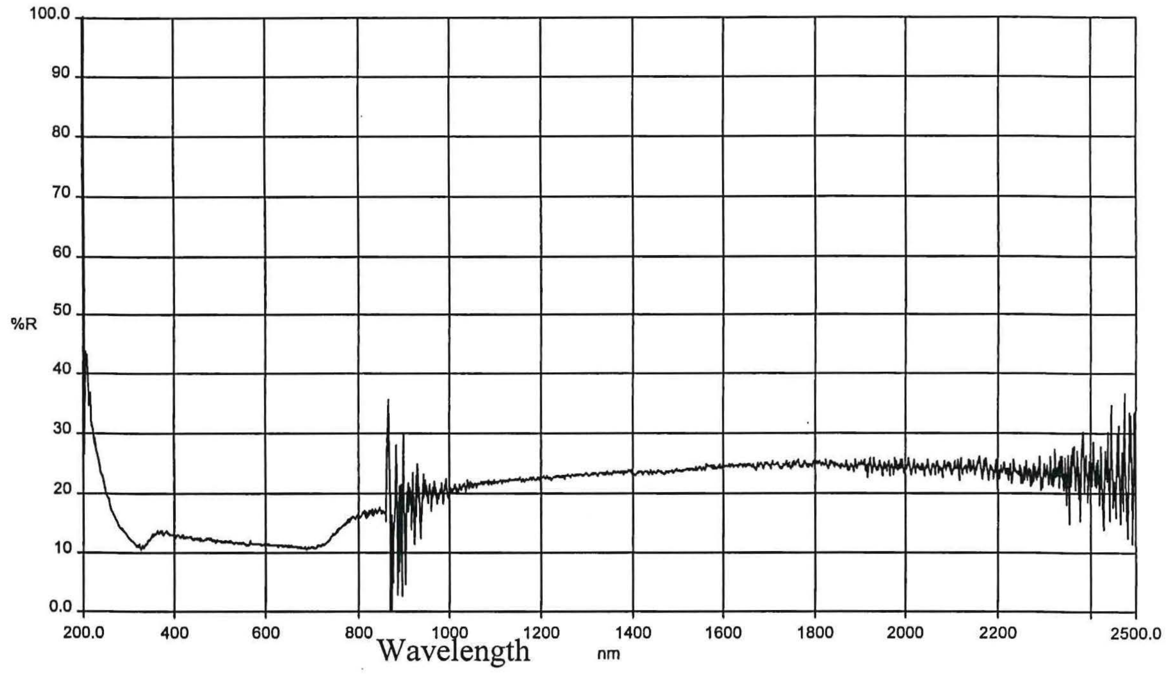

Figure 4. 8 : Reflectance of 0.04 g of Platinum against wavelength

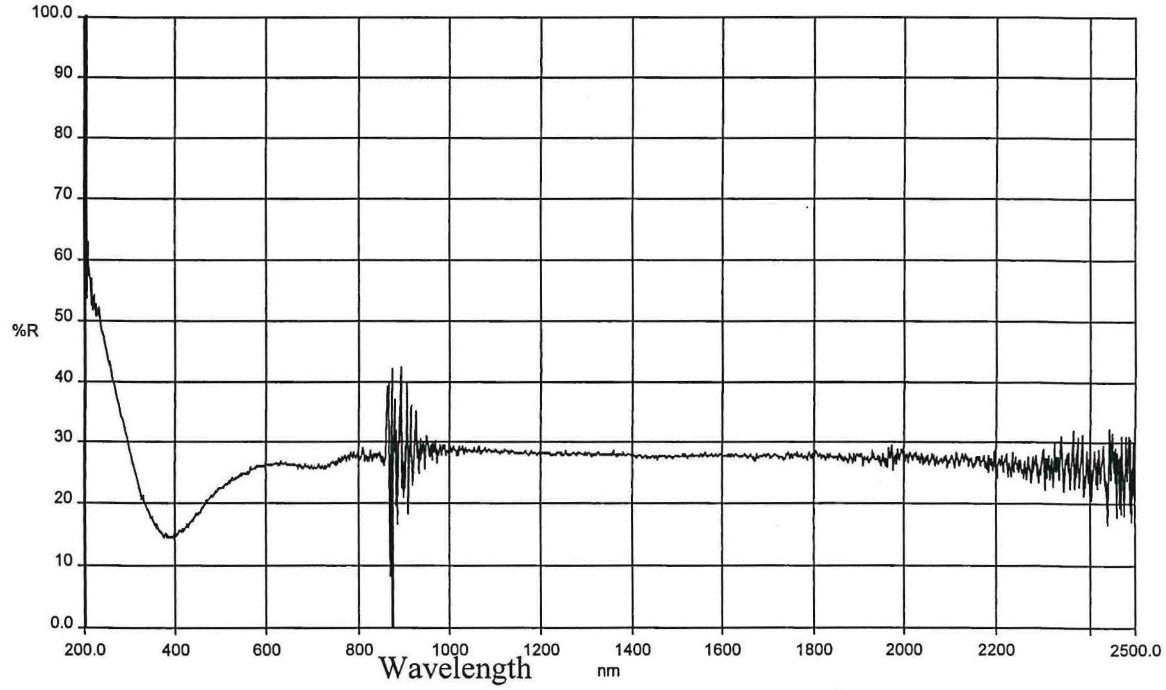

Figure 4. 9 : Reflectance of 0.06 g of Platinum against wavelength

From Figure 4.7, 0.02 g coating of platinum has a maximum reflectance of 28%. In addition, the reflectance in the visible region is lower compared to that in the infrared region a characteristic which is useful for coatings made for warm climates. As is the case with palladium films, there are strikingly pronounced interference effects between 800-1000 nm and between 2000-2500 nm.

From Figure 4.8, the maximum reflectance for 0.04 g coating is 35%. Similarly, the infrared reflectance is higher than the visible and this is a desirable feature for a coating meant for infra-red reflection.

Figure 4.9 shows reflectance for 0.06 g coating of platinum illustrates that the infra-red reflectance are higher compared to that of 0.04 g coating with a maximum reflectance of 42%. Therefore, reflectance characteristics of platinum are influenced by film thickness and are significantly different in various film thicknesses.

4.2.2 Transmittance of platinum thin films

Transmittances for platinum thin films are visualized in the figures below.

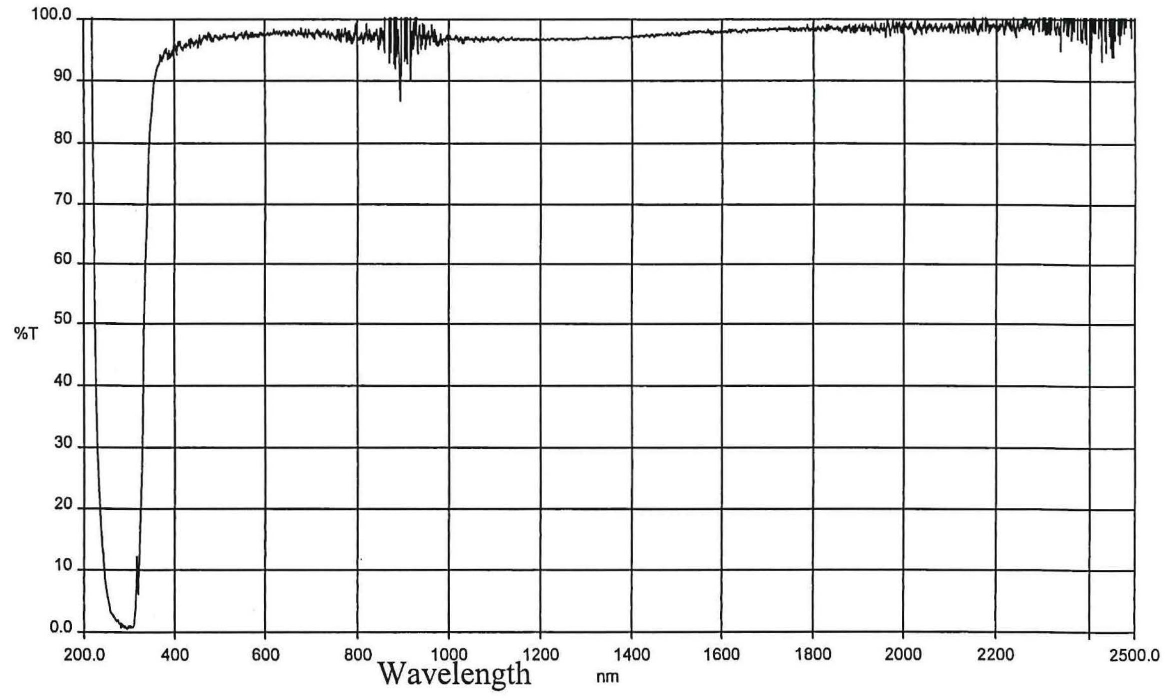

Figure 4. 10 : Transmittance of 0.02 g of platinum against wavelength

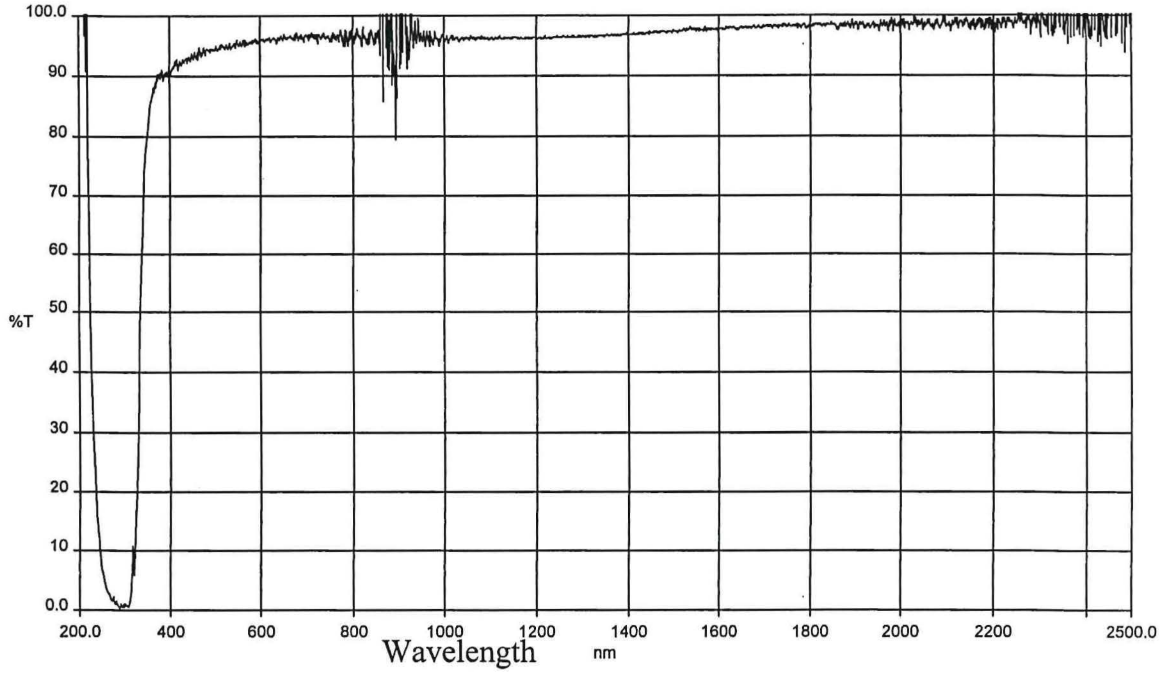

Figure 4. 11 : Transmittance of 0.04 g of platinum against wavelength

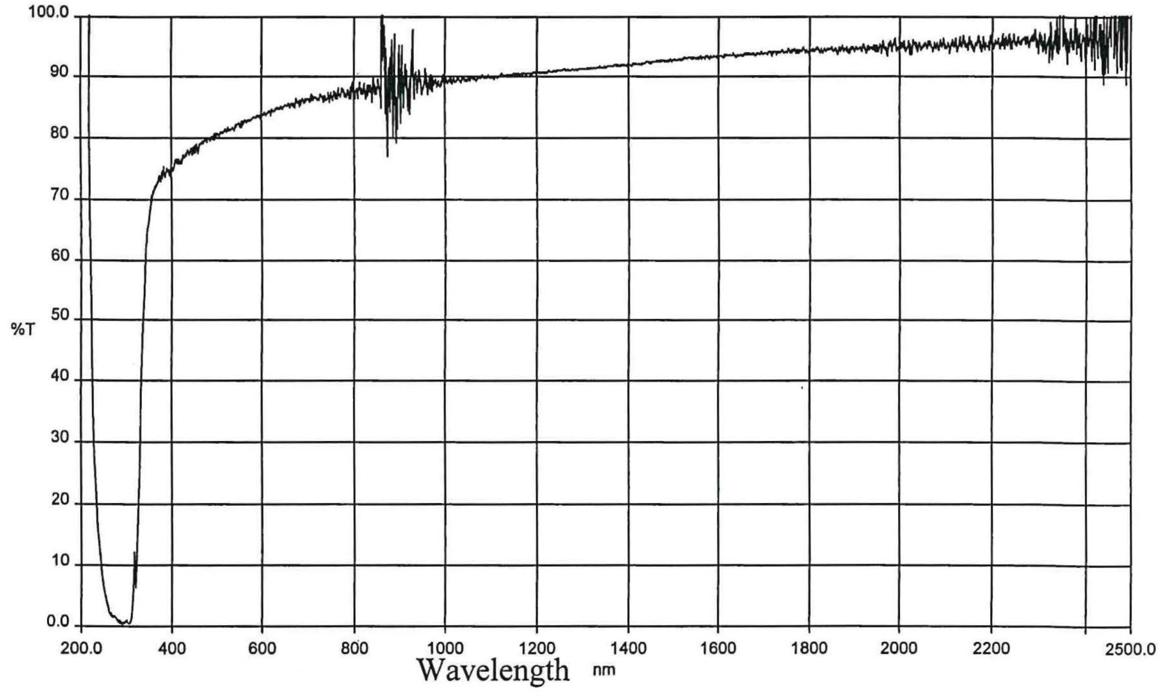

Figure 4. 12 : Transmittance of 0.06 g of platinum against wavelength

As depicted in Figures 4.10, 4.11 and 4.12 platinum thin films are characterized with high transmission. However, comparing Figure 4.11 and 4.12, the transmittance reduces when the thickness of platinum film increases. The high transmission of the films may be an indication of non-uniformity in the films and thereby leaving voids which makes the film transparent. (Akalton, 2015). It should be noted that the nanostructure of films is strongly affected by film preparation procedures and deposition conditions.

4.3 Comparison of reflectance of various thickness of palladium and platinum

The effect of thickness of the thin films of platinum and palladium are compared using the

Figure 4.13.

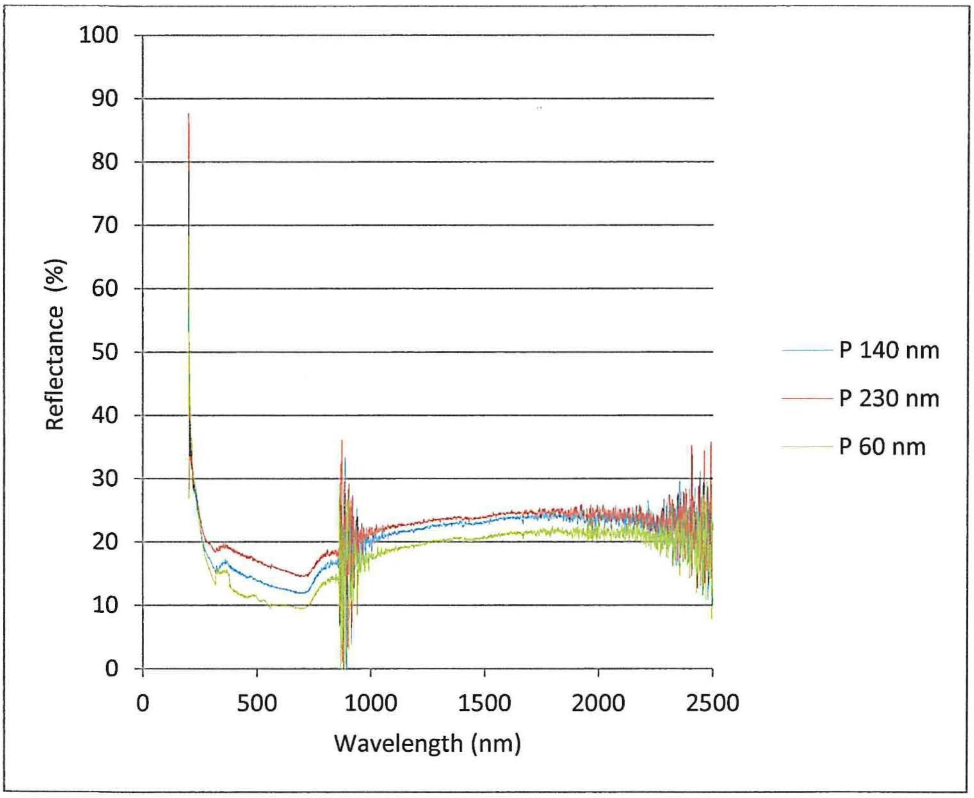

Figure 4. 13 : Reflectance of palladium thin films of various thicknesses

The wavelength range is reduced to better view the variation as depicted in Figure 4.14.

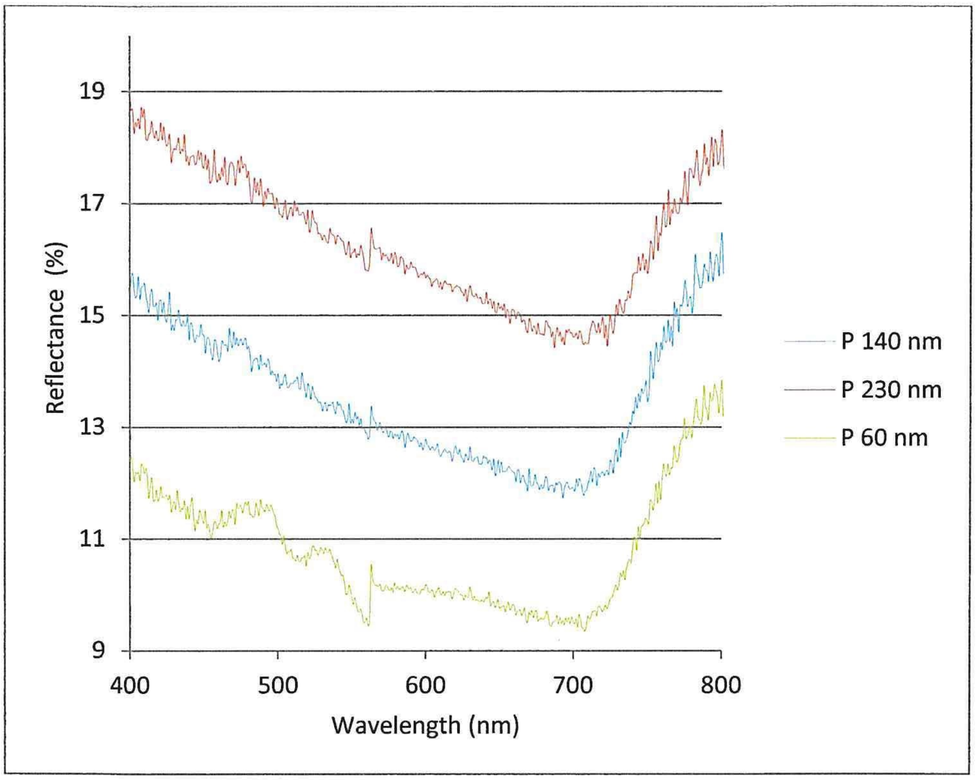

Figure 4. 14 : Reflectance of palladium films in the 400-800 nm range

The trend of reflectance is the same for all the thin films of palladium irrespective of the thickness. It is only the magnitude that varies. At 564 nm, 230 nm film of palladium has reflectance of 16%, 140 nm film a reflectance of 13% and 60 nm reflectance of 9%. The noticeable peak of 230 nm film of 16% is at 564 nm, for 140 nm film at 563 nm and for 60 nm at 562 nm. It is noted that the peaks shift towards the higher wavelengths with increasing thickness of the film. The peak shift is brought about by the structural improvement represented by increasing the grain size. The phenomenon of peaks shifting is called band shift.

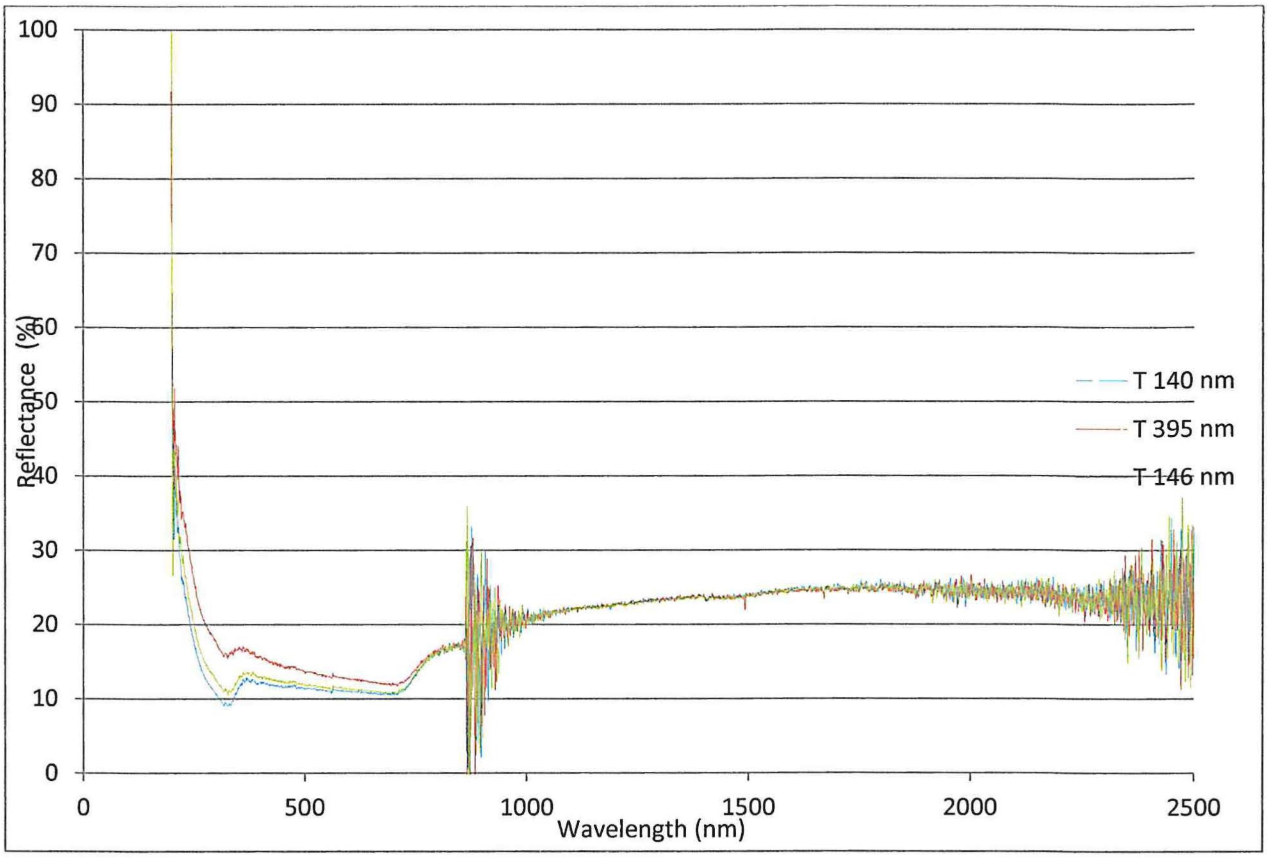

Figure 4. 15 : Reflectance of platinum films of various thicknesses

From Figure 4.15, it can be seen clearly that reflectance increases with film thickness in the visible range of 400-800 nm. In the infra red range (800-2500 nm), there is no significant change in reflectance with varying thickness. This seems to suggest that the optimum thickness had been reached for maximum reflectance in the infrared range.

For the same film thickness of palladium and platinum coating (140 nm), the reflectance characteristics for the two materials are compared in Figure 4.16.

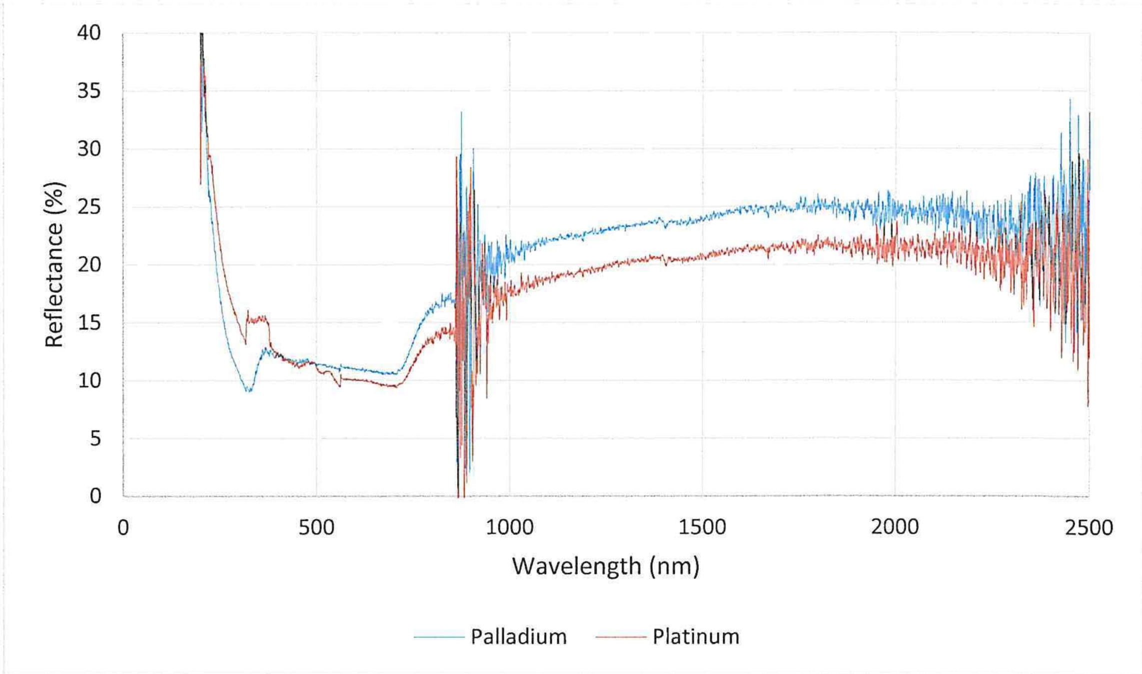

Figure 4. 16 : Reflectance of 140 nm films of Platinum and Palladium

It can be observed in Figure 4.16 that for the same thicknesses, palladium has greater reflectance than platinum. This shows that for the same film thickness, palladium film is a better reflector of infrared radiation than platinum film on glass.

4.4 Thin film thicknesses, refractive indices and absorption coefficients

The film thickness d, refractive indices and absorption coefficients of the films were determined using Pointwise Unconstrained Minimization Approach (PUMA).

Table 4. 1 : Calculated values of film thickness for palladium and platinum single films

Film	Mass evaporated (g)±0.005g	Thickness (nm)±5 nm
P1	0.02	60.0
P2	0.04	140.0
P3	0.06	230.0
T1	0.02	140.0
T2	0.04	146.0
T3	0.06	395.0

From the Table 4.1, it is observed that thickness of the film correlates well with the quantity of palladium or platinum evaporated; although not linearly. This may be as a result of 'spitting' during deposition, whereby a rapid rate of evaporation results into some particles jumping off the boat.

Table 4. 2 : Refractive indices of single the films at specific wavelengths

λ(nm)	nP1 ($x10^{10}$)	nP2	nP3	nT1	nT2	nT3
400	20	2.1417	1.9194	2.1618	2.1236	1.8850
600	17	2.1417	1.4680	2.1618	2.1236	1.8850
800	16	2.1417	1.2448	2.1618	2.1236	1.8850
1000	12	2.1417	1.0387	2.1618	2.1236	1.8850
1200	9.6	2.1417	1.0033	2.1618	2.1236	1.8850
1400	7.2	2.1417	1.0020	2.1618	2.1236	1.8850
1600	4.8	2.1417	1.0007	2.1618	2.1236	1.8850
1800	2.2	2.1417	1.0000	2.1618	2.1236	1.8850
2000	3.1	2.1417	1.0000	2.1618	2.1236	1.8850

The refractive indices for P2, T1, T2, and T3 are constant across all wavelengths. On the contrary, the refractive indices for P1 and P3 reduce with wavelength. Furthermore, the refractive indices P1are exceedingly high compared to that of P3 and P2.

It is observed that, the smaller the thickness of the film, the higher the refractive index. But as the film thickness increases, its refractive index gets closure to the refractive index of its bulk material and; thus dependence of refractive index of the film on film thickness ceases with greater film thicknesses.

The Figure 4.17 shows the variation of absorption coefficients of platinum films with wavelength depicting linear dependence of absorption coefficients of the films with wavelength. The absorption coefficients were retrieved from PUMA program. The inflexion points of absorption of the films are 700 nm, 500 nm and 800 nm for T1, T2 and T3 respectively.

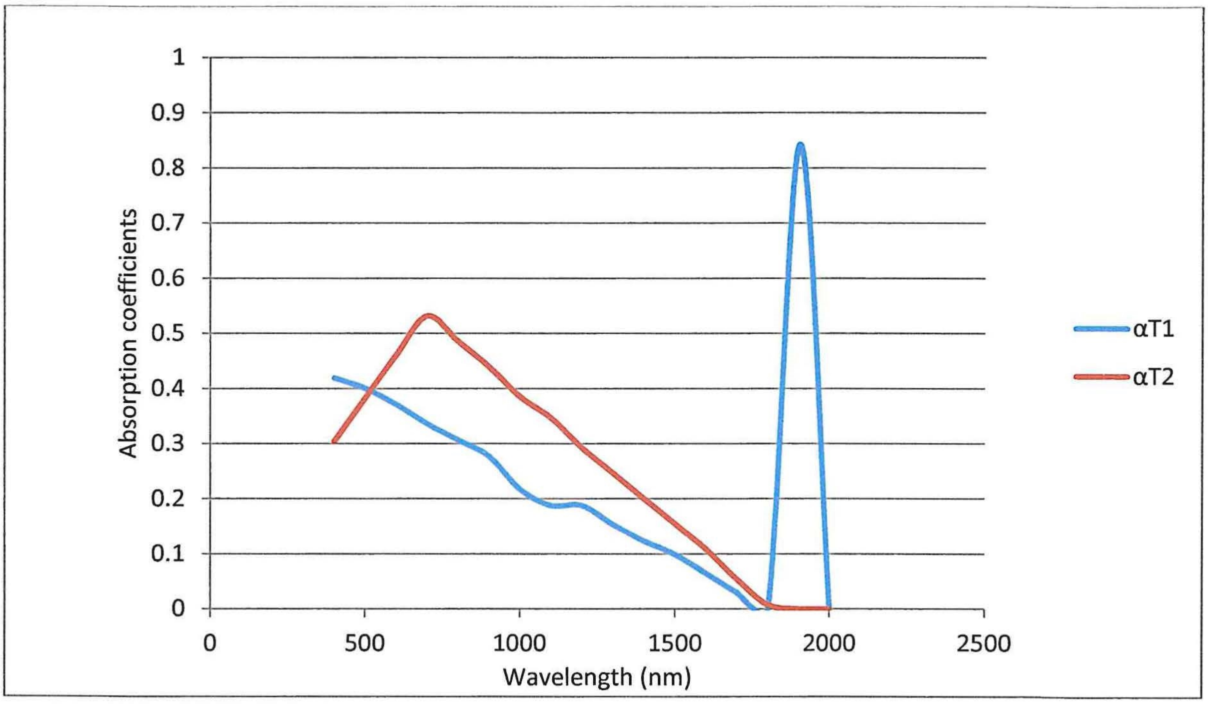

Figure 4. 17 : Absorption coefficient of platinum against wavelength

However, the absorption coefficients for T3 were far too high in comparison to that of T1 and T2; thus, the separate Figure 4.18. This anomalous increase in absorption coefficient is quite intriguing and questionable especially since there was an incidence of fusion of the boat during preparation of the samples. It could be that the film for T3 is not entirely due to evaporation of platinum; an assumption that can only be proven by carrying out X-Ray Diffraction tests on the sample. This quest was regrettably beyond the scope of this study.

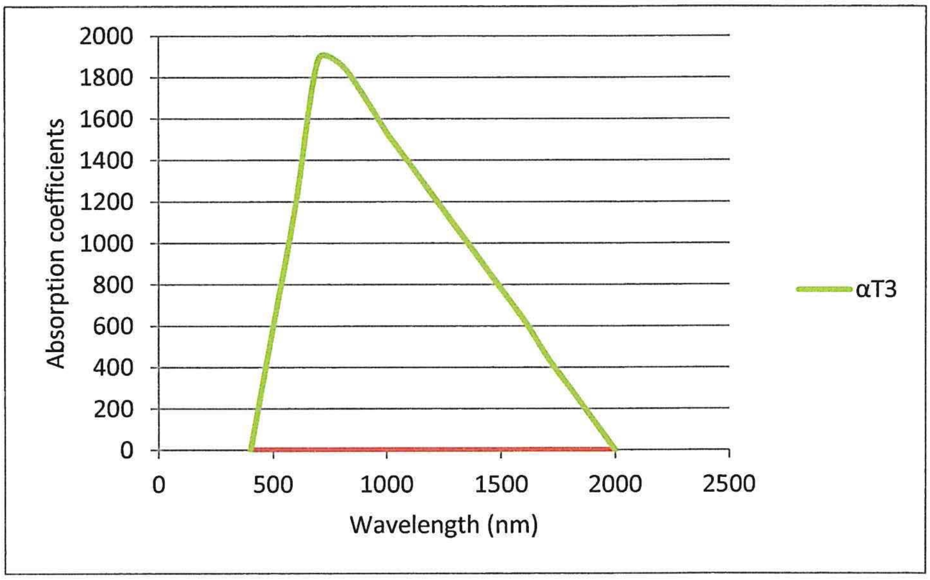

Figure 4. 18 : Absorption coefficient of T3 against wavelength

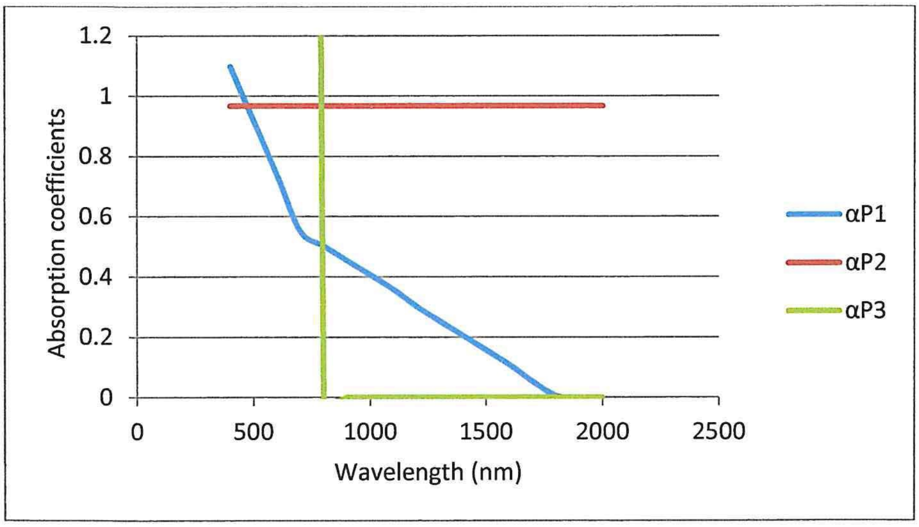

Figure 4. 19 : Absorption coefficient of Palladium against wavelength

Absorption coefficient for P2 is constant across all wavelengths. For P1 the absorption coefficient linearly reduces with wavelength; at a wavelength of 700 nm, there is an inflection point after which the gradient of the curve reduces. For P3, the absorption coefficient is far higher than that of P1 and P2 at wavelengths below 700 nm, and too low for wavelengths above 800 nm.

The absorption coefficient describes how much light of a given wavelength is absorbed by a material of a given thickness.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions of this research and recommendations based on the analysis of the results.

5.1 Conclusions

Results show that the reflectance and transmittance of platinum and palladium films vary with wavelength. The reflectance and transmittance are lower in the visible range and higher in the infra-red range. It has also been found that film thickness influence the reflectance and transmittance characteristics of the optical thin films. Reflectance increases with increase in film thickness up to a point where the film behaves like its bulk material.

For the same film thickness, palladium has more reflectance than platinum. Therefore, industrial requirements are supported by selecting coating's materials and film thickness.

Thermally evaporated palladium and platinum thin films are quite inhomogeneous. The films are however characterized by higher reflectance in the infra-red region than that in the visible region. In that case, they may be useful as heat mirrors. Since in this case transmission is already high, these metal films do not require a dielectric to enhance their transmission; but they may be used to increase the stability of the film on substrate.

It has been ascertained that the increase in the amount of the material evaporated implies an increase in thickness though not linearly dependent: That is, there is correlation between mass evaporated and film thickness achieved. However, it is advisable that one carries out ex situ measurements to determine the exact thickness of the film.

The absorption coefficients of P3 and T3 vary significantly from that of P1, P2 and T1, T2 respectively fabricated by evaporating the same material.

From Table 4.2, the refractive indices of thin films decrease with increase in thickness and it approaches the refractive index of its bulk material. Beyond this point, it would be wasteful to increase film thickness in an attempt to decrease the refractive index and thus increase reflectance of thin films. Further research should be carried out to ascertain the maximum thickness beyond which the film properties do not change.

The transmittances of palladium and platinum films decrease with increase in film thickness. The generally high transmittances observed could be a result of voids in the film which reduce as the thickness of the films increase; thereby leading to reduced transmittance. Since void density decreases with increasing substrate temperature, the substrate should be heated during deposition. Furthermore, lower deposition rates should be used during deposition. This improves stability of the films and the uniformity in thickness. The lower deposition rates can be ensured by presetting the deposition conditions on the crystal monitor. It is also important to ensure high vacuum conditions to reduce the influence of residual gas pressure; another factor that that determines the void volume and density.

5.2 Recommendations

With the precautions put in place, further research should be carried out to investigate the applicability of platinum and palladium films as infra-red reflectors.

Optimization of the film thickness of palladium and platinum for better infrared reflection is required.

It is highly recommended that one carries out X-ray diffraction analysis after preparation of thermally deposited films to determine the real material of the film. X-ray diffraction analysis will also help to investigate the effect of film topology on the optical characteristics of the films.

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APPENDIX

ESTIMATED THICKNESSES

Thickness of film P1 = 60.00 nm

ESTIMATED INFLEXION POINTS

Inflexion point of the absorption coefficient of film P1 = 0.00 nm

ESTIMATED REFRACTIVE INDICES AND ABSORPTION COEFFICIENTS

Film 1

lambda	n	kappa
4.000000000000000000e+002	2.141710051228910700000e+000	1.098566916961477800000e+000
4.161616161616161700000e+002	2.141710051148933300000e+000	1.068605365359143200000e+000
4.323232323232323300000e+002	2.141710051068956000000e+000	1.038643813756808600000e+000
4.484848484848485000000e+002	2.141710050988978600000e+000	1.008682262154474000000e+000
4.646464646464646600000e+002	2.141710050909001200000e+000	9.787207105521392700000e-001
4.808080808080808300000e+002	2.141710050829023900000e+000	9.487591589498046700000e-001
4.969696969696970000000e+002	2.141710050749046500000e+000	9.187976073474700700000e-001
5.131313131313131600000e+002	2.141710050669069200000e+000	8.888360557451354700000e-001
5.292929292929293300000e+002	2.141710050589091800000e+000	8.588745041428008700000e-001
5.454545454545455000000e+002	2.141710050509114400000e+000	8.289129525404662600000e-001
5.616161616161616600000e+002	2.141710050429137100000e+000	7.989514009381316600000e-001
5.777777777777778300000e+002	2.141710050349159700000e+000	7.689898493357970600000e-001
5.939393939393939900000e+002	2.141710050269182400000e+000	7.390282977334624600000e-001
6.101010101010101600000e+002	2.141710050189205000000e+000	7.090667461311278600000e-001

6.2626262626262626330000e+002 2.1417100501092277000e+000 6.7910519452879325000e-001

6.4242424242424242490000e+002 2.1417100500292503000e+000 6.4914364292645865000e-001

6.5858585858585858660000e+002 2.1417100499492729000e+000 6.1918209132412405000e-001

6.7474747474747474710000e+002 2.1417100498692956000e+000 5.8922053972178945000e-001

6.9090909090909090880000e+002 2.1417100497893182000e+000 5.5925898811945485000e-001

7.0707070707070707040000e+002 2.1417100497093409000e+000 5.5121645202341729000e-001

7.2323232323232323210000e+002 2.1417100496293635000e+000 5.4317391592737974000e-001

7.3939393939393939380000e+002 2.1417100495493862000e+000 5.3513137983134218000e-001

7.5555555555555555540000e+002 2.1417100494694088000e+000 5.2708884373530462000e-001

7.7171717171717171710000e+002 2.1417100493894314000e+000 5.1904630763926707000e-001

7.8787878787878787880000e+002 2.1417100493094541000e+000 5.1100377154322951000e-001

8.0404040404040404040000e+002 2.1417100492294767000e+000 5.0296123544719196000e-001

8.2020202020202020210000e+002 2.1417100491494994000e+000 4.9491869935115440000e-001

8.3636363636363636370000e+002 2.1417100490695220000e+000 4.8687616325511685000e-001

8.5252525252525252540000e+002 2.1417100489895446000e+000 4.7883362715907929000e-001

8.6868686868686868710000e+002 2.1417100489095673000e+000 4.7079109106304173000e-001

8.8484848484848484870000e+002 2.1417100488295899000e+000 4.6274855496700418000e-001

9.0101010101010101040000e+002 2.1417100487496126000e+000 4.5470601887096662000e-001

9.1717171717171717210000e+002 2.1417100486696352000e+000 4.4666348277492907000e-001

9.3333333333333333370000e+002 2.1417100485896579000e+000 4.3862094667889151000e-001

9.4949494949494949540000e+002 2.1417100485096805000e+000 4.3057841058285395000e-001

9.6565656565656565700000e+002 2.1417100484297031000e+000 4.2253587448681640000e-001

9.8181818181818181870000e+002 2.1417100483497258000e+000 4.1449333839077884000e-001

9.9797979797979798040000e+002 2.1417100482697484000e+000 4.0645080229474129000e-001

1.0141414141414141420000e+003 2.1417100481897711000e+000 3.9840826619870373000e-001

1.0303030303030303030000e+003 2.1417100481097937000e+000 3.9036573010266618000e-001

1.0464646464646464640000e+003 2.1417100480298163000e+000 3.8232319400662862000e-001

1.0626262626262626260000e+003 2.1417100479498390000e+000 3.7428065791059106000e-001

1.0787878787878788000e+003 2.1417100478698616000e+000 3.6623812181453351000e-001

1.0949494949494949000e+003 2.1417100477898843000e+000 3.5819558571851595000e-001

1.1111111111111111000e+003 2.1417100477099069000e+000 3.5015304962247840000e-001

1.1272727272727273000e+003 2.1417100476299296000e+000 3.4211051352644084000e-001

1.1434343434343434000e+003 2.1417100475499522000e+000 3.3406797743040328000e-001

1.1595959595959596000e+003 2.1417100474699748000e+000 3.2602544133436573000e-001

1.1757575757575758000e+003 2.1417100473899975000e+000 3.1798290523832817000e-001

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1.2080808080808081000e+003 2.1417100472300428000e+000 3.0189783304625306000e-001

1.2242424242424242000e+003 2.1417100471500654000e+000 2.9385529695021551000e-001

1.2404040404040404000e+003 2.1417100470700881000e+000 2.8581276085417795000e-001

1.2565656565656566000e+003 2.1417100469901107000e+000 2.7777022475814039000e-001

1.2727272727272727000e+003 2.1417100469101333000e+000 2.6972768866210284000e-001

1.2888888888888889000e+003 2.1417100468301560000e+000 2.6168515256606528000e-001

1.3050505050505051000e+003 2.1417100467501786000e+000 2.5364261647002773000e-001

1.3212121212121212000e+003 2.1417100466702013000e+000 2.4560008037399017000e-001

1.3373737373737374000e+003 2.1417100465902239000e+000 2.3755754427795261000e-001

1.3535353535353536000e+003 2.1417100465102465000e+000 2.2951500818191506000e-001

1.3696969696969697000e+003 2.1417100464302692000e+000 2.2147247208587750000e-001

1.3858585858585859000e+003 2.1417100463502918000e+000 2.1342993598983995000e-001

1.4020202020202021000e+003 2.1417100462703145000e+000 2.0538739989380239000e-001

1.4181818181818182000e+003 2.1417100461903371000e+000 1.9734486379776484000e-001

1.4343434343434344000e+003 2.1417100461103598000e+000 1.8930232770172728000e-001

1.4505050505050506000e+003 2.1417100460303824000e+000 1.8125979160568972000e-001

1.4666666666666667000e+003 2.1417100459504050000e+000 1.7321725550965217000e-001

1.4828282828282829000e+003 2.1417100458704277000e+000 1.6517471941361461000e-001

1.4989898989898991000e+003 2.1417100457904503000e+000 1.5713218331757706000e-001

1.5151515151515152000e+003 2.1417100457104730000e+000 1.4908964722153950000e-001

1.53131313131313140000e+003	2.14171004563068970000e+000	1.41047111125501940000e-001
1.54747474747474760000e+003	2.14171004555090640000e+000	1.33004575029464390000e-001
1.56363636363636370000e+003	2.14171004547112310000e+000	1.24962038933426830000e-001
1.57979797979797990000e+003	2.14171004539133980000e+000	1.16919502837389290000e-001
1.59595959595959610000e+003	2.14171004531155650000e+000	1.08876966741351750000e-001
1.61212121212121220000e+003	2.14171004523177320000e+000	1.00834430645314210000e-001
1.62828282828282840000e+003	2.14171004515198990000e+000	9.27918945492766660000e-002
1.64444444444444460000e+003	2.14171004507220660000e+000	8.47493584532391240000e-002
1.66060606060606070000e+003	2.14171004499242330000e+000	7.67068223572015820000e-002
1.67676767676767690000e+003	2.14171004491264010000e+000	6.86642862611640400000e-002
1.69292929292929310000e+003	2.14171004483285680000e+000	6.06217501651264910000e-002
1.70909090909090920000e+003	2.14171004475307390000e+000	5.25792140690889420000e-002
1.72525252525252540000e+003	2.14171004467329110000e+000	4.45366779730513930000e-002
1.74141414141414160000e+003	2.14171004459350820000e+000	3.64941418770138440000e-002
1.75757575757575770000e+003	2.14171004451372540000e+000	2.84516057809762950000e-002
1.77373737373737390000e+003	2.14171004443394250000e+000	2.04090696849387470000e-002
1.78989898989899010000e+003	2.14171004435415970000e+000	1.23665335889011960000e-002
1.80606060606060620000e+003	2.14171004427437680000e+000	6.18326687491797640000e-003
1.82222222222222240000e+003	2.14171004419459400000e+000	1.60934757263949180000e-010
1.83838383838383860000e+003	2.14171004411481110000e+000	1.60934757197740920000e-010
1.85454545454545470000e+003	2.14171004403502830000e+000	1.60934757131532660000e-010
1.87070707070707090000e+003	2.14171004395524540000e+000	1.60934757131532660000e-010
1.88686868686868710000e+003	2.14171004387546260000e+000	1.60934757131532660000e-010
1.90303030303030320000e+003	2.14171004379567980000e+000	1.60934757131532660000e-010
1.91919191919191940000e+003	2.14171004371589690000e+000	1.60934757131532660000e-010
1.93535353535353560000e+003	2.14171004363611410000e+000	1.60934757131532660000e-010
1.95151515151515150000e+003	2.14171004355633120000e+000	1.60934757131532660000e-010
1.96767676767676770000e+003	2.14171004347654840000e+000	1.60934757131532660000e-010

1.98383838383838380000e+003 2.14171004347654840000e+000 1.60934757131532660000e-010

2.00000000000000000000e+003 2.14171004347654840000e+000 1.60934757131532660000e-010

REFLECTANCE WITH THE ESTIMATED THICKNESSES AND OPTICAL PARAMETERS

lambda	r
4.00000000000000000000e+002	8.97998690885875860000e-002
4.16161616161616170000e+002	8.92135392285412640000e-002
4.32323232323232330000e+002	8.86966335967328960000e-002
4.48484848484848500000e+002	8.82384589489315780000e-002
4.64646464646464660000e+002	8.78303283907924810000e-002
4.80808080808080830000e+002	8.74651215614583730000e-002
4.96969696969697000000e+002	8.71369542568957710000e-002
5.13131313131313160000e+002	8.68409272257518180000e-002
5.29292929292929330000e+002	8.65729330269585930000e-002
5.45454545454545500000e+002	8.63295060023229060000e-002
5.61616161616161660000e+002	8.61077046349596060000e-002
5.77777777777777830000e+002	8.59050184937142500000e-002
5.93939393939393990000e+002	8.57192940264585450000e-002
6.10101010101010160000e+002	8.55486749363244680000e-002
6.26262626262626330000e+002	8.53915539366851000000e-002
6.42424242424242490000e+002	8.52465334554470540000e-002
6.58585858585858660000e+002	8.51123934303750500000e-002
6.74747474747474710000e+002	8.49880647623069830000e-002
6.90909090909090880000e+002	8.48726073124203420000e-002
7.07070707070707040000e+002	8.47651915715581520000e-002
7.23232323232323210000e+002	8.46650833142739840000e-002
7.39393939393939380000e+002	8.45716306922898180000e-002

7.55555555555555540000e+002 8.44842533320945000000e-002

7.71717171717171710000e+002 8.44024330872247820000e-002

7.87878787878787880000e+002 8.43257061631268600000e-002

8.04040404040404040000e+002 8.42536563856704500000e-002

8.20202020202020210000e+002 8.41859094266281390000e-002

8.36363636363636370000e+002 8.41221278331479860000e-002

8.52525252525252540000e+002 8.40620067353143600000e-002

8.68686868686868710000e+002 8.40052701277210910000e-002

8.84848484848484870000e+002 8.39516676386737050000e-002

9.01010101010101040000e+002 8.39009717150363130000e-002

9.17171717171717210000e+002 8.38529751625157610000e-002

9.33333333333333370000e+002 8.38074889908422830000e-002

9.49494949494949540000e+002 8.37643405212704360000e-002

9.65656565656565700000e+002 8.37233717204221850000e-002

9.81818181818181870000e+002 8.36844377299610090000e-002

9.97979797979798040000e+002 8.36474055661541870000e-002

1.01414141414141420000e+003 8.36121529671908920000e-002

1.03030303030303030000e+003 8.35785673693251880000e-002

1.04646464646464640000e+003 8.35465449956049600000e-002

1.06262626262626260000e+003 8.35159900432205500000e-002

1.07878787878787880000e+003 8.34868139574319320000e-002

1.09494949494949490000e+003 8.34589347816637600000e-002

1.11111111111111110000e+003 8.34322765747521480000e-002

1.12727272727272730000e+003 8.34067688875082260000e-002

1.14343434343434340000e+003 8.33823462917836490000e-002

1.15959595959595960000e+003 8.33589479560900290000e-002

1.17575757575757580000e+003 8.33365172625762230000e-002

1.19191919191919190000e+003 8.33150014608097370000e-002

1.20808080808080810000e+003 8.32943513543679260000e-002

1.22424242424242420000e+003 8.32745210167248890000e-002

1.24040404040404040000e+003 8.32554675333412870000e-002

1.25656565656565660000e+003 8.32371507672244600000e-002

1.27272727272727270000e+003 8.32195331455449770000e-002

1.28888888888888890000e+003 8.32025794651724830000e-002

1.30505050505050510000e+003 8.31862567152337890000e-002

1.32121212121212120000e+003 8.31705339150078100000e-002

1.33737373737373740000e+003 8.31553819656594830000e-002

1.35353535353535360000e+003 8.31407735144764900000e-002

1.36969696969696970000e+003 8.31266828304137730000e-002

1.38585858585858590000e+003 8.31130856898843890000e-002

1.40202020202020210000e+003 8.30999592718394960000e-002

1.41818181818181820000e+003 8.30872820612826300000e-002

1.43434343434343440000e+003 8.30750337604529290000e-002

1.45050505050505060000e+003 8.30631952069858240000e-002

1.46666666666666670000e+003 8.30517482984311220000e-002

1.48282828282828290000e+003 8.30406759225703620000e-002

1.49898989898989910000e+003 8.30299618930274570000e-002

1.51515151515151520000e+003 8.30195908897193860000e-002

1.53131313131313140000e+003 8.30095484037330360000e-002

1.54747474747474760000e+003 8.29998206862572060000e-002

1.56363636363636370000e+003 8.29903947012308600000e-002

1.57979797979797990000e+003 8.29812580814026650000e-002

1.59595959595959610000e+003 8.29723990875217700000e-002

1.61212121212121220000e+003 8.29638065704082770000e-002

1.62828282828282840000e+003 8.29554699356729870000e-002

1.64444444444444460000e+003 8.29473791108767680000e-002

1.66060606060606070000e+003 8.29395245149383560000e-002

1.67676767676767690000e+003 8.29318970296156620000e-002

1.69292929292929310000e+003 8.29244879729025140000e-002

1.70909090909090920000e+003 8.29172890741942670000e-002

1.72525252525252540000e+003 8.29102924510882740000e-002

1.74141414141414160000e+003 8.29034905876989550000e-002

1.75757575757575770000e+003 8.28968763143744650000e-002

1.77373737373737390000e+003 8.28904427887119380000e-002

1.78989898989899010000e+003 8.28841834777769290000e-002

1.80606060606060620000e+003 8.28780921414420110000e-002

1.82222222222222240000e+003 8.28721628167632670000e-002

1.83838383838383860000e+003 8.28663898033208530000e-002

1.85454545454545470000e+003 8.28607676494582250000e-002

1.87070707070707090000e+003 8.28552911393553440000e-002

1.88686868686868710000e+003 8.28499552808810020000e-002

1.90303030303030320000e+003 8.28447552941667110000e-002

1.91919191919191940000e+003 8.28396866008604270000e-002

1.93535353535353560000e+003 8.28347448140062530000e-002

1.95151515151515150000e+003 8.28299257285154410000e-002

1.96767676767676770000e+003 8.28252253121855990000e-002

1.98383838383838380000e+003 8.28206396972334250000e-002

2.00000000000000000000e+003 8.28161651723080540000e-002

QUADRATIC ERROR = 1.366629e-002

ESTIMATED THICKNESSES

Thickness of film P2 = 140.00 nm

ESTIMATED INFLEXION POINTS

Inflexion point of the absorption coefficient of film P2 = 400.00 nm

ESTIMATED REFRACTIVE INDICES AND ABSORPTION COEFFICIENTS

Film 1

lambda	n	kappa
4.0000000000000000000e+002	1.9194175090431191000e+000	9.6739117343179770000e-001
4.1616161616161617000e+002	1.8713855773302863000e+000	9.6739117329555024000e-001
4.3232323232323233000e+002	1.8233550626378885000e+000	9.6739117328101987000e-001
4.4848484848484850000e+002	1.7753245479454907000e+000	9.6739117326648949000e-001
4.6464646464646466000e+002	1.7272940332530928000e+000	9.6739117325195911000e-001
4.8080808080808083000e+002	1.6792635185606950000e+000	9.6739117323742874000e-001
4.9696969696969697000e+002	1.6317381078994868000e+000	9.6739117322289836000e-001
5.1313131313131316000e+002	1.5842126972382786000e+000	9.6739117320836798000e-001
5.2929292929292933000e+002	1.5366872865770704000e+000	9.6739117319383761000e-001
5.4545454545454550000e+002	1.5195149784541981000e+000	9.6739117317930723000e-001
5.6161616161616166000e+002	1.5023426703313258000e+000	9.6739117316477685000e-001
5.7777777777777783000e+002	1.4851703622084536000e+000	9.6739117315024648000e-001
5.9393939393939399000e+002	1.4679980547353437000e+000	9.6739117313571610000e-001
6.1010101010101016000e+002	1.4508257472622339000e+000	9.6739117312118572000e-001
6.2626262626262633000e+002	1.4336534397891241000e+000	9.6739117310665534000e-001
6.4242424242424249000e+002	1.4164811323160142000e+000	9.6739117309212497000e-001
6.5858585858585866000e+002	1.3993088248429044000e+000	9.6739117307759459000e-001
6.7474747474747471000e+002	1.3821365173697946000e+000	9.6739117306306421000e-001
6.9090909090909088000e+002	1.3649642098966848000e+000	9.6739117304853384000e-001
7.0707070707070704000e+002	1.3477919024235749000e+000	9.6739117303400346000e-001

7.2323232323232321000e+002 1.3306195949504651000e+000 9.6739117301947308000e-001
7.3939393939393938000e+002 1.3134472874773553000e+000 9.6739117300494271000e-001
7.5555555555555554000e+002 1.2962749800042455000e+000 9.6739117299041233000e-001
7.7171717171717171000e+002 1.2791026725311356000e+000 9.6739117297588195000e-001
7.8787878787878788000e+002 1.2619303650580258000e+000 9.6739117296135158000e-001
8.0404040404040404000e+002 1.2447580575849160000e+000 9.6739117294682120000e-001
8.2020202020202021000e+002 1.2275857501118062000e+000 9.6739117293229082000e-001
8.3636363636363637000e+002 1.2104134426386963000e+000 9.6739117291776044000e-001
8.5252525252525254000e+002 1.1932411351655865000e+000 9.6739117290323007000e-001
8.6868686868686871000e+002 1.1760688276924767000e+000 9.6739117288869969000e-001
8.8484848484848487000e+002 1.1588965202193668000e+000 9.6739117287416931000e-001
9.0101010101010104000e+002 1.1417242127462570000e+000 9.6739117285963894000e-001
9.1717171717171721000e+002 1.1245519052731472000e+000 9.6739117284510856000e-001
9.3333333333333337000e+002 1.1073795978000374000e+000 9.6739117283057818000e-001
9.4949494949494954000e+002 1.0902072903269275000e+000 9.6739117281604781000e-001
9.6565656565656570000e+002 1.0730349828538177000e+000 9.6739117280151743000e-001
9.8181818181818187000e+002 1.0558626753807079000e+000 9.6739117278698705000e-001
9.9797979797979804000e+002 1.0386903679075981000e+000 9.6739117277245668000e-001
1.0141414141414142000e+003 1.0215180604344882000e+000 9.6739117275792630000e-001
1.0303030303030303000e+003 1.0043457529613784000e+000 9.6739117274339592000e-001
1.0464646464646464000e+003 1.0042422826527742000e+000 9.6739117272886554000e-001
1.0626262626262626000e+003 1.0041388123441699000e+000 9.6739117271433517000e-001
1.0787878787878788000e+003 1.0040353420355657000e+000 9.6739117269980479000e-001
1.0949494949494949000e+003 1.0039318717269614000e+000 9.6739117268527441000e-001
1.1111111111111111000e+003 1.0038284014183572000e+000 9.6739117267074404000e-001
1.1272727272727273000e+003 1.0037249311097529000e+000 9.6739117265621366000e-001
1.1434343434343434000e+003 1.0036214608011487000e+000 9.6739117264168328000e-001
1.1595959595959596000e+003 1.0035179904925444000e+000 9.6739117262715291000e-001
1.1757575757575758000e+003 1.0034145201839402000e+000 9.6739117261262253000e-001
1.1919191919191919000e+003 1.0033110498753359000e+000 9.6739117259809215000e-001
1.2080808080808081000e+003 1.0032075795667317000e+000 9.6739117258356178000e-001
1.2242424242424242000e+003 1.0031041092581274000e+000 9.6739117256903140000e-001
1.2404040404040404000e+003 1.0030006389495232000e+000 9.6739117255450102000e-001

1.2565656565656565660000e+003	1.0028971686409189000e+000	9.6739117253997631000e-001
1.2727272727272727270000e+003	1.0027936983323147000e+000	9.6739117252545159000e-001
1.2888888888888888890000e+003	1.0026902280237104000e+000	9.6739117251092688000e-001
1.3050505050505050510000e+003	1.0025867577151062000e+000	9.6739117249640216000e-001
1.3212121212121212120000e+003	1.0024832874065019000e+000	9.6739117248187745000e-001
1.3373737373737373740000e+003	1.0023798170978977000e+000	9.6739117246735273000e-001
1.3535353535353535360000e+003	1.0022763467892934000e+000	9.6739117245282802000e-001
1.3696969696969696970000e+003	1.0021728764806892000e+000	9.6739117243843553000e-001
1.3858585858585858590000e+003	1.0020694061720850000e+000	9.6739117242404304000e-001
1.4020202020202020210000e+003	1.0019659358634807000e+000	9.6739117240965056000e-001
1.4181818181818181820000e+003	1.0018624655548765000e+000	9.6739117239525807000e-001
1.4343434343434343440000e+003	1.0017589952462722000e+000	9.6739117238086558000e-001
1.4505050505050505060000e+003	1.0016555249376680000e+000	9.6739117236647310000e-001
1.4666666666666666670000e+003	1.0015520546290637000e+000	9.6739117235208061000e-001
1.4828282828282828290000e+003	1.0014485843204595000e+000	9.6739117233768812000e-001
1.4989898989898989910000e+003	1.0013451140118552000e+000	9.6739117232364469000e-001
1.5151515151515151520000e+003	1.0012416437032510000e+000	9.6739117230960125000e-001
1.5313131313131313140000e+003	1.0011381733946467000e+000	9.6739117229555782000e-001
1.5474747474747474760000e+003	1.0010347030860425000e+000	9.6739117228151439000e-001
1.5636363636363636370000e+003	1.0009312327774382000e+000	9.6739117226747096000e-001
1.5797979797979797990000e+003	1.0008277624688340000e+000	9.6739117225342752000e-001
1.5959595959595959610000e+003	1.0007242921602297000e+000	9.6739117223938409000e-001
1.6121212121212121220000e+003	1.0006208218516255000e+000	9.6739117222611382000e-001
1.6282828282828282840000e+003	1.0005173515430212000e+000	9.6739117221284354000e-001
1.6444444444444444460000e+003	1.0004138812344170000e+000	9.6739117219957327000e-001
1.6606060606060606070000e+003	1.0003104109258127000e+000	9.6739117218630299000e-001
1.6767676767676767690000e+003	1.0002069406172085000e+000	9.6739117217303272000e-001
1.6929292929292929310000e+003	1.0001034703086042000e+000	9.6739117215976245000e-001
1.7090909090909090920000e+003	1.0000000000000000000e+000	9.6739117214723913000e-001
1.7252525252525252540000e+003	1.0000000000000000000e+000	9.6739117213471582000e-001
1.7414141414141414160000e+003	1.0000000000000000000e+000	9.6739117212219250000e-001
1.7575757575757575770000e+003	1.0000000000000000000e+000	9.6739117210966918000e-001
1.7737373737373737390000e+003	1.0000000000000000000e+000	9.6739117209714587000e-001

1.78989898989898990100000e+003	1.00000000000000000000e+000	9.67391172084622550000e-001
1.80606060606060620000e+003	1.00000000000000000000e+000	9.67391172072099240000e-001
1.82222222222222240000e+003	1.00000000000000000000e+000	9.67391172059575920000e-001
1.83838383838383860000e+003	1.00000000000000000000e+000	9.67391172047052610000e-001
1.85454545454545470000e+003	1.00000000000000000000e+000	9.67391172034529290000e-001
1.87070707070707090000e+003	1.00000000000000000000e+000	9.67391172022005970000e-001
1.88686868686868710000e+003	1.00000000000000000000e+000	9.67391172009482660000e-001
1.90303030303030320000e+003	1.00000000000000000000e+000	9.67391172009482660000e-001
1.91919191919191940000e+003	1.00000000000000000000e+000	9.67391172009482660000e-001
1.93535353535353560000e+003	1.00000000000000000000e+000	9.67391172009482660000e-001
1.95151515151515150000e+003	1.00000000000000000000e+000	9.67391172009482660000e-001
1.96767676767676770000e+003	1.00000000000000000000e+000	9.67391172009482660000e-001
1.98383838383838380000e+003	1.00000000000000000000e+000	9.67391172009482660000e-001
2.00000000000000000000e+003	1.00000000000000000000e+000	9.67391172009482660000e-001

REFLECTANCE WITH THE ESTIMATED THICKNESSES AND OPTICAL PARAMETERS

lambda	r
4.00000000000000000000e+002	1.88342698698714530000e-001
4.16161616161616170000e+002	1.84485178649091170000e-001
4.32323232323232330000e+002	1.80849302710204140000e-001
4.48484848484848500000e+002	1.77593391478225950000e-001
4.64646464646464660000e+002	1.74802142296371120000e-001
4.80808080808080830000e+002	1.72456937368412640000e-001
4.96969696969697000000e+002	1.70482286354836340000e-001
5.13131313131313160000e+002	1.68726106346855950000e-001
5.29292929292929330000e+002	1.67091804826664080000e-001
5.45454545454545500000e+002	1.66469014317468880000e-001
5.61616161616161660000e+002	1.65727046991741590000e-001
5.77777777777777830000e+002	1.64875720148409950000e-001
5.93939393939393990000e+002	1.63941643376733000000e-001
6.10101010101010160000e+002	1.62964229530943750000e-001
6.26262626262626330000e+002	1.61991300744138700000e-001

6.424242424242424490000e+002 1.610748853997037200000e-001

6.585858585858586600000e+002 1.602675683419489700000e-001

6.747474747474747100000e+002 1.596195664843623700000e-001

6.909090909090908800000e+002 1.591765662917857000000e-001

7.070707070707070400000e+002 1.589782738615437000000e-001

7.232323232323232100000e+002 1.590575820079281900000e-001

7.393939393939393800000e+002 1.594402403318851400000e-001

7.555555555555555400000e+002 1.601449137188317200000e-001

7.717171717171717100000e+002 1.611835244060321500000e-001

7.878787878787878800000e+002 1.625617873742412100000e-001

8.040404040404040400000e+002 1.642798649286921200000e-001

8.202020202020202100000e+002 1.663330819287863200000e-001

8.363636363636363700000e+002 1.687126571493509600000e-001

8.525252525252525400000e+002 1.714064182664191400000e-001

8.686868686868687100000e+002 1.743994778797852700000e-001

8.848484848484848700000e+002 1.776748559362894300000e-001

9.010101010101010400000e+002 1.812140401214625300000e-001

9.171717171717172100000e+002 1.849974804965048000000e-001

9.333333333333333700000e+002 1.890050181251399000000e-001

9.494949494949495400000e+002 1.932162498940916700000e-001

9.656565656565657000000e+002 1.976108333878772400000e-001

9.818181818181818700000e+002 2.021687367100007100000e-001

9.979797979797980400000e+002 2.068704386964499200000e-001

1.014141414141414200000e+003 2.116970851654796400000e-001

1.030303030303030300000e+003 2.166306067885639100000e-001

1.046464646464646400000e+003 2.180811104771836800000e-001

1.062626262626262600000e+003 2.195027249921069600000e-001

1.078787878787878800000e+003 2.208924862540591300000e-001

1.094949494949494900000e+003 2.222477659115687200000e-001

1.111111111111111100000e+003 2.235662551657144900000e-001

1.127272727272727300000e+003 2.248459478610331800000e-001

1.143434343434343400000e+003 2.260851231418471400000e-001

1.159595959595959600000e+003 2.272823279263533900000e-001

1.1757575757575758000e+003 2.2843635940925169000e-001
1.1919191919191919000e+003 2.2954624776703281000e-001
1.2080808080808081000e+003 2.3061123920789309000e-001
1.2242424242424242000e+003 2.3163077948015229000e-001
1.2404040404040404000e+003 2.3260449792865212000e-001
1.2565656565656566000e+003 2.3353219216752866000e-001
1.2727272727272727000e+003 2.3441381341962275000e-001
1.2888888888888889000e+003 2.3524945255733873000e-001
1.3050505050505051000e+003 2.3603932686660142000e-001
1.3212121212121212000e+003 2.3678376754454619000e-001
1.3373737373737374000e+003 2.3748320793233563000e-001
1.3535353535353536000e+003 2.3813817247689512000e-001
1.3696969696969697000e+003 2.3874926640918290000e-001
1.3858585858585859000e+003 2.3931716612141068000e-001
1.4020202020202021000e+003 2.3984261022217723000e-001
1.4181818181818182000e+003 2.4032639124508859000e-001
1.4343434343434344000e+003 2.4076934798358884000e-001
1.4505050505050506000e+003 2.4117235842518389000e-001
1.4666666666666667000e+003 2.4153633325445797000e-001
1.4828282828282829000e+003 2.4186220989598370000e-001
1.4989898989898991000e+003 2.4215094706704013000e-001
1.5151515151515152000e+003 2.4240351981002503000e-001
1.5313131313131314000e+003 2.4262091497616933000e-001
1.5474747474747476000e+003 2.4280412713105168000e-001
1.5636363636363637000e+003 2.4295415485455202000e-001
1.5797979797979799000e+003 2.4307199740831281000e-001
1.5959595959595961000e+003 2.4315865174490175000e-001
1.6121212121212122000e+003 2.4321510983418743000e-001
1.6282828282828284000e+003 2.4324235628244009000e-001
1.6444444444444446000e+003 2.4324136622374334000e-001
1.6606060606060606000e+003 2.4321310346064778000e-001
1.6767676767676769000e+003 2.4315851883507533000e-001
1.6929292929292929310000e+003 2.4307854881050150000e-001

1.70909090909090920000e+003 2.42974114247967000000e-001

1.72525252525252540000e+003 2.42834210954398000000e-001

1.74141414141414160000e+003 2.42672061579666670000e-001

1.75757575757575770000e+003 2.42488525984318000000e-001

1.77373737373737390000e+003 2.42284445068887770000e-001

1.78989898989899010000e+003 2.42060640319319180000e-001

1.80606060606060620000e+003 2.41817913459568990000e-001

1.82222222222222240000e+003 2.41557046200914640000e-001

1.83838383838383860000e+003 2.41278800078275040000e-001

1.85454545454545470000e+003 2.40983916364599540000e-001

1.87070707070707090000e+003 2.40673116055090700000e-001

1.88686868686868710000e+003 2.40347099913682670000e-001

1.90303030303030320000e+003 2.40006548577755610000e-001

1.91919191919191940000e+003 2.39652122699989640000e-001

1.93535353535353560000e+003 2.39284463150978700000e-001

1.95151515151515150000e+003 2.38904191247756970000e-001

1.96767676767676770000e+003 2.38511909018133100000e-001

1.98383838383838380000e+003 2.38108199493421710000e-001

2.00000000000000000000e+003 2.37693627025531930000e-001

QUADRATIC ERROR = 2.433482e-002

ESTIMATED THICKNESSES

Thickness of film P3 = 230.00 nm

ESTIMATED INFLEXION POINTS

Inflexion point of the absorption coefficient of film 3 = 400.00 nm

ESTIMATED REFRACTIVE INDICES AND ABSORPTION COEFFICIENTS

Film 1

lambda	n	kappa
4.00000000000000000000e+002	1.96534906532170350000e+011	3.89347384087545380000e+002
4.16161616161616170000e+002	1.94529448593420840000e+011	3.69880014883183380000e+002
4.32323232323232330000e+002	1.92523990654671330000e+011	3.50412645678821380000e+002
4.48484848484848500000e+002	1.90518532715921810000e+011	3.30945276474459380000e+002
4.64646464646464660000e+002	1.88513074777172300000e+011	3.11477907270097380000e+002
4.80808080808080830000e+002	1.86507616838422790000e+011	2.92010538065735370000e+002
4.96969696969697000000e+002	1.84502158899673280000e+011	2.72543168861373370000e+002
5.13131313131313160000e+002	1.82496700960923770000e+011	2.53075799657011400000e+002
5.29292929292929330000e+002	1.80491243022174260000e+011	2.33608430452649460000e+002
5.45454545454545500000e+002	1.78485785083424740000e+011	2.14141061248287510000e+002
5.61616161616161660000e+002	1.76480327144675230000e+011	1.94673692043925570000e+002
5.77777777777777830000e+002	1.74474869205925720000e+011	1.75206322839563630000e+002
5.93939393939393990000e+002	1.72469411267176210000e+011	1.55738953635201680000e+002
6.10101010101010160000e+002	1.70463953328426700000e+011	1.36271584430839740000e+002
6.26262626262626330000e+002	1.68458495389677190000e+011	1.16804215226477790000e+002
6.42424242424242490000e+002	1.66453037450927670000e+011	9.73368460221158500000e+001
6.58585858585858660000e+002	1.64447579512178160000e+011	7.78694768177539060000e+001
6.74747474747474710000e+002	1.62442121573428650000e+011	5.84021076133919690000e+001
6.90909090909090880000e+002	1.60436663634679140000e+011	3.89347384090300320000e+001
7.07070707070707040000e+002	1.58431205695929630000e+011	1.94673692046680960000e+001

7.2323232323232321000 0e+002	1.5642574775718011000 0e+011	3.0615781934332087000 0e-010
7.3939393939393938000 0e+002	1.5442028981843060000 0e+011	2.8503673031842979000 0e-010
7.5555555555555554000 0e+002	1.5241483187968109000 0e+011	2.6392426310044288000 0e-010
7.7171717171717171000 0e+002	1.5040937394093158000 0e+011	2.4281179588245597000 0e-010
7.8787878787878788000 0e+002	1.4840391600218207000 0e+011	2.2169935265023304000 0e-010
8.0404040404040404000 0e+002	1.4639845806343256000 0e+011	2.0058690941801011000 0e-010
8.2020202020202021000 0e+002	1.4439300012468304000 0e+011	1.8000243598616621000 0e-010
8.3636363636363637000 0e+002	1.4238754218593353000 0e+011	1.5941796255432232000 0e-010
8.5252525252525254000 0e+002	1.4038208424718402000 0e+011	1.4075907490163923000 0e-010
8.6868686868686871000 0e+002	1.3837662630843451000 0e+011	1.2210018724895614000 0e-010
8.8484848484848487000 0e+002	1.3637116836968498000 0e+011	1.0780282307433350000 0e-010
9.0101010101010104000 0e+002	1.3436571043093544000 0e+011	9.3505458899710869000 0e-011
9.1717171717171721000 0e+002	1.3236025249218590000 0e+011	7.9208094725088238000 0e-011
9.3333333333333337000 0e+002	1.3035479455343636000 0e+011	6.9430493152088807000 0e-011
9.4949494949494954000 0e+002	1.2834933661468681000 0e+011	5.9652891579089376000 0e-011
9.6565656565656570000 0e+002	1.2634387867593727000 0e+011	4.9875290006089944000 0e-011
9.8181818181818187000 0e+002	1.2433842073718773000 0e+011	4.5719925989656818000 0e-011
9.9797979797979804000 0e+002	1.2233296279843819000 0e+011	4.1564561973223692000 0e-011
1.0141414141414142000 0e+003	1.2032750485968864000 0e+011	3.7409197956790565000 0e-011
1.0303030303030303000 0e+003	1.1832204692093910000 0e+011	3.3253833940357439000 0e-011
1.0464646464646464000 0e+003	1.1631658898218956000 0e+011	2.9098469923924313000 0e-011
1.0626262626262626000 0e+003	1.1431113104344002000 0e+011	2.4943105907491186000 0e-011
1.0787878787878788000 0e+003	1.1230567310469048000 0e+011	2.0787741891058060000 0e-011
1.0949494949494949000 0e+003	1.1030021516594093000 0e+011	1.6632377874624934000 0e-011
1.1111111111111111000 0e+003	1.0829475722719139000 0e+011	1.2477013858191807000 0e-011
1.1272727272727273000 0e+003	1.0628929928844185000 0e+011	8.3216498417586793000 0e-012
1.1434343434343434000 0e+003	1.0428384134969231000 0e+011	4.1662858253255505000 0e-012
1.1595959595959596000 0e+003	1.0227838341094276000 0e+011	1.0921808892421560000 0e-014
1.1757575757575758000 0e+003	1.0027292547219322000 0e+011	9.9357531746517952000 0e-015
1.1919191919191919000 0e+003	9.8267467533443680000 0e+010	8.9496974568820304000 0e-015
1.2080808080808081000 0e+003	9.6262009594694138000 0e+010	7.9636417391122655000 0e-015
1.2242424242424242000 0e+003	9.4256551655944595000 0e+010	6.9775860213425006000 0e-015
1.2404040404040404000 0e+003	9.2251093717195053000 0e+010	5.9915303035727358000 0e-015

1.2565656565656565660000e+003	9.0245635778445511000 0e+010	5.0054745858029709000 0e-015
1.2727272727272727270000e+003	8.8240177839695984000 0e+010	4.0194188680332060000 0e-015
1.2888888888888888890000e+003	8.6234719900946457000 0e+010	3.0333631502634412000 0e-015
1.3050505050505050510000e+003	8.4229261962196930000 0e+010	2.0473074324936759000 0e-015
1.3212121212121212120000e+003	8.2223804023447449000 0e+010	1.0612517147239108000 0e-015
1.3373737373737373740000e+003	8.0218346084697968000 0e+010	7.5195996954145835000 0e-017
1.3535353535353535360000e+003	7.8212888145948608000 0e+010	6.5934758468083212000 0e-017
1.3696969696969696970000e+003	7.6207430207199249000 0e+010	5.6673519982020590000 0e-017
1.3858585858585858590000e+003	7.4201972268449890000 0e+010	4.7412281495957967000 0e-017
1.4020202020202020210000e+003	7.2196514329700974000 0e+010	3.8151043009895344000 0e-017
1.4181818181818181820000e+003	7.0191056390952057000 0e+010	2.8889804523832721000 0e-017
1.4343434343434343440000e+003	6.8185598452203140000 0e+010	1.9628566037770098000 0e-017
1.4505050505050505060000e+003	6.6180140513456032000 0e+010	1.0367327551707475000 0e-017
1.4666666666666666670000e+003	6.4174682574708923000 0e+010	1.1060890656448520000 0e-018
1.4828282828282828290000e+003	6.2169224635961815000 0e+010	1.0900176173594334000 0e-018
1.4989898989898989910000e+003	6.0163766697222054000 0e+010	1.0739461690740148000 0e-018
1.5151515151515151520000e+003	5.8158308758482292000 0e+010	1.0578747207885962000 0e-018
1.5313131313131313140000e+003	5.6152850819742531000 0e+010	1.0418032725031776000 0e-018
1.5474747474747474760000e+003	5.4147392881029190000 0e+010	1.0257318242177590000 0e-018
1.5636363636363636370000e+003	5.2141934942315849000 0e+010	1.0096603759323404000 0e-018
1.5797979797979797990000e+003	5.0136477003602509000 0e+010	9.9483879366947469000 0e-019
1.5959595959595959610000e+003	4.8131019064974197000 0e+010	9.8001721140660901000 0e-019
1.6121212121212121220000e+003	4.6125561126345886000 0e+010	9.6519562914374333000 0e-019
1.6282828282828282840000e+003	4.4120103187904366000 0e+010	9.5037404688087765000 0e-019
1.6444444444444444460000e+003	4.2114645249462845000 0e+010	9.3555246461801196000 0e-019
1.6606060606060606070000e+003	4.0109187311021324000 0e+010	9.2073088235514628000 0e-019
1.6767676767676767690000e+003	3.8103729373371506000 0e+010	9.0590937920904880000 0e-019
1.6929292929292929310000e+003	3.6098271435721687000 0e+010	8.9108787606295133000 0e-019
1.7090909090909090920000e+003	3.4092813498071873000 0e+010	8.7626637291685385000 0e-019
1.7252525252525252540000e+003	3.2087355563114105000 0e+010	8.6144486977075627000 0e-019
1.7414141414141414160000e+003	3.0081897628156338000 0e+010	8.4664777077185816000 0e-019
1.7575757575757575770000e+003	2.8076439693198570000 0e+010	8.3185067177296005000 0e-019
1.7737373737373737390000e+003	2.6070981766309441000 0e+010	8.1705357277406194000 0e-019

1.7898989898989899010000e+003 2.4065523839420311000e+010 8.0239998021566216000e-019

1.8060606060606060620000e+003 2.2060065912531181000e+010 7.8774638765726239000e-019

1.8222222222222222240000e+003 2.0054608012471840000e+010 7.7315539096347997000e-019

1.8383838383838383860000e+003 1.8049150112412498000e+010 7.5856439426969755000e-019

1.8545454545454545470000e+003 1.6043692212353157000e+010 7.4397339757591514000e-019

1.8707070707070707090000e+003 1.4038234375283606000e+010 7.2959851000596932000e-019

1.8868686868686868710000e+003 1.2032776538214054000e+010 7.1522362243602350000e-019

1.9030303030303030320000e+003 1.0027318887032951000e+010 7.0084873486607769000e-019

1.9191919191919191940000e+003 8.0218612358518476000e+009 6.8647384729613187000e-019

1.9353535353535353560000e+003 6.0164035846707430000e+009 6.7889149851005313000e-019

1.9515151515151515150000e+003 4.0109461805265698000e+009 6.7130914972397440000e-019

1.9676767676767676770000e+003 2.0054887763823965000e+009 6.6378639698226865000e-019

1.9838383838383838380000e+003 3.1372238223286695000e+004 6.5626364424056291000e-019

2.0000000000000000000000e+003 3.1372236101872688000e+004 6.5626364305674798000e-019

REFLECTANCE WITH THE ESTIMATED THICKNESSES AND OPTICAL PARAMETERS

lambda r

4.0000000000000000000000e+002 9.9999999999796472800000e-001

4.1616161616161616170000e+002 9.9999999999794380000000e-001

4.3232323232323232330000e+002 9.9999999999792237300000e-001

4.4848484848484848500000e+002 9.9999999999790045700000e-001

4.6464646464646464660000e+002 9.9999999999787813100000e-001

4.8080808080808080830000e+002 9.9999999999785530400000e-001

4.9696969696969697000000e+002 9.9999999999783200100000e-001

5.1313131313131313160000e+002 9.9999999999780816400000e-001

5.2929292929292929330000e+002 9.9999999999778385100000e-001

5.4545454545454545500000e+002 9.9999999999775887000000e-001

5.6161616161616161660000e+002 9.9999999999773345700000e-001

5.7777777777777777830000e+002 9.9999999999770741200000e-001

5.9393939393939393990000e+002 9.9999999999768081100000e-001

6.1010101010101010160000e+002 9.9999999999765347700000e-001

6.26262626262626330000e+002 9.99999999976255110000e-001

6.42424242424242490000e+002 9.99999999975969560000e-001

6.58585858585858660000e+002 9.99999999975676680000e-001

6.74747474747474710000e+002 9.99999999975375810000e-001

6.90909090909090880000e+002 9.99999999975067830000e-001

7.07070707070707040000e+002 9.99999999974752970000e-001

7.23232323232323210000e+002 1.00000000000000000000e+000

7.39393939393939380000e+002 1.00000000000000000000e+000

7.55555555555555540000e+002 1.00000000000000000000e+000

7.71717171717171710000e+002 9.99999999999999890000e-001

7.87878787878787880000e+002 1.00000000000000000000e+000

8.04040404040404040000e+002 9.99999999999999890000e-001

8.20202020202020210000e+002 1.00000000000000020000e+000

8.36363636363636370000e+002 1.00000000000000020000e+000

8.52525252525252540000e+002 1.00000000000000000000e+000

8.68686868686868710000e+002 9.99999999999999560000e-001

8.84848484848484870000e+002 1.00000000000000000000e+000

9.01010101010101040000e+002 1.00000000000000000000e+000

9.17171717171717210000e+002 9.99999999999999780000e-001

9.33333333333333370000e+002 1.00000000000000000000e+000

9.49494949494949540000e+002 1.00000000000000020000e+000

9.65656565656565700000e+002 1.00000000000000020000e+000

9.81818181818181870000e+002 9.99999999999999560000e-001

9.97979797979798040000e+002 1.00000000000000000000e+000

1.01414141414141420000e+003 9.99999999999999670000e-001

1.03030303030303030000e+003 1.00000000000000000000e+000

1.04646464646464640000e+003 1.00000000000000000000e+000

1.06262626262626260000e+003 1.00000000000000000000e+000

1.07878787878787880000e+003 1.00000000000000000000e+000

1.09494949494949490000e+003 1.00000000000000040000e+000

1.11111111111111110000e+003 9.99999999999999670000e-001

1.12727272727272730000e+003 1.00000000000000000000e+000

1.14343434343434340000e+003 1.00000000000000000000e+000

ESTIMATED THICKNESSES

Thickness of film T2 = 146.00 nm

ESTIMATED INFLEXION POINTS

Inflexion point of the absorption coefficient of film T2 = 500.00 nm

ESTIMATED REFRACTIVE INDICES AND ABSORPTION COEFFICIENTS

Film 1

lambda	n	kappa
4.00000000000000000000e+002	2.12367308352062700000e+000	4.19240246962817860000e-001
4.16161616161616170000e+002	2.12367308352062700000e+000	4.19741930474888840000e-001
4.32323232323232330000e+002	2.12367308352062700000e+000	4.20243613986959810000e-001
4.48484848484848500000e+002	2.12367308352062700000e+000	4.15389624568996250000e-001
4.64646464646464660000e+002	2.12367308352062700000e+000	4.10535635151032700000e-001
4.80808080808080830000e+002	2.12367308352062700000e+000	4.05589420063535820000e-001
4.96969696969697000000e+002	2.12367308352062700000e+000	4.00643204976038950000e-001
5.13131313131313160000e+002	2.12367308352062700000e+000	3.95696989888542070000e-001
5.29292929292929330000e+002	2.12367308352062700000e+000	3.90750774801045200000e-001
5.45454545454545500000e+002	2.12367308352062700000e+000	3.85804559778516240000e-001
5.61616161616161660000e+002	2.12367308352062700000e+000	3.80858344755987290000e-001
5.77777777777777830000e+002	2.12367308352062700000e+000	3.75912129733458330000e-001
5.93939393939393990000e+002	2.12367308352062700000e+000	3.70965914710929380000e-001
6.10101010101010160000e+002	2.12367308352062700000e+000	3.66019699688400420000e-001
6.26262626262626330000e+002	2.12367308352062700000e+000	3.61073484665871470000e-001
6.42424242424242490000e+002	2.12367308352062700000e+000	3.56127269643342510000e-001
6.58585858585858660000e+002	2.12367308352062700000e+000	3.51181054620813560000e-001
6.74747474747474710000e+002	2.12367308352062700000e+000	3.46234839598284600000e-001
6.90909090909090880000e+002	2.12367308352062700000e+000	3.41288624575755650000e-001
7.07070707070707040000e+002	2.12367308352062700000e+000	3.36342409553226700000e-001

7.2323232323232323210000e+002 2.12367308352062700000e+000 3.31396194530697740000e-001
7.3939393939393939380000e+002 2.12367308352062700000e+000 3.26449979508168790000e-001
7.5555555555555555540000e+002 2.12367308352062700000e+000 3.21503764485639830000e-001
7.7171717171717171710000e+002 2.12367308352062700000e+000 3.16557549463110880000e-001
7.8787878787878787880000e+002 2.12367308352062700000e+000 3.11611334440581920000e-001
8.0404040404040404040000e+002 2.12367308352062700000e+000 3.06665119418052970000e-001
8.2020202020202020210000e+002 2.12367308352062700000e+000 3.01718904395524010000e-001
8.3636363636363636370000e+002 2.12367308352062700000e+000 2.96772689372995060000e-001
8.5252525252525252540000e+002 2.12367308352062700000e+000 2.91826474350466100000e-001
8.6868686868686868710000e+002 2.12367308352062700000e+000 2.86880259327937150000e-001
8.8484848484848484870000e+002 2.12367308352062700000e+000 2.81934044305408190000e-001
9.0101010101010101040000e+002 2.12367308352062700000e+000 2.76987829282879240000e-001
9.1717171717171717210000e+002 2.12367308352062700000e+000 2.72041614260350280000e-001
9.3333333333333333370000e+002 2.12367308352062700000e+000 2.67095399237821330000e-001
9.4949494949494949540000e+002 2.12367308352062700000e+000 2.62149184215292370000e-001
9.6565656565656565700000e+002 2.12367308352062700000e+000 2.57202969192763420000e-001
9.8181818181818181870000e+002 2.12367308352062700000e+000 2.52256754170234470000e-001
9.9797979797979798040000e+002 2.12367308352062700000e+000 2.47310539147705480000e-001
1.0141414141414141420000e+003 2.12367308352062700000e+000 2.42364324125176500000e-001
1.0303030303030303030000e+003 2.12367308352062700000e+000 2.37418109102647520000e-001
1.0464646464646464640000e+003 2.12367308352062700000e+000 2.32471894080118540000e-001
1.0626262626262626260000e+003 2.12367308352062700000e+000 2.27525679057589550000e-001
1.0787878787878787880000e+003 2.12367308352062700000e+000 2.22579464035060570000e-001
1.0949494949494949490000e+003 2.12367308352062700000e+000 2.17633249012531590000e-001
1.1111111111111111110000e+003 2.12367308352062700000e+000 2.12687033990002610000e-001
1.1272727272727272730000e+003 2.12367308352062700000e+000 2.07740818967473620000e-001
1.1434343434343434340000e+003 2.12367308352062700000e+000 2.02794603944944640000e-001
1.1595959595959595960000e+003 2.12367308352062700000e+000 1.97848388922415660000e-001
1.1757575757575757580000e+003 2.12367308352062700000e+000 1.92902173899886680000e-001
1.1919191919191919190000e+003 2.12367308352062700000e+000 1.87955958877357690000e-001
1.2080808080808080810000e+003 2.12367308352062700000e+000 1.83009743854828710000e-001
1.2242424242424242420000e+003 2.12367308352062700000e+000 1.78063528832299730000e-001
1.2404040404040404040000e+003 2.12367308352062700000e+000 1.73117313809770750000e-001

1.2565656565656565660000e+003	2.1236730835206270000e+000	1.6817109878724176000e-001
1.2727272727272727270000e+003	2.1236730835206270000e+000	1.6322488376471278000e-001
1.2888888888888888890000e+003	2.1236730835206270000e+000	1.5827866874218380000e-001
1.3050505050505050510000e+003	2.1236730835206270000e+000	1.5333245371965482000e-001
1.3212121212121212120000e+003	2.1236730835206270000e+000	1.4838623869712583000e-001
1.3373737373737373740000e+003	2.1236730835206270000e+000	1.4344002367459685000e-001
1.3535353535353535360000e+003	2.1236730835206270000e+000	1.3849381596168264000e-001
1.3696969696969696970000e+003	2.1236730835206270000e+000	1.3354760824876843000e-001
1.3858585858585858590000e+003	2.1236730835206270000e+000	1.2860140053585423000e-001
1.4020202020202020210000e+003	2.1236730835206270000e+000	1.2365519282294002000e-001
1.4181818181818181820000e+003	2.1236730835206270000e+000	1.1870898511002580000e-001
1.4343434343434343440000e+003	2.1236730835206270000e+000	1.1376277397111580000e-001
1.4505050505050505060000e+003	2.1236730835206270000e+000	1.0881656968419735000e-001
1.4666666666666666670000e+003	2.1236730835206270000e+000	1.0387036197128313000e-001
1.4828282828282828290000e+003	2.1236730835206270000e+000	9.8924154258368910000e-002
1.4989898989898989910000e+003	2.1236730835206270000e+000	9.3977946545454688000e-002
1.5151515151515151520000e+003	2.1236730835206270000e+000	8.9031738832540466000e-002
1.5313131313131313140000e+003	2.1236730835206270000e+000	8.4085531119626244000e-002
1.5474747474747474760000e+003	2.1236730835206270000e+000	7.9139323406712023000e-002
1.5636363636363636370000e+003	2.1236730835206270000e+000	7.4193115693797801000e-002
1.5797979797979797990000e+003	2.1236730835206270000e+000	6.9246907980883579000e-002
1.5959595959595959610000e+003	2.1236730835206270000e+000	6.4300700267969357000e-002
1.6121212121212121220000e+003	2.1236730835206270000e+000	5.9354492555055136000e-002
1.6282828282828282840000e+003	2.1236730835206270000e+000	5.4408284842140907000e-002
1.6444444444444444460000e+003	2.1236730835206270000e+000	4.9462077129226678000e-002
1.6606060606060606070000e+003	2.1236730835206270000e+000	4.4515869416312449000e-002
1.6767676767676767690000e+003	2.1236730835206270000e+000	3.9569661703398221000e-002
1.6929292929292929310000e+003	2.1236730835206270000e+000	3.4623453990483992000e-002
1.7090909090909090920000e+003	2.1236730835206270000e+000	2.9677246277569760000e-002
1.7252525252525252540000e+003	2.1236730835206270000e+000	2.4731038564655528000e-002
1.7414141414141414160000e+003	2.1236730835206270000e+000	1.9784830851741295000e-002
1.7575757575757575770000e+003	2.1236730835206270000e+000	1.4838623138827061000e-002
1.7737373737373737390000e+003	2.1236730835206270000e+000	9.8924154259128275000e-003

1.7898989898989899010000e+003	2.1236730835206270000e+000	4.9462077129985935000e-003
1.8060606060606060620000e+003	2.1236730835206270000e+000	8.4360041045167871000e-014
1.8222222222222222240000e+003	2.1236730835206270000e+000	8.4360041045167871000e-014
1.8383838383838383860000e+003	2.1236730835206270000e+000	8.4360041045167871000e-014
1.8545454545454545470000e+003	2.1236730835206270000e+000	8.4360041045167871000e-014
1.8707070707070707090000e+003	2.1236730835206270000e+000	8.4360041045167871000e-014
1.8868686868686868710000e+003	2.1236730835206270000e+000	8.4360041045167871000e-014
1.9030303030303030320000e+003	2.1236730835206270000e+000	8.4360041045167871000e-014
1.9191919191919191940000e+003	2.1236730835206270000e+000	8.4360041045167871000e-014
1.9353535353535353560000e+003	2.1236730835206270000e+000	8.4360041045167871000e-014
1.9515151515151515150000e+003	2.1236730835206270000e+000	8.4360041045167871000e-014
1.9676767676767676770000e+003	2.1236730835206270000e+000	8.4360041045167871000e-014
1.9838383838383838380000e+003	2.1236730835206270000e+000	8.4360041045167871000e-014
2.0000000000000000000000e+003	2.1236730835206270000e+000	8.4360041045167871000e-014

REFLECTANCE WITH THE ESTIMATED THICKNESSES AND OPTICAL PARAMETERS

lambda	r
4.0000000000000000000000e+002	1.6201555232825748000e-001
4.1616161616161616170000e+002	1.6594218379453815000e-001
4.3232323232323232330000e+002	1.6740261301749301000e-001
4.4848484848484848500000e+002	1.6649305588489033000e-001
4.6464646464646464660000e+002	1.6343288792216645000e-001
4.8080808080808080830000e+002	1.5861471858229581000e-001
4.9696969696969697000000e+002	1.5250154238133121000e-001
5.1313131313131313160000e+002	1.4556918808075545000e-001
5.2929292929292929330000e+002	1.3827058866148950000e-001
5.4545454545454545500000e+002	1.3101426826467846000e-001
5.6161616161616161660000e+002	1.2415194396646696000e-001
5.7777777777777777830000e+002	1.1797208504778929000e-001
5.9393939393939393990000e+002	1.1269763460620470000e-001
6.1010101010101010160000e+002	1.0848690549426981000e-001

6.2626262626262630000e+002 1.0543704758742499000e-001

6.4242424242424249000e+002 1.0358960281453095000e-001

6.5858585858585866000e+002 1.0293765147773608000e-001

6.7474747474747471000e+002 1.0343400489010469000e-001

6.9090909090909088000e+002 1.0499987447375003000e-001

7.0707070707070704000e+002 1.0753347250452444000e-001

7.2323232323232321000e+002 1.1091807600970947000e-001

7.3939393939393938000e+002 1.1502919873875982000e-001

7.5555555555555554000e+002 1.1974064599564778000e-001

7.7171717171717171000e+002 1.2492935348146064000e-001

7.8787878787878788000e+002 1.3047901921320448000e-001

8.0404040404040404000e+002 1.3628261877254177000e-001

8.2020202020202021000e+002 1.4224394650931504000e-001

8.3636363636363637000e+002 1.4827835138661938000e-001

8.5252525252525254000e+002 1.5431284106879117000e-001

8.6868686868686871000e+002 1.6028571772079975000e-001

8.8484848484848487000e+002 1.6614588961760154000e-001

9.0101010101010104000e+002 1.7185197887765624000e-001

9.1717171717171721000e+002 1.7737132100868475000e-001

9.3333333333333337000e+002 1.8267892884182818000e-001

9.4949494949494954000e+002 1.8775647316631561000e-001

9.6565656565656570000e+002 1.9259131552482239000e-001

9.8181818181818187000e+002 1.9717561523118082000e-001

9.9797979797979804000e+002 2.0150552245199804000e-001

1.0141414141414142000e+003 2.0558046171659786000e-001

1.0303030303030303000e+003 2.0940250499678251000e-001

1.0464646464646464000e+003 2.1297583005400297000e-001

1.0626262626262626000e+003 2.1630625766148090000e-001

1.0787878787878788000e+003 2.1940086021347180000e-001

1.0949494949494949000e+003 2.2226763384251336000e-001

1.1111111111111111000e+003 2.2491522625122420000e-001

1.1272727272727273000e+003 2.2735271285631667000e-001

1.1434343434343434000e+003 2.2958941441289155000e-001

1.15959595959595960000e+003 2.31634749947096850000e-001

1.17575757575757580000e+003 2.33498119513168710000e-001

1.19191919191919190000e+003 2.35188811966126320000e-001

1.20808080808080810000e+003 2.36715933578778210000e-001

1.22424242424242420000e+003 2.38088353917011470000e-001

1.24040404040404040000e+003 2.39314665913997800000e-001

1.25656565656565660000e+003 2.40403157550504650000e-001

1.27272727272727270000e+003 2.41361792956712030000e-001

1.28888888888888890000e+003 2.42198201104561080000e-001

1.30505050505050510000e+003 2.42919670563511600000e-001

1.32121212121212120000e+003 2.43533149051845200000e-001

1.33737373737373740000e+003 2.44045246735609980000e-001

1.35353535353535360000e+003 2.44462241617257300000e-001

1.36969696969696970000e+003 2.44790090281838460000e-001

1.38585858585858590000e+003 2.45034435485240290000e-001

1.40202020202020210000e+003 2.45200618049252330000e-001

1.41818181818181820000e+003 2.45293688725456290000e-001

1.43434343434343440000e+003 2.45318420518135490000e-001

1.45050505050505060000e+003 2.45279321226788110000e-001

1.46666666666666670000e+003 2.45180646019797670000e-001

1.48282828282828290000e+003 2.45026409892626310000e-001

1.49898989898989910000e+003 2.44820399898078610000e-001

1.51515151515151520000e+003 2.44566187064044070000e-001

1.53131313131313140000e+003 2.44267137936701850000e-001

1.54747474747474760000e+003 2.43926425705414980000e-001

1.56363636363636370000e+003 2.43547040880186470000e-001

1.57979797979797990000e+003 2.43131801504228140000e-001

1.59595959595959610000e+003 2.42683362893450470000e-001

1.61212121212121220000e+003 2.42204226901937240000e-001

1.62828282828282840000e+003 2.41696750718096240000e-001

1.64444444444444460000e+003 2.41163155200482150000e-001

1.66060606060606070000e+003 2.40605532765504610000e-001

1.67676767676767690000e+003 2.40025854841587890000e-001

1.692929292929293100000e+003 2.394259789059901300000e-001

1.709090909090909200000e+003 2.388076551215826400000e-001

1.725252525252525400000e+003 2.381725325915140200000e-001

1.741414141414141600000e+003 2.375221652499757400000e-001

1.757575757575757700000e+003 2.368580174072853800000e-001

1.773737373737373900000e+003 2.361814689672977500000e-001

1.789898989898990100000e+003 2.354938203347780300000e-001

1.806060606060606200000e+003 2.347962970298842200000e-001

1.822222222222222400000e+003 2.334878662348075200000e-001

1.838383838383838600000e+003 2.321821830670184100000e-001

1.854545454545454700000e+003 2.308799740471125800000e-001

1.870707070707070900000e+003 2.295819115181028900000e-001

1.886868686868687100000e+003 2.282886170646608000000e-001

1.903030303030303200000e+003 2.270006647132919700000e-001

1.919191919191919400000e+003 2.257185839283828400000e-001

1.935353535353535600000e+003 2.244428624179599700000e-001

1.951515151515151500000e+003 2.231739487619931500000e-001

1.967676767676767700000e+003 2.219122548751414300000e-001

1.983838383838383800000e+003 2.206581583149798700000e-001

2.000000000000000000000e+003 2.194120044459549900000e-001

QUADRATIC ERROR = 4.553171e-002

ESTIMATED THICKNESSES

Thickness of film T1 = 140.00 nm

ESTIMATED INFLEXION POINTS

Inflexion point of the absorption coefficient of film T1 = 700.00 nm

ESTIMATED REFRACTIVE INDICES AND ABSORPTION COEFFICIENTS

Film 1

lambda	n	kappa
4.0000000000000000000e+002	2.1618116782407895000e+000	3.0426607604439759000e-001
4.1616161616161617000e+002	2.1618116782407895000e+000	3.1733687643374131000e-001
4.3232323232323233000e+002	2.1618116782407895000e+000	3.3040767682308503000e-001
4.4848484848484850000e+002	2.1618116782407895000e+000	3.4347847721242875000e-001
4.6464646464646466000e+002	2.1618116782407895000e+000	3.5654927760177246000e-001
4.8080808080808083000e+002	2.1618116782407895000e+000	3.6962007799111618000e-001
4.9696969696969697000e+002	2.1618116782407895000e+000	3.8269087838045990000e-001
5.1313131313131316000e+002	2.1618116782407895000e+000	3.9576167876980362000e-001
5.2929292929292933000e+002	2.1618116782407895000e+000	4.0883247915914733000e-001
5.4545454545454550000e+002	2.1618116782407895000e+000	4.2190327954849105000e-001
5.6161616161616166000e+002	2.1618116782407895000e+000	4.3497407993783477000e-001
5.7777777777777783000e+002	2.1618116782407895000e+000	4.4804488032717849000e-001
5.9393939393939399000e+002	2.1618116782407895000e+000	4.6111568071652220000e-001
6.1010101010101016000e+002	2.1618116782407895000e+000	4.7418648110586592000e-001
6.2626262626262633000e+002	2.1618116782407895000e+000	4.8725728149520964000e-001
6.4242424242424249000e+002	2.1618116782407895000e+000	5.0032808188455336000e-001
6.5858585858585866000e+002	2.1618116782407895000e+000	5.1339888227389707000e-001
6.7474747474747471000e+002	2.1618116782407895000e+000	5.2646968266324079000e-001
6.9090909090909088000e+002	2.1618116782407895000e+000	5.3954048305258451000e-001
7.0707070707070704000e+002	2.1618116782407895000e+000	5.3183276189444340000e-001

7.2323232323232323210000e+002	2.16181167824078950000e+000	5.24125040736302280000e-001
7.3939393939393939380000e+002	2.16181167824078950000e+000	5.16417319578161170000e-001
7.5555555555555555540000e+002	2.16181167824078950000e+000	5.08709598420020060000e-001
7.7171717171717171710000e+002	2.16181167824078950000e+000	5.01001877261878950000e-001
7.8787878787878787880000e+002	2.16181167824078950000e+000	4.93294156103737840000e-001
8.0404040404040404040000e+002	2.16181167824078950000e+000	4.85586434945596670000e-001
8.2020202020202020210000e+002	2.16181167824078950000e+000	4.77878713787455500000e-001
8.3636363636363636370000e+002	2.16181167824078950000e+000	4.70170992629314330000e-001
8.5252525252525252540000e+002	2.16181167824078950000e+000	4.62463271471173170000e-001
8.6868686868686868710000e+002	2.16181167824078950000e+000	4.54755550313032000000e-001
8.8484848484848484870000e+002	2.16181167824078950000e+000	4.47047829154890830000e-001
9.0101010101010101040000e+002	2.16181167824078950000e+000	4.39340107996749660000e-001
9.1717171717171717210000e+002	2.16181167824078950000e+000	4.31632386838608490000e-001
9.3333333333333333370000e+002	2.16181167824078950000e+000	4.23924665680467330000e-001
9.4949494949494949540000e+002	2.16181167824078950000e+000	4.16216944522326160000e-001
9.6565656565656565700000e+002	2.16181167824078950000e+000	4.08509223364184990000e-001
9.8181818181818181870000e+002	2.16181167824078950000e+000	4.00801502206043820000e-001
9.9797979797979798040000e+002	2.16181167824078950000e+000	3.93093781047902660000e-001
1.0141414141414141420000e+003	2.16181167824078950000e+000	3.85386059889761490000e-001
1.0303030303030303030000e+003	2.16181167824078950000e+000	3.77678338731620320000e-001
1.0464646464646464640000e+003	2.16181167824078950000e+000	3.69970617573479150000e-001
1.0626262626262626260000e+003	2.16181167824078950000e+000	3.62262896415337990000e-001
1.0787878787878787880000e+003	2.16181167824078950000e+000	3.54555175257196820000e-001
1.0949494949494949490000e+003	2.16181167824078950000e+000	3.46847454099055650000e-001
1.1111111111111111110000e+003	2.16181167824078950000e+000	3.39139732940914480000e-001
1.1272727272727272730000e+003	2.16181167824078950000e+000	3.31432011782773320000e-001
1.1434343434343434340000e+003	2.16181167824078950000e+000	3.23724290624632150000e-001
1.1595959595959595960000e+003	2.16181167824078950000e+000	3.16016569466490980000e-001
1.1757575757575757580000e+003	2.16181167824078950000e+000	3.08308848308349810000e-001
1.1919191919191919190000e+003	2.16181167824078950000e+000	3.00601127150208650000e-001
1.2080808080808080810000e+003	2.16181167824078950000e+000	2.92893405992067480000e-001
1.2242424242424242420000e+003	2.16181167824078950000e+000	2.85185684833926310000e-001
1.2404040404040404040000e+003	2.16181167824078950000e+000	2.77477963675785140000e-001

1.2565656565656565660000e+003	2.1618116782407895000e+000	2.6977024251764398000e-001
1.2727272727272727270000e+003	2.1618116782407895000e+000	2.6206252135950281000e-001
1.2888888888888888890000e+003	2.1618116782407895000e+000	2.5435480020136164000e-001
1.3050505050505050510000e+003	2.1618116782407895000e+000	2.4664707904322050000e-001
1.3212121212121212120000e+003	2.1618116782407895000e+000	2.3893935788507936000e-001
1.3373737373737373740000e+003	2.1618116782407895000e+000	2.3123163672693822000e-001
1.3535353535353535360000e+003	2.1618116782407895000e+000	2.2352391556879708000e-001
1.3696969696969696970000e+003	2.1618116782407895000e+000	2.1581619441065594000e-001
1.3858585858585858590000e+003	2.1618116782407895000e+000	2.0810847325251480000e-001
1.4020202020202020210000e+003	2.1618116782407895000e+000	2.0040075209437366000e-001
1.4181818181818181820000e+003	2.1618116782407895000e+000	1.9269303093623252000e-001
1.4343434343434343440000e+003	2.1618116782407895000e+000	1.8498530977809138000e-001
1.4505050505050505060000e+003	2.1618116782407895000e+000	1.7727758861995024000e-001
1.4666666666666666670000e+003	2.1618116782407895000e+000	1.6956986746180910000e-001
1.4828282828282828290000e+003	2.1618116782407895000e+000	1.6186214630366796000e-001
1.4989898989898989910000e+003	2.1618116782407895000e+000	1.5415442514552682000e-001
1.5151515151515151520000e+003	2.1618116782407895000e+000	1.4644670398738568000e-001
1.5313131313131313140000e+003	2.1618116782407895000e+000	1.3873898282924454000e-001
1.5474747474747474760000e+003	2.1618116782407895000e+000	1.3103126167110341000e-001
1.5636363636363636370000e+003	2.1618116782407895000e+000	1.2332354051296227000e-001
1.5797979797979797990000e+003	2.1618116782407895000e+000	1.1561581935482111000e-001
1.5959595959595959610000e+003	2.1618116782407895000e+000	1.0790809819667996000e-001
1.6121212121212121220000e+003	2.1618116782407895000e+000	1.0020037703853880000e-001
1.6282828282828282840000e+003	2.1618116782407895000e+000	9.2492655880397651000e-002
1.6444444444444444460000e+003	2.1618116782407895000e+000	8.4784934722256497000e-002
1.6606060606060606070000e+003	2.1618116782407895000e+000	7.7077213564115343000e-002
1.6767676767676767690000e+003	2.1618116782407895000e+000	6.9369492405974190000e-002
1.6929292929292929310000e+003	2.1618116782407895000e+000	6.1661771247833043000e-002
1.7090909090909090920000e+003	2.1618116782407895000e+000	5.3954050089691896000e-002
1.7252525252525252540000e+003	2.1618116782407895000e+000	4.6246328931550749000e-002
1.7414141414141414160000e+003	2.1618116782407895000e+000	3.8538607773409603000e-002
1.7575757575757575770000e+003	2.1618116782407895000e+000	3.0830886615268456000e-002
1.7737373737373737390000e+003	2.1618116782407895000e+000	2.3123165457127309000e-002

1.7898989898989899010000e+003	2.1618116782407895000e+000	1.5415444298986161000e-002
1.8060606060606062000e+003	2.1618116782407895000e+000	7.7077231408674857000e-003
1.8222222222222224000e+003	2.1618116782407895000e+000	1.9827488112975373000e-009
1.8383838383838386000e+003	2.1618116782407895000e+000	1.0599109299159185000e-009
1.8545454545454547000e+003	2.1618116782407895000e+000	1.3707304853429969000e-010
1.8707070707070709000e+003	2.1618116782407895000e+000	1.3707264513837459000e-010
1.8868686868686871000e+003	2.1618116782407895000e+000	1.3707224174244950000e-010
1.9030303030303032000e+003	2.1618116782407895000e+000	1.3707183834652440000e-010
1.9191919191919194000e+003	2.1618116782407895000e+000	1.3707143495059931000e-010
1.9353535353535356000e+003	2.1618116782407895000e+000	1.3707103155467421000e-010
1.9515151515151515000e+003	2.1618116782407895000e+000	1.3707062815874912000e-010
1.9676767676767677000e+003	2.1618116782407895000e+000	1.3707022476282402000e-010
1.9838383838383838000e+003	2.1618116782407895000e+000	1.3706982136689893000e-010
2.0000000000000000000e+003	2.1618116782407895000e+000	1.3706941797097383000e-010

REFLECTANCE WITH THE ESTIMATED THICKNESSES AND OPTICAL PARAMETERS

lambda	r
4.0000000000000000000e+002	1.6574852422453118000e-001
4.1616161616161617000e+002	1.7055270133593553000e-001
4.3232323232323233000e+002	1.7229735422303502000e-001
4.4848484848484850000e+002	1.7136471811457016000e-001
4.6464646464646466000e+002	1.6833882105276604000e-001
4.8080808080808083000e+002	1.6385119384685909000e-001
4.9696969696969700000e+002	1.5849588018676961000e-001
5.1313131313131316000e+002	1.5278823847560946000e-001
5.2929292929292933000e+002	1.4714945671581248000e-001
5.4545454545454550000e+002	1.4190549884772666000e-001
5.6161616161616166000e+002	1.3729380972601798000e-001
5.7777777777777783000e+002	1.3347388325550974000e-001
5.9393939393939399000e+002	1.3053939362496994000e-001
6.1010101010101016000e+002	1.2853050557299994000e-001

6.262626262626263300000e+002 1.274455268863704500000e-001

6.424242424242424900000e+002 1.272514154342727400000e-001

6.585858585858586600000e+002 1.278928902077222100000e-001

6.747474747474747100000e+002 1.293000623842539300000e-001

6.909090909090908800000e+002 1.313946183672348400000e-001

7.070707070707070400000e+002 1.317915841401153000000e-001

7.232323232323232100000e+002 1.329061637834345300000e-001

7.393939393939393800000e+002 1.346835908452262100000e-001

7.555555555555555400000e+002 1.370589725219983300000e-001

7.717171717171717100000e+002 1.399608448932423400000e-001

7.878787878787878800000e+002 1.433143532080463400000e-001

8.040404040404040400000e+002 1.470439859719095100000e-001

8.202020202020202100000e+002 1.510758282296323900000e-001

8.363636363636363700000e+002 1.553393317157212800000e-001

8.525252525252525400000e+002 1.597686255143590300000e-001

8.686868686868687100000e+002 1.643034096956750300000e-001

8.848484848484848700000e+002 1.688894861790401800000e-001

9.010101010101010400000e+002 1.734789866077355900000e-001

9.171717171717172100000e+002 1.780303574897171300000e-001

9.333333333333333700000e+002 1.825081595949467100000e-001

9.494949494949495400000e+002 1.868827328792780600000e-001

9.656565656565657000000e+002 1.911297711354290600000e-001

9.818181818181818700000e+002 1.952298430313512100000e-001

9.979797979797980400000e+002 1.991678882413444100000e-001

1.014141414141414200000e+003 2.029327152536332900000e-001

1.030303030303030300000e+003 2.065165051629225500000e-001

1.046464646464646400000e+003 2.099143533620377000000e-001

1.062626262626262600000e+003 2.131238361484053500000e-001

1.078787878787878800000e+003 2.161446186596835100000e-001

1.094949494949494900000e+003 2.189781017642872000000e-001

1.111111111111111100000e+003 2.216271083781272400000e-001

1.127272727272727300000e+003 2.240956078179139300000e-001

1.143434343434343400000e+003 2.263884759537736500000e-001

1.1595959595959596000e+003 2.2851128841091747000e-001

1.1757575757575758000e+003 2.3047014380959274000e-001

1.1919191919191919000e+003 2.3227151395675757000e-001

1.2080808080808081000e+003 2.3392211795719287000e-001

1.2242424242424242000e+003 2.3542881735336516000e-001

1.2404040404040404000e+003 2.3679852959948580000e-001

1.2565656565656566000e+003 2.3803815740144010000e-001

1.2727272727272727000e+003 2.3915453169285883000e-001

1.2888888888888889000e+003 2.4015436625606662000e-001

1.3050505050505051000e+003 2.4104422222660413000e-001

1.3212121212121212000e+003 2.4183048093611384000e-001

1.3373737373737374000e+003 2.4251932374756108000e-001

1.3535353535353536000e+003 2.4311671771758492000e-001

1.3696969696969697000e+003 2.4362840608295838000e-001

1.3858585858585859000e+003 2.4405990271216110000e-001

1.4020202020202021000e+003 2.4441648978990624000e-001

1.4181818181818182000e+003 2.4470321811339135000e-001

1.4343434343434344000e+003 2.4492490947545947000e-001

1.4505050505050506000e+003 2.4508616069323003000e-001

1.4666666666666667000e+003 2.4519134891250893000e-001

1.4828282828282829000e+003 2.4524463787977704000e-001

1.4989898989898991000e+003 2.4524998492605357000e-001

1.5151515151515152000e+003 2.4521114845159239000e-001

1.5313131313131314000e+003 2.4513169573823057000e-001

1.5474747474747476000e+003 2.4501501094821002000e-001

1.5636363636363637000e+003 2.4486430319525052000e-001

1.5797979797979799000e+003 2.4468261459629104000e-001

1.5959595959595961000e+003 2.4447282823126645000e-001

1.6121212121212122000e+003 2.4423767595409288000e-001

1.6282828282828284000e+003 2.4397974601117867000e-001

1.6444444444444446000e+003 2.4370149043465145000e-001

1.6606060606060607000e+003 2.4340523218646892000e-001

1.6767676767676769000e+003 2.4309317203693123000e-001

1.6929292929292929310000e+003	2.4276739516712068000e-001
1.7090909090909090920000e+003	2.4242987748966210000e-001
1.7252525252525252540000e+003	2.4208249168610146000e-001
1.7414141414141414160000e+003	2.4172701296233429000e-001
1.7575757575757575770000e+003	2.4136512452595749000e-001
1.7737373737373737390000e+003	2.4099842279133565000e-001
1.7898989898989899010000e+003	2.4062842231961915000e-001
1.8060606060606060620000e+003	2.4025656050202968000e-001
1.8222222222222222240000e+003	2.3988420199551386000e-001
1.8383838383838383860000e+003	2.3860932503935484000e-001
1.8545454545454545470000e+003	2.3733757866139044000e-001
1.8707070707070707090000e+003	2.3606963089862412000e-001
1.8868686868686868710000e+003	2.3480610010858990000e-001
1.9030303030303030320000e+003	2.3354755777560776000e-001
1.9191919191919191940000e+003	2.3229453153803756000e-001
1.9353535353535353560000e+003	2.3104750792619722000e-001
1.9515151515151515150000e+003	2.2980693492885562000e-001
1.9676767676767676770000e+003	2.2857322439963657000e-001
1.9838383838383838380000e+003	2.2734675431386267000e-001
2.0000000000000000000000e+003	2.2612787088563152000e-001

QUADRATIC ERROR = 2.263732e-002

ESTIMATED THICKNESSES

Thickness of film T3= 395.00 nm

ESTIMATED INFLEXION POINTS

Inflexion point of the absorption coefficient of film T3= 800.00 nm

ESTIMATED REFRACTIVE INDICES AND ABSORPTION COEFFICIENTS

Film 1

lambda	n	kappa
4.0000000000000000000e+002	1.8851112639512648000e+000	-2.0536815277773712000e-001
4.1616161616161617000e+002	1.8851112639512648000e+000	9.9154374324822356000e+001
4.3232323232323233000e+002	1.8851112639512648000e+000	1.9851411680242245000e+002
4.4848484848484850000e+002	1.8851112639512648000e+000	2.9787385928002254000e+002
4.6464646464646466000e+002	1.8851112639512648000e+000	3.9723360175762264000e+002
4.8080808080808083000e+002	1.8851112639512648000e+000	4.9659334423522273000e+002
4.9696969696969700000e+002	1.8851112639512648000e+000	5.9595308671282282000e+002
5.1313131313131316000e+002	1.8851112639512648000e+000	6.9531282919042292000e+002
5.2929292929292933000e+002	1.8851112639512648000e+000	7.9467257166802301000e+002
5.4545454545454550000e+002	1:8851112639512648000e+000	8.9403231414562310000e+002
5.6161616161616166000e+002	1.8851112639512648000e+000	9.9339205662322320000e+002
5.7777777777777783000e+002	1.8851112639512648000e+000	1.0927517991008233000e+003
5.9393939393939399000e+002	1.8851112639512648000e+000	1.1921115415784234000e+003
6.1010101010101016000e+002	1.8851112639512648000e+000	1.2914712840560235000e+003
6.2626262626262633000e+002	1.8851112639512648000e+000	1.3908310265336236000e+003
6.4242424242424249000e+002	1.8851112639512648000e+000	1.4901907690112237000e+003
6.5858585858585866000e+002	1.8851112639512648000e+000	1.5895505114888238000e+003
6.7474747474747471000e+002	1.8851112639512648000e+000	1.6889102539664239000e+003
6.9090909090909088000e+002	1.8851112639512648000e+000	1.7882699964440239000e+003
7.0707070707070704000e+002	1.8851112639512648000e+000	1.8876297389216240000e+003
7.2323232323232321000e+002	1:8851112639512648000e+000	1.9869894813992241000e+003
7.3939393939393938000e+002	1.8851112639512648000e+000	1.9618377158118910000e+003
7.5555555555555554000e+002	1.8851112639512648000e+000	1.9366859502245579000e+003

7.71717171717171710000e+002	1.885111263951264800000e+000	1.911534184637224800000e+003
7.87878787878787880000e+002	1.885111263951264800000e+000	1.886382419049891500000e+003
8.04040404040404040000e+002	1.885111263951264800000e+000	1.861230653462558200000e+003
8.20202020202020210000e+002	1.885111263951264800000e+000	1.836078887875224200000e+003
8.36363636363636370000e+002	1.885111263951264800000e+000	1.810927122287890100000e+003
8.52525252525252540000e+002	1.885111263951264800000e+000	1.785775356700556400000e+003
8.68686868686868710000e+002	1.885111263951264800000e+000	1.760623591113222600000e+003
8.84848484848484870000e+002	1.885111263951264800000e+000	1.735471825525889200000e+003
9.01010101010101040000e+002	1.885111263951264800000e+000	1.710320059938555900000e+003
9.17171717171717210000e+002	1.885111263951264800000e+000	1.685168294351222600000e+003
9.33333333333333370000e+002	1.885111263951264800000e+000	1.660016528763888950000e+003
9.49494949494949540000e+002	1.885111263951264800000e+000	1.634864763176556400000e+003
9.65656565656565700000e+002	1.885111263951264800000e+000	1.609712997589223300000e+003
9.81818181818181870000e+002	1.885111263951264800000e+000	1.584561232001890600000e+003
9.97979797979798040000e+002	1.885111263951264800000e+000	1.559409466414558000000e+003
1.01414141414141420000e+003	1.885111263951264800000e+000	1.534257700827225300000e+003
1.03030303030303030000e+003	1.885111263951264800000e+000	1.509105935239892700000e+003
1.04646464646464640000e+003	1.885111263951264800000e+000	1.483954169652560000000e+003
1.06262626262626260000e+003	1.885111263951264800000e+000	1.458802404065227400000e+003
1.07878787878787880000e+003	1.885111263951264800000e+000	1.433650638477894700000e+003
1.09494949494949490000e+003	1.885111263951264800000e+000	1.408498872890562100000e+003
1.11111111111111110000e+003	1.885111263951264800000e+000	1.383347107303229400000e+003
1.12727272727272730000e+003	1.885111263951264800000e+000	1.358195341715896800000e+003
1.14343434343434340000e+003	1.885111263951264800000e+000	1.333043576128564200000e+003
1.15959595959595960000e+003	1.885111263951264800000e+000	1.307891810541231500000e+003
1.17575757575757580000e+003	1.885111263951264800000e+000	1.282740044953899500000e+003
1.19191919191919190000e+003	1.885111263951264800000e+000	1.257588279366567600000e+003
1.20808080808080810000e+003	1.885111263951264800000e+000	1.232436513779235600000e+003
1.22424242424242420000e+003	1.885111263951264800000e+000	1.207284748191903600000e+003
1.24040404040404040000e+003	1.885111263951264800000e+000	1.182132982604571700000e+003
1.25656565656565660000e+003	1.885111263951264800000e+000	1.156981217017239700000e+003
1.27272727272727270000e+003	1.885111263951264800000e+000	1.131829451429907700000e+003
1.28888888888888890000e+003	1.885111263951264800000e+000	1.106677685842575800000e+003

1.305050505050505100000e+003	1.885111263951264800000e+000	1.081525920255243800000e+003
1.321212121212121200000e+003	1.885111263951264800000e+000	1.056374154667911900000e+003
1.337373737373737400000e+003	1.885111263951264800000e+000	1.031222389080579900000e+003
1.353535353535353600000e+003	1.885111263951264800000e+000	1.006070623493248600000e+003
1.369696969696969700000e+003	1.885111263951264800000e+000	9.809188579059173200000e+002
1.385858585858585900000e+003	1.885111263951264800000e+000	9.557670923185860400000e+002
1.402020202020202100000e+003	1.885111263951264800000e+000	9.306153267312547500000e+002
1.418181818181818200000e+003	1.885111263951264800000e+000	9.054635611439234700000e+002
1.434343434343434400000e+003	1.885111263951264800000e+000	8.803117955565921900000e+002
1.450505050505050600000e+003	1.885111263951264800000e+000	8.551600299692609000000e+002
1.466666666666666700000e+003	1.885111263951264800000e+000	8.300082643819296200000e+002
1.482828282828282900000e+003	1.885111263951264800000e+000	8.048564987945986800000e+002
1.498989898989899100000e+003	1.885111263951264800000e+000	7.797047332072677400000e+002
1.515151515151515200000e+003	1.885111263951264800000e+000	7.545529676199367900000e+002
1.531313131313131400000e+003	1.885111263951264800000e+000	7.294012020326058500000e+002
1.547474747474747600000e+003	1.885111263951264800000e+000	7.042494364452749100000e+002
1.563636363636363700000e+003	1.885111263951264800000e+000	6.790976708579439700000e+002
1.579797979797979900000e+003	1.885111263951264800000e+000	6.539459052706132500000e+002
1.595959595959596100000e+003	1.885111263951264800000e+000	6.287941396832825400000e+002
1.612121212121212200000e+003	1.885111263951264800000e+000	6.036423740959518200000e+002
1.628282828282828400000e+003	1.885111263951264800000e+000	5.784906085086211100000e+002
1.644444444444444600000e+003	1.885111263951264800000e+000	5.533388429212903900000e+002
1.660606060606060700000e+003	1.885111263951264800000e+000	5.281870773339596800000e+002
1.676767676767676900000e+003	1.885111263951264800000e+000	5.030353117466291300000e+002
1.692929292929293100000e+003	1.885111263951264800000e+000	4.778835461592986500000e+002
1.709090909090909200000e+003	1.885111263951264800000e+000	4.527317805719681600000e+002
1.725252525252525400000e+003	1.885111263951264800000e+000	4.275800149846376700000e+002
1.741414141414141600000e+003	1.885111263951264800000e+000	4.024282493973072400000e+002
1.757575757575757700000e+003	1.885111263951264800000e+000	3.772764838099768100000e+002
1.773737373737373900000e+003	1.885111263951264800000e+000	3.521247182226463800000e+002
1.789898989898990100000e+003	1.885111263951264800000e+000	3.269729526353160100000e+002
1.806060606060606200000e+003	1.885111263951264800000e+000	3.018211870479856300000e+002
1.822222222222222400000e+003	1.885111263951264800000e+000	2.766694214606553100000e+002

1.83838383838383860000e+003	1.88511126395126480000e+000	2.51517655873325000000e+002
1.85454545454545470000e+003	1.88511126395126480000e+000	2.26365890285994680000e+002
1.87070707070707090000e+003	1.88511126395126480000e+000	2.01214124698664420000e+002
1.88686868686868710000e+003	1.88511126395126480000e+000	1.76062359111334160000e+002
1.90303030303030320000e+003	1.88511126395126480000e+000	1.50910593524003900000e+002
1.91919191919191940000e+003	1.88511126395126480000e+000	1.25758827936673650000e+002
1.93535353535353560000e+003	1.88511126395126480000e+000	1.00607062349343650000e+002
1.95151515151515150000e+003	1.88511126395126480000e+000	7.54552967620136460000e+001
1.96767676767676770000e+003	1.88511126395126480000e+000	5.03035311746840680000e+001
1.98383838383838380000e+003	1.88511126395126480000e+000	2.51517655873544860000e+001
2.00000000000000000000e+003	1.88511126395126480000e+000	2.57105129113241830000e-011

REFLECTANCE WITH THE ESTIMATED THICKNESSES AND OPTICAL PARAMETERS

lambda	r
4.00000000000000000000e+002	1.30836095416236040000e+001
4.16161616161616170000e+002	9.99233687896279870000e-001
4.32323232323232330000e+002	9.99808696698796350000e-001
4.48484848484848500000e+002	9.99915024944865280000e-001
4.64646464646464660000e+002	9.99952216042597430000e-001
4.80808080808080830000e+002	9.99969424009698900000e-001
4.96969696969697000000e+002	9.99978769381114740000e-001
5.13131313131313160000e+002	9.99984403432927940000e-001
5.29292929292929330000e+002	9.99988059711827360000e-001
5.45454545454545500000e+002	9.99990566213912020000e-001
5.61616161616161660000e+002	9.99992358969194580000e-001
5.77777777777777830000e+002	9.99993685326620250000e-001
5.93939393939393990000e+002	9.99994694080573840000e-001
6.10101010101010160000e+002	9.99995479095800000000e-001
6.26262626262626330000e+002	9.99996101959291120000e-001
6.42424242424242490000e+002	9.99996604438395000000e-001
6.58585858585858660000e+002	9.99997015669738640000e-001
6.74747474747474710000e+002	9.99997356480200160000e-001

6.9090909090909090880000e+002	9.99997642076725480000e-001
7.0707070707070707040000e+002	9.99997883772549610000e-001
7.2323232323232323210000e+002	9.99998090125069680000e-001
7.3939393939393939380000e+002	9.99998040840107020000e-001
7.5555555555555555540000e+002	9.99997989622514290000e-001
7.7171717171717171710000e+002	9.99997936369907410000e-001
7.8787878787878787880000e+002	9.99997880973033770000e-001
8.0404040404040404040000e+002	9.99997823315206370000e-001
8.2020202020202020210000e+002	9.99997763271694980000e-001
8.3636363636363636370000e+002	9.99997700709044260000e-001
8.5252525252525252540000e+002	9.99997635484337290000e-001
8.6868686868686868710000e+002	9.99997567444375180000e-001
8.8484848484848484870000e+002	9.99997496424779310000e-001
9.0101010101010101040000e+002	9.99997422248994460000e-001
9.1717171717171717210000e+002	9.99997344727192930000e-001
9.3333333333333333370000e+002	9.99997263655058700000e-001
9.4949494949494949540000e+002	9.99997178812438550000e-001
9.6565656565656565700000e+002	9.99997089961846110000e-001
9.8181818181818181870000e+002	9.99996996846799100000e-001
9.9797979797979798040000e+002	9.99996899189966700000e-001
1.0141414141414141420000e+003	9.99996796691099310000e-001
1.0303030303030303030000e+003	9.99996689024721390000e-001
1.0464646464646464640000e+003	9.99996575837542650000e-001
1.0626262626262626260000e+003	9.99996456745556590000e-001
1.0787878787878787880000e+003	9.99996331330779920000e-001
1.0949494949494949490000e+003	9.99996199137577870000e-001
1.1111111111111111110000e+003	9.99996059668522010000e-001
1.1272727272727272730000e+003	9.99995912379703640000e-001
1.1434343434343434340000e+003	9.99995756675423620000e-001
1.1595959595959595960000e+003	9.99995591902156810000e-001
1.1757575757575757580000e+003	9.99995417341687950000e-001
1.1919191919191919190000e+003	9.99995232203266800000e-001
1.2080808080808080810000e+003	9.99995035614641090000e-001

1.2242424242424242420000e+003 9.9999482661176320000 0e-001

1.2404040404040404040000e+003 9.9999460412694929000 0e-001

1.2565656565656565660000e+003 9.9999436697521304000 0e-001

1.2727272727272727270000e+003 9.9999411383846015000 0e-001

1.2888888888888888890000e+003 9.9999384324712892000 0e-001

1.3050505050505050510000e+003 9.9999355355881792000 0e-001

1.3212121212121212120000e+003 9.9999324293329939000 0e-001

1.3373737373737373740000e+003 9.9999290930323081000 0e-001

1.3535353535353535360000e+003 9.9999255033965895000 0e-001

1.3696969696969696970000e+003 9.9999216341127273000 0e-001

1.3858585858585858590000e+003 9.9999174553604164000 0e-001

1.4020202020202020210000e+003 9.9999129332358916000 0e-001

1.4181818181818181820000e+003 9.9999080290620934000 0e-001

1.4343434343434343440000e+003 9.9999026985588579000 0e-001

1.4505050505050505060000e+003 9.9998968908399799000 0e-001

1.4666666666666666670000e+003 9.9998905471942068000 0e-001

1.4828282828282828290000e+003 9.9998835995956126000 0e-001

1.4989898989898989910000e+003 9.9998759688723393000 0e-001

1.5151515151515151520000e+003 9.9998675624410283000 0e-001

1.5313131313131313140000e+003 9.9998582714853423000 0e-001

1.5474747474747474760000e+003 9.9998479674167795000 0e-001

1.5636363636363636370000e+003 9.9998364974014764000 0e-001

1.5797979797979797990000e+003 9.9998236786602712000 0e-001

1.5959595959595959610000e+003 9.9998092911418424000 0e-001

1.6121212121212121220000e+003 9.9997930680158276000 0e-001

1.6282828282828282840000e+003 9.9997746832117629000 0e-001

1.6444444444444444460000e+003 9.9997537349063281000 0e-001

1.6606060606060606070000e+003 9.9997297233800531000 0e-001

1.6767676767676767690000e+003 9.9997020209377763000 0e-001

1.6929292929292929310000e+003 9.9996698304672338000 0e-001

1.7090909090909090920000e+003 9.9996321274529787000 0e-001

1.7252525252525252540000e+003 9.9995875774427412000 0e-001

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