

Terahertz plasmonic metasurface sensor with graphene–CNT–copper integration for enhanced glucose sensing performance

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Abstract: This study presents a simplified terahertz biosensor that synergistically integrates graphene, carbon nanotubes, and copper to achieve an enhanced glucose sensing performance. Meanwhile, our sensing platform consists of a centrally positioned square resonator functionalized with carbon nanotubes, coupled to two copper-modified rectangular resonators lithographically patterned on a silicon dioxide substrate. The numerical findings based on the well-known Finite element method simulations performed in COMSOL Multiphysics identify an optimal operating frequency of 0.58 THz, delivering a maximum sensitivity of 1000 GHzRIU^{-1} over a refractive index range of 1.335–1.347 RIU. Additionally, our biosensor demonstrates strong performance metrics, including a quality factor (Q-factor) of 8.391, a figure of merit (FOM) of 14.493 RIU^{-1} , and a detection limit of 0.133. Moreover, the machine learning analysis based on Polynomial regression technique is considered to validate the analytical consistency and operational robustness of the device, achieving predictive accuracies exceeding 90% under the variations of both graphene chemical potential and incident angle of the propagating electromagnetic waves. In this regard, we believe that, the combination of high sensitivity, predictive stability, and resilience to multi-parameter perturbations establishes the X-configuration architecture as a competitive platform for glucose biosensing. Moreover, the multi-material engineering strategy constitutes a meaningful advancement in terahertz biosensor design by exploiting complementary physicochemical properties within an optimized X-shaped geometry to enhance functional performance.

Keywords: Glucose biosensor; Graphene; Carbon nanotubes; Finite element method simulation; Metasurface

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1. Introduction

Real-time glucose monitoring remains essential in clinical diagnostics and modern healthcare, necessitating biosensors with high sensitivity, stability, and rapid response characteristics. Recent progress in two-dimensional material heterostructures and nanophotonic engineering has significantly advanced biosensing technologies, while terahertz (THz) sensing enables label-free and non-invasive