Interstrip coupling effects in graphene-based metasurface

K. S. Kuznetsova[1], Z. E. Eremenko[1], V. A. Pashynska[1,2]

[1] *Usikov Institute for Radiophysics and Electronics, NAS of Ukraine, 12 Academ. Proskury Str., Kharkiv 61085, Ukraine*
[2] *Verkin Institute for Low Temperature Physics and Engineering, NAS of Ukraine, 47 Nauky Ave., 61103, Kharkiv 61103, Ukraine*
vlada.pashynska@gmail.com

INTRODUCTION

Graphene-based metasurfaces have gained significant attention in recent years due to their unique and tunable optical and electronic properties, enabling precise control of plasmonic resonances that opens great possibilities for the development of sensors, absorbers, and other devices [1]. Precisely controlling surface plasmon interactions provided by the metasurface structural modifications is essential for optimizing device performance.

MODELLING

We present a numerical study of a graphene-based metasurface integrated into a polymer and demonstrate its potential for biosensing applications. A unit cell of the metasurface consists of a thin silicon carbide (SiC) layer with a centrally positioned graphene strip respectively (Fig. 1). The size along one axis is fixed (P1 = 7 μm), while the distance between neighboring graphene strips (P) has been varied under optimization from 1 to 7 μm to evaluate coupling effects between graphene strips.

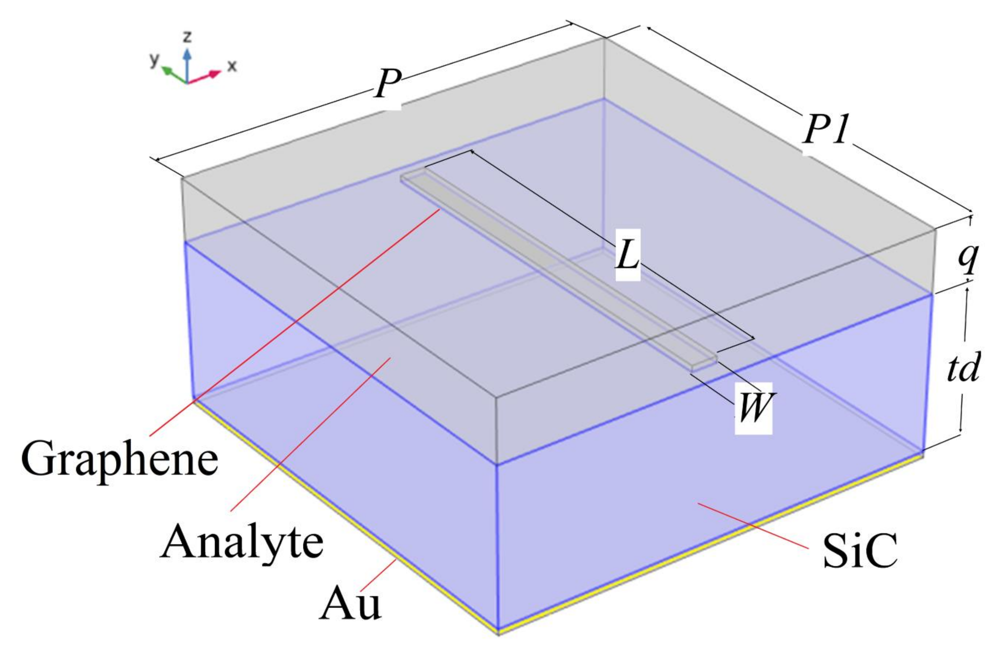

Fig. 1. The unit cell of the graphene-based metasurface, consisting of SiC layer (td = 2.5 μm) with a centrally positioned graphene strip, W = 0.4 μm, L = 6.36 μm.

RESULTS AND DISCUSSION

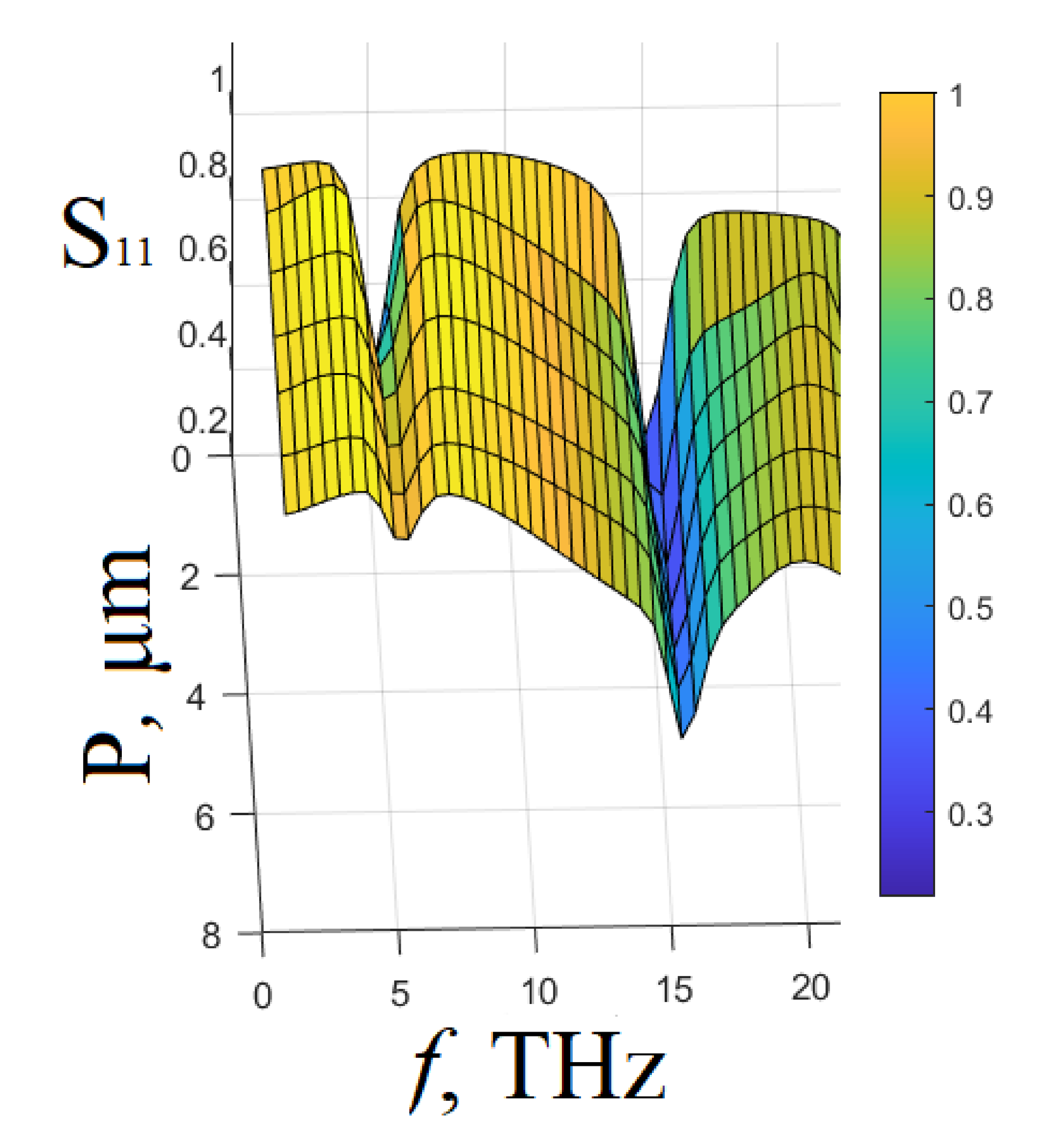

Fig. 2. The reflection coefficient S11 as a function of frequency f and distance between neighboring graphene strips P.

Two resonance modes are observed at approximately f1 = 5 THz and f_2 = 15 THz (Fig. 2). The intensity of the first resonance f1 increases with the distance P decrease, while the second resonance f_2 remains almost unchanged. Additional higher-order resonances are detected above 20 THz and shift with the P variations. Electric field distribution at resonance exhibits characteristic edge-localized maxima (Fig. 3). The strongest field localization is observed near the edges of the graphene strip, forming a dipole-like pattern.

Electric field distribution analysis reveals that for f1 the maximum field concentration occurs at the narrow edges *W* of the graphene strip. At f_2 the electric field maximum concentrated along the long edges *L* of the graphene strip, the corresponding fields exhibits a dipole-like behavior [2].

The f1 resonance intensity is highly dependent on the P value variations. This tunability is particularly relevant for the development of reconfigurable plasmonic devices and highly sensitive biosensors operating in the terahertz frequency range [3].

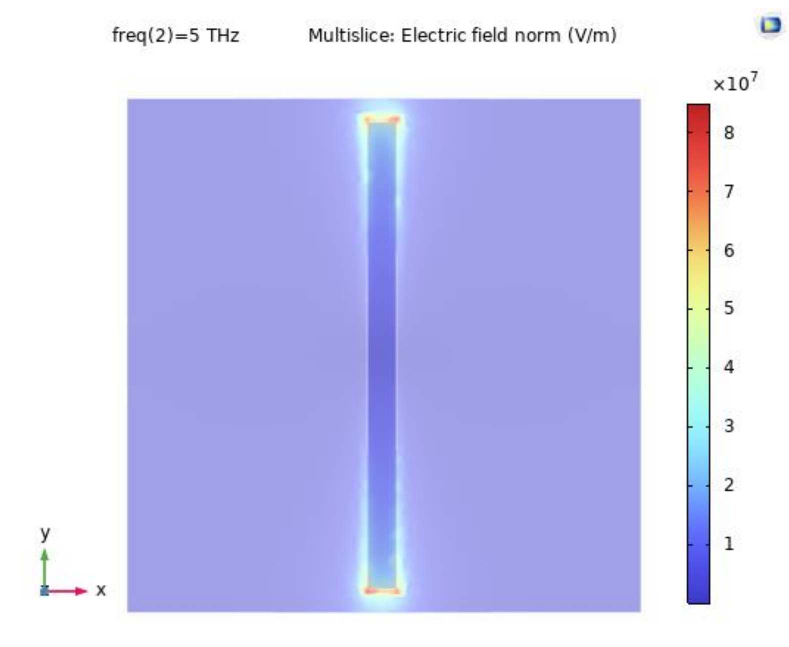

Fig. 3. Electric field distribution in metasurface unit cell at 5 THz.

Graphene-based metasurface for bovine serum albumin (BSA) determination in liquid samples

The electric field distribution reveals strong field concentration in the gaps between the graphene strips, confirming the presence of significant interstrip coupling. This enhanced field localization can be exploited for the detection of biologically active substances in liquid samples, as even slight changes in dielectric properties of the analyte can noticeably affect the resonance behavior in the sensing structure.

Simulation results demonstrate that developed graphene-based metasurface exhibits an absorption peak in the THz range, which is highly sensitive to the dielectric properties of the liquid layer q=0.5 μm (Fig. 4). A resonance is observed at 5.64 THz for the bare metasurface. Upon addition of water/ BSA solution with concentrations of 100 mg/ml, the resonance shifts to 5.5 THz. The observed broadening of the resonance peak with analyte loading suggests increased loss, caused by the absorption properties of aqueous solutions of protein.

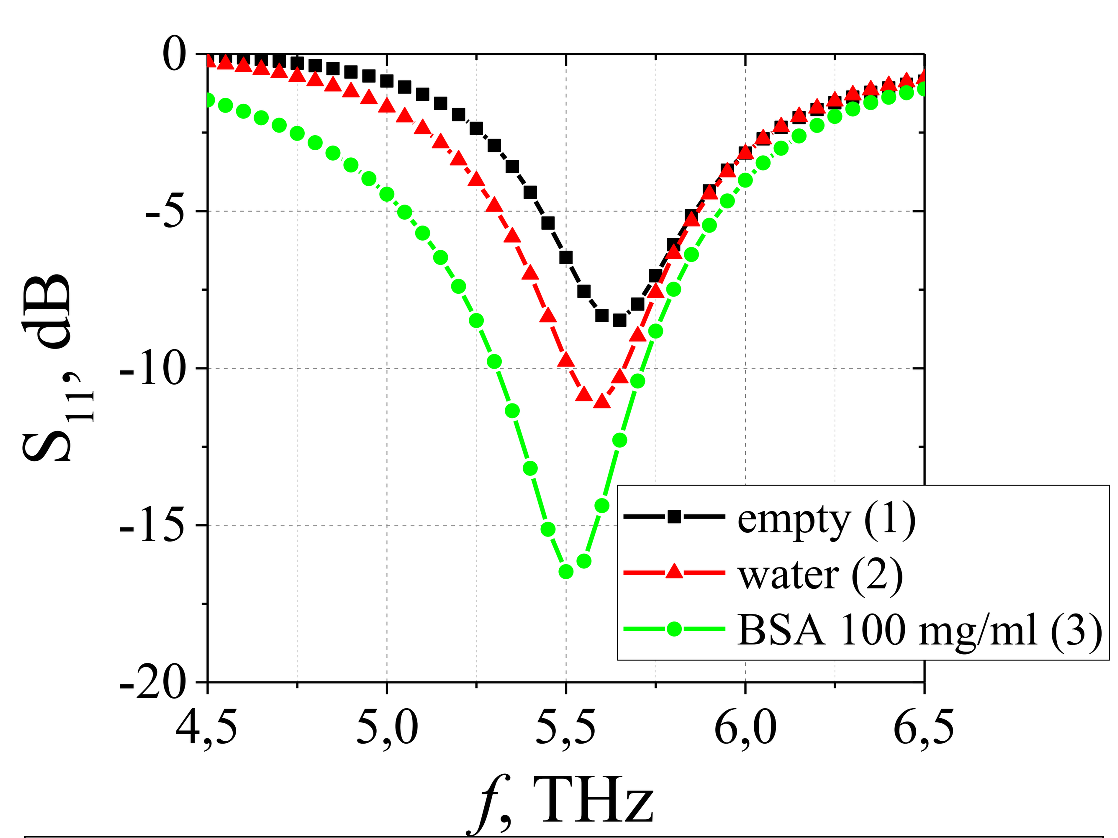

Fig. 4. The behaviour of reflection coefficient S11 of the graphene-based metasurfaces with different analyte layers: (1) no analyte, (2) water layer, (3) 100 mg/mL BSA aqueous solution.

SUMMARY

It has been demonstrated that variations in geometrical parameters, such as the distance between strips and their dimensions, significantly influence the resonant properties of the graphene-based metasurface structure. Optimal unit cell parameters have been identified for potential application of the sensor structure for detection of biologically active substances like proteins in liquid samples. It was shown, that loading of the liquid layer in the developed sensor structure based on the metasurface with graphene nanostrips causes the shift of the maximum and change amplitude of absorption peak, which is highly sensitive to the dielectric properties of the tested liquid.

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