Analysis of the coupling between surface plasmon polariton mode and dipole mode at terahertz metasurface absorber

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***Abstract*—We have investigated the interaction of surface plasmon polariton (SPP) mode with dipole mode at terahertz perfect metamaterial absorber (PMA) consisted of a metasurface layer, a dielectric spacer layer, and a metallic ground. The dependence of SPP modes generated by PMA on the lattice constant of the unit cell was investigated. Also, high-quality-factor resonance is observed, which has been a subject of numerous investigations since an elevated quality factor is highly desirable for the practical application.**

I. INTRODUCTION

The advent of perfect absorption has spawned extensive research into metamaterial absorber over the past decade. Metamaterial absorber has attracted a great deal of research interest not only for their exotic electromagnetic properties, but also their potential for applications, including chemical detection, biological sensing, cloaking, energy harvesting, and imaging. Generally, the properties of the resulting metamaterial are defined by the geometry of the metasurface patterns and response to the incidence electromagnetic field. However, in addition to the intrinsic modes, the grating constituted from the metallic array can also excite the surface plasmon polariton (SPP) mode. Previous studies have shown that SPP mode is related to the period of unit cell. In addition, absorption of SPP modes can lead to extremely sharp resonances which are highly desirable for a number of applications. In order to exert the advantages of SPP modes, an in-depth understanding of the SPP modes produce and the coupling process between SPP mode and intrinsic mode is necessary.

To this end, the absorption properties of terahertz absorber with different lattice constants are analyzed to demonstrate the relation between lattice constant and operation frequency of SPP mode. And also, we employ the vacuum Rabi splitting model to obtain analytical expression for the frequency shift of the SPP mode and dipole mode.

II. RESULTS

The Jerusalem cross dipole resonator is adopted in this work. The structure of the unit cell is shown in inset of Fig. 1. The dimensions of the Jerusalem cross were set as follows: the length of short side l=12μm, the length of long side a=28μm, and line width w=4μm. The period of the unit cell p=95μm; the thickness of each pattern and that of the ground plane are the same t_m=200nm; all the patterns are arranged neatly on a polyimide layer with a thickness of t_s = 8 μm. The simulation results are obtained by using FDTD method. Polyimide is selected as spacer and model as lossy polymer with a permittivity of 3.3 + 0.009i. The ground plane and Jerusalem cross patterns are gold structure with an electrical conductivity of 4.561×10^7 S/m. The incident THz field is set to propagate along z axis with the electric field along x axis. These geometries and material properties are optimized to excite unit absorption at the frequency range of interest. The features of the proposed tunable absorber are presented in the inset of Fig.1. For the SPP mode generated by square lattice, the operating frequency can be described by following equation:

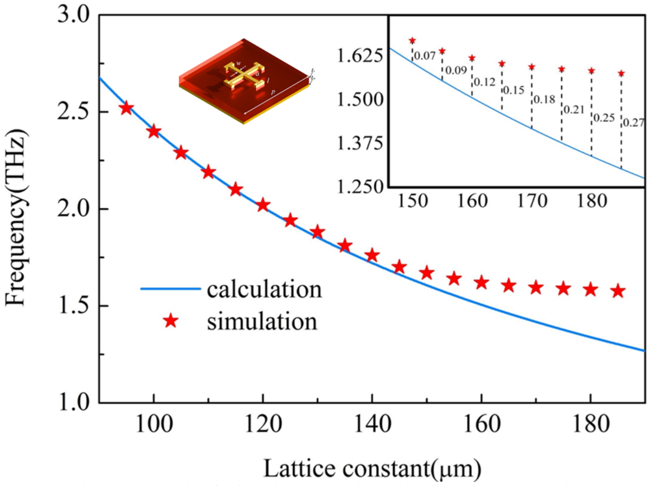

Fig. 1. The structural of absorber and the calculated (0, 1) order SPP response frequencies of varying lattice constants.

$$f_{\mathrm{SPP}} = \frac{c\sqrt{i^2 + j^2}}{p\sqrt{\varepsilon_{\mathrm{eff}}}} \tag{1}$$

where i and j are denoting the order of the reciprocal lattice vector, f_{SPP} is the operating frequency of the SPP mode, c is light speed, p is the period of the unit cell, and $\varepsilon_{\mathrm{eff}}$ is effective relative permittivity.

The results of the (0,1) order SPP mode are shown in Fig. 1. The red stars are the results obtained from the simulation, while the blue line is the results calculated according to equation (1). The deviation gradually increases to 0.27 THz while the lattice constant exceeds to 150 μm.

However, the deviations between calculation and simulation are not generated in (2,0) order SPP mode. As shown in Fig.2, the simulation results agree well with the calculation results. As expected, the (2,0) order SPP mode is not coupled with the dipole mode produced by metallic Jerusalem cross. Because the resonance of the cross resonator disappears as the period increases further.

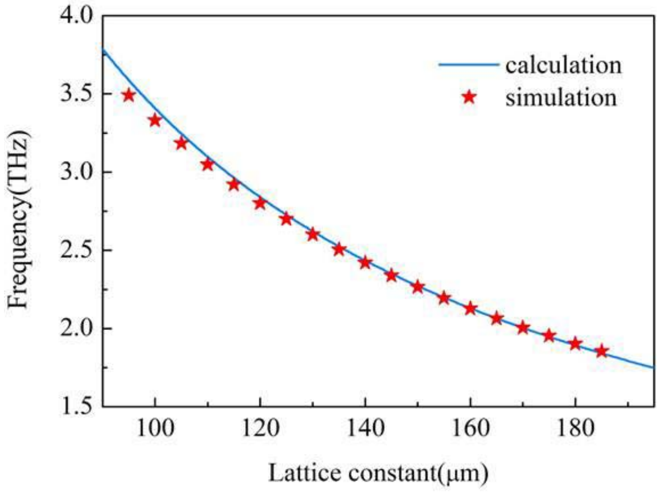

Fig. 2. The structural of absorber and the calculated (2, 0) order SPP response frequencies of varying lattice constants.

We deduced that this disparity of anti-crossing effects can be described by Rabi splitting. The absorption frequencies extracted from simulated results are marked with stars in Fig. 3, and the calculated results combined with Rabi splitting are plotted. The simulation results are consistent with the calculated results.

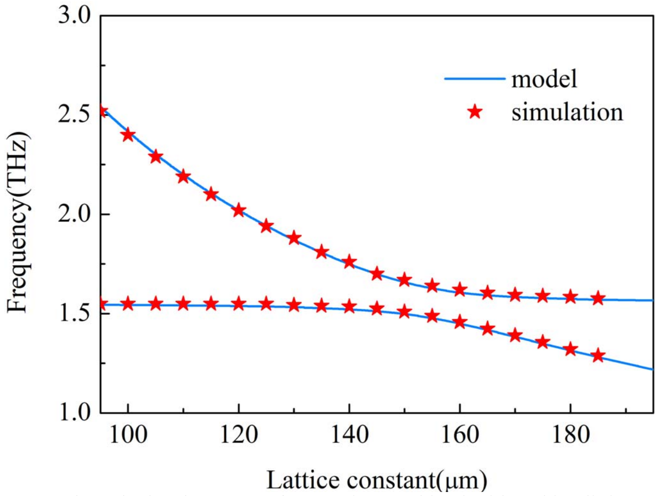

Fig. 3. The calculated response frequencies combined with Rabi splitting (line) and operating frequencies extracted from simulated results (stars).

III. SUMMARY

A strong coupling between SPP mode and intrinsic absorption mode is demonstrated, which will lead a deviation of the absorption frequencies. With a proper coupling strength of Rabi splitting, the calculated operating frequencies of coupled SPP modes and the intrinsic modes can be used to quantitatively describe splitting frequency difference.

IV. ACKNOWLEDGED

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