Tunable Terahertz Plasmonic Perfect Absorber Based on Arrow-shaped InSb Array

Jitong Wang, Hao Zhang, Xiangjun Zhang
School of Information and Control Engineering
China University of Mining and Technology
Zhangxj@cumt.edu.cn

Abstract-In this paper, a nearly perfect terahertz absorber for transverse magnetic (TM) polarization based on Arrow-shaped InSb array is proposed and numerically investigated. Incident wave at the Fabry-Perot resonant frequency can be totally absorbed into the narrow grooves between the two adjacent Arrow-shaped InSb arms. The absorption mechanism is theoretically and numerically studied by using the Fabry-Perot model and the finite element method (FEM), respectively. The absorption peak can be controlled by varying the temperature. Furthermore, a new absorption peak will emerge while breaking the symmetry of the Arrow-shaped InSb array. This tunable THz perfect absorber may find important applications in THz devices such as microbolometers, coherent thermal emitters, solar cells, photo detectors, and sensors.

Key words- Absorber; Terahertz; Plasmonic; Tunable

I. INTRODUCTION

Terahertz (THz) technology has attracted much attention in relation to various application areas such as biological science, medical imaging, security, and space science [1]. Intensive studies fueled by emerging applications of THz frequency are now focusing on developing various functional devices such as emitters, modulators, filters, detectors, and absorbers in efforts to realize THz systems with better performance and new functions [2]. Among these devices, the THz absorber is believed to facilitate the development of more powerful THz detectors operating at room temperature and of stealth materials, thermal emitters, and sensors. During the past decade, research on planar metamaterial to suppress the surface reflection has been actively carried out [3]. Thanks to reduced reflection at the resonance frequency, THz absorbers based on various metamaterial designs have exhibited high absorption properties. Different kinds of THz absorber based on metamaterial have been reported, such as polarization independent [4], omnidirectional [5], dual-band [6], triple-band [7], ultra-narrow band [8], and wide-band absorber [9]. Unfortunately, the absorption peaks of these absorbers based on metamaterial are not tunable without changing the geometry parameters. Surface plasmon polaritons (SPPs) are the electromagnetic excitations propagating along the interface between a dielectric and a conductor [10], providing solutions for overcoming the diffraction limit. Thanks to their sub-wavelength and local field enhancement effects, SPPs can be applied in various areas, such as plasmonic modulator, filters, all-optical switching, plasmonic nanosensor, and plasmonic perfect absorber [11-13]. There is an urgent need to find a material that can support THz SPP wave. Some semiconductors have a permittivity at THz range close to that of metal at optical range. InSb, whose permittivity can be modified by varying temperature, has been proposed for designing THz plasmonic devices. tunable plasmonic THz devices based on InSb material by tuning temperature seems interesting and promising [14-15].

In this paper, we propose and numerically investigate a THz nearly perfect plasmonic absorber for transverse magnetic (TM) polarization based on InSb arrow-shaped array. Incident wave at the Fabry-Perot resonant frequency can be totally absorbed into the cavities between the adjacent arrow-shaped InSb structures. The absorption properties of the proposed structure are numerically studied by using the finite element method (FEM). The absorption peak can be controlled by tuning the temperature. Additionally, it is found that dual-band plasmonic nearly perfect absorber can be achieved by breaking the symmetry of the arrow-shaped InSb array. This tunable THz perfect absorber has potential applications in THz technology and devices such as microbolometers, coherent thermal emitters, solar cells, photo detectors, and sensors.

II. STRUCTURE AND MATERIAL

The schematic of the proposed THz absorber is shown in Fig.1. The symmetric InSb Arrow-shaped array is periodically arranged on the InSb ground plane periodicity of p=200μm, the InSb ground is thick enough (t_2=300μm) to make sure that there is no light can pass through this structure, and at the bottom of the InSb ground is a SiO_2 substrate with thickness of t_1=300μm. The geometric parameters of the Arrow-shaped structure are set to be w_1=60μm, $w_2=w_3$=45μm, w_4=10μm, t_3=40μm, and t_4=100μm, t_5=25μm, L=60μm. *So,* the gap between the adjacent Arrow-shaped arms is w_g=p−w_1−w_2−w_3 =50μm. In this paper, t_1, t_2, t_3, t_4, t_5 and p are unchanged throughout this paper. θ is the angle between the incident wave and the y-axis as shown in Fig. 1. The permittivity of InSb can be approximately given by the simple Drude model approximation [16]:

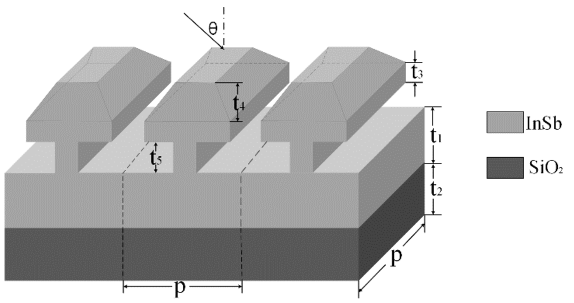
$$\varepsilon(\omega) = \varepsilon_\infty - \frac{\omega_p^2}{\omega^2 + i\gamma\omega} \tag{1}$$

where ε_∞ represents the high-frequency permittivity, ω is the angular frequency, and γ is the damping constant. The plasma frequency $w_p = \sqrt{Ne^2/\varepsilon_0 m^*}$ depends on the intrinsic carrier density N, the electronic charge *e*, the vacuum permittivity ε_0, and the effective mass m* of free carriers. The intrinsic carrier density N (in m^{-3}) of InSb obeys the relationship [17]:

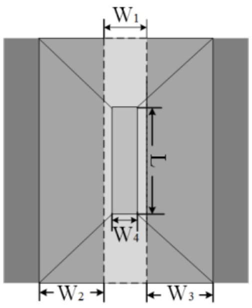
$$N = 5.76 \times 10^{20} T^{1.5} \exp\left(-0.26/2k_B T\right) \tag{2}$$

where k_B is the Boltzmann constant and *T* is the temperature in kelvin. It should be noted that the damping constant γ of InSb is proportional to the electron mobility μ as γ=*em**/*μ*, which in turn depends on the temperature. Thus, while changing the temperature, γ will change as well, and then, it will influence the absorption property of InSb. However, when the temperature ranges from 160 to 350 K within the frequency regime from 0.1 to 2.2 THz, the electron mobility μ changes slightly. Consequently, the damping constant γ can be seen as a constant, which is consistent with the experimental report [18]. For InSb, ε_∞=15.6, m^*=0.015m_e (m_e is the mass of electron), and γ=0.1π THz. The permittivity of SiO_2 is 2.25. The whole structure is surrounded by air with permittivity of 1.

One of the great differences between InSb and Ag is that the plasma frequency ω_p of InSb increases exponentially with the increase of temperature. Therefore, tunable plasmonic THz absorber based on InSb by tuning temperature seems interesting and promising. The whole structure is illuminated by a transverse magnetic (TM) polarized plane wave (the magnetic



(a)



(b)

Fig. 1 (a) The 3D schematic of the proposed THz absorber. (b) Top view of the proposed THz absorber unit cell.

field is perpendicular to the incident plane). As the thickness of the InSb substrate t_2 is much larger than the skin depth in the THz regime, therefore, no light can transmit through the whole structure and the transmission T is close to zero. Thus, the absorption can be calculated by A=1−R, where R is the reflection of the incident wave. In this paper, all numerical calculations have been performed by using the commercial software CST.

III. SIMULATION RESULTS AND DISCUSSION

At first, we set the temperature to be 270 K. The absorption spectra for transverse magnetic (TM) polarized plane wave with $\theta=10^{\circ}$ and $\theta=20^{\circ}$ are plotted in Fig. 2. For plane wave with $\theta=10^{\circ}$, there is an absorption peak located at 1.584 THz with absorptivity of 96.1%. The absorption spectra under TM polarization with $\theta=20^{\circ}$ are presented in Fig. 2 with short dashed line. There is an absorption peak located at 1.651 THz with absorptivity of 96.5%. The absorptivity kept a low value ranging from 0.8 to 1.5 THz indicating low absorption occurs in our structure for TM polarization. Therefore, the absorption is angle dependent. Hence, THz absorbers based on InSb material can be made wavelength selective and angle dependent which are not possible in conventional bulk material-based absorbers. According to Equation (2), we can clearly see that the resonance frequency corresponding to the absorption peak has a blueshift with the increasing of the temperature. Therefore, one can easily manipulate the resonance frequency corresponding to the absorption peak of the proposed absorber by tuning the temperature.

IV. CONCLUSIONS

In conclusion, we have designed a THz wide-angle plasmonic nearly perfect absorber based on arrow-shaped InSb array. This absorber has an absorption peak around the frequency 1.6 THz with the absorptivity more than 96.1%. The nature of the absorption is due to the SPP mode excited in the cavities. More importantly, by taking advantage of the permittivity of thermally tunable properties of InSb, the resonant frequency can also be controlled by tuning the temperature. This tunable THz perfect absorber may find important applications in THz devices such as microbolometers,

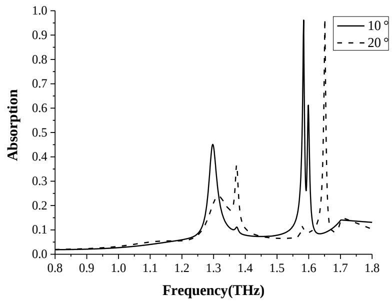


Fig. 2 The absorption spectra for transverse magnetic (TM) polarized plane wave with $\theta=10^{\circ}$ and $\theta=20^{\circ}$.

coherent thermal emitters, solar cells, photo detectors, and sensors.

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