Basic Study of an InSb Grating Filter in the Terahertz Region

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Abstract **– We investigate the transmission and reflection characteristics of an InSb grating filter utilizing the localized surface plasmon resonance (SPR) at terahertz frequencies. The filter is shown to yield a wide tunability of the transmission dip and the reflection peak due to the dispersion property of InSb. It is observed that the frequency of the transmission dip does not match that of the reflection peak, and shifts towards higher frequencies. The SPR frequency of the grating structure is also found to appear as the frequency of the reflection peak.**

Index Terms **— Indium antimonide (InSb), grating filter, terahertz (THz) wave, localized surface plasmon resonance, finite-difference time-domain (FDTD) method.**

1. Introduction

At THz frequencies, indium antimonide (InSb) exhibits a negative permittivity, allowing the excitation of a surface plasmon resonance (SPR) around an InSb/dielectric interface [1]. In addition, its permittivity significantly varies with temperature, leading to the application to tunable devices. Using these characteristics of InSb, several temperature-dependent devices have been proposed at THz frequencies, e.g., grating filters [2], waveguide filters [3], lenses [4], sensors [5] and so on.

In this article, we study the characteristics of a simple InSb grating filter using the frequency-dependent FDTD method. Note that the transmission characteristics have mainly been examined in previous papers regarding the InSb grating filter. We here pay attention not only to the transmission but also to reflection characteristics.

First, we present the InSb permittivity expressed by the Drude model, which is incorporated into the frequency-dependent FDTD method based on the trapezoidal recursive convolution (TRC) technique [6]. Next, the transmission and reflection characteristics are calculated using the plane wave and point source excitations. It is shown that the filter yields a wide tunability of the transmission dip and the reflection peak. In this case, it is observed that the frequency of the transmission dip does not match that of the reflection peak, and appreciably shifts towards higher frequencies. Finally, we point out that the SPR frequency of the InSb grating structure coincides with the frequency at the reflection peak.

2. Discussion

The configuration of an InSb grating filter is shown in Fig. 1, in which a two-dimensional structure is investigated

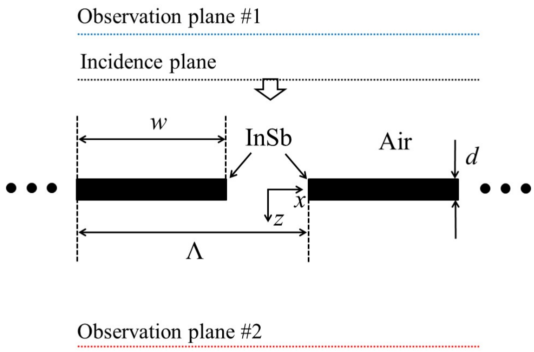


Fig. 1. Configuration of an InSb grating filter.

and only a single unit (-20 μm $\leq x \leq$ 20 μm) is analyzed using the periodic boundary condition. The configuration parameters are $\Lambda = 40\,\mu$m, $w = 35\,\mu$m and $d = 5\,\mu$m. The relative permittivity of InSb is expressed by the following Drude model with frequency and temperature dependence [5]:

$$\varepsilon_r(\omega,T) = \varepsilon_\infty + \frac{\omega_p^2(T)}{\omega(j\Gamma(T)-\omega)}$$

where ω_p is the plasma frequency, Γ is the collision rate of the charge carriers, and ε_∞ is the high-frequency permittivity. This Drude model is incorporated into the FDTD method based on the TRC technique that is much simpler than the piecewise linear recursive convolution technique with the comparable accuracy [6]. The E_x polarized plane wave is excited from the incidence plane at z =–50 μm

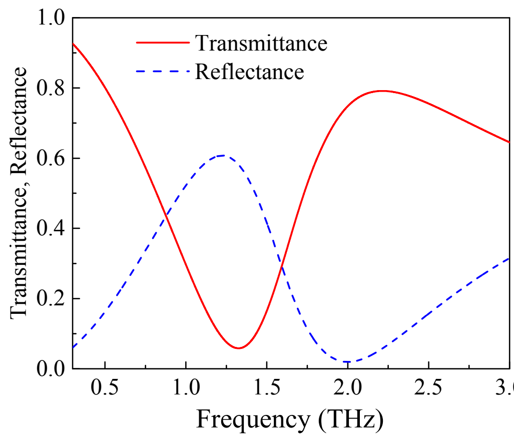


Fig. 2. Transmittance and reflectance versus frequency.

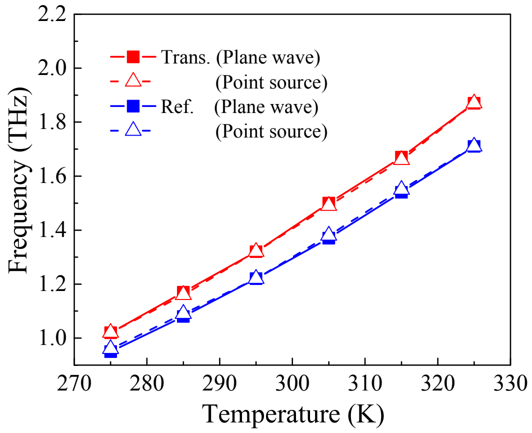
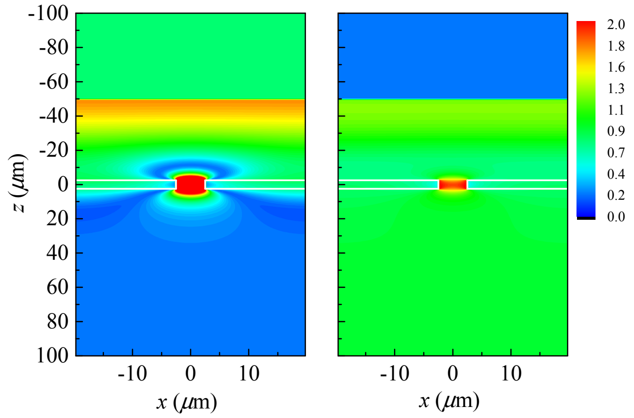


Fig. 3. Frequencies of the transmission dip and the reflection peak.



(a) 1.31 THz (b) 2.22 THz

Fig. 4. Field distributions (E_x component).

towards +z direction. The transmissivity and reflectivity are respectively calculated at the observation plane #2 and #1 at z =±75 μm.

Fig. 2 shows the typical transmittance and reflectance as a function of frequency at 295 K. It is seen that the InSb gratings act as a notch-type filter. Notice that the frequency of the transmission dip is higher than that of the reflection peak. Since InSb has a temperature-dependent permittivity, we next investigate how temperature affects the transmission and reflection characteristics.

The frequencies of the transmission dip and the reflection peak are shown in Fig. 3, in which the temperature is varied from 270 to 325 K. In addition to the analysis using the plane wave excitation, we also analyze this structure using the point source excitation together with the supper cell approach, in which the source is placed at (0, -7.5) and the transmission and reflection components are observed at (0, ±75) in microns. It is seen that the results using the plane wave and point source excitations agree quite well with each other, validating the numerical results. The resonance frequency is seen to increase as the temperature is increased, yielding large frequency shifts of 0.85 and 0.75 THz for the transmittance and reflectance, respectively. This temperature-dependent characteristic is used to form several functional devices [2]-[5]. It is also observed that the frequency of the transmission dip is higher than that of the reflection peak at all temperatures.

To find the SPR frequency of the grating structure, we excite the point source at the center of the grating (x=z=0). As a result, although not shown in Fig. 3, the obtained resonance frequencies perfectly match the frequencies of the reflection peak at all temperatures. In other words, the SPR frequency of the grating structure appears as the frequency of the reflection peak. In [2], it is stated that the localized SPRs are identified as dips in the transmission spectrum. To be more precise, however, the localized SPRs are identified as peaks in the reflection spectrum.

Finally, we illustrate the field distributions at 1.31 THz for the transmission dip and at 2.22 THz for the transmission peak in Fig. 4. At 1.31 THz, a strong localized SPR is seen between the InSb gratings, resulting in a strong reflection. Since InSb gets closer to a normal dielectric at 2.22 THz, the localized SPR becomes weaker, leading to a high transmission.

3. Conclusion

We have investigated the transmission and reflection characteristics of an InSb grating filter utilizing the localized surface plasmon resonance at terahertz frequencies. The filter is shown to yield a wide tunability of the transmission dip and the reflection peak due to the dispersion property of InSb. It is observed that the transmission dip appreciably shifts towards higher frequencies compared to the reflection peak at all temperature, the reason of which is now under investigation. It is also found that the SPR frequency of the grating structure appears as the frequency of the reflection peak.

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