Suppression of Specular Reflection Under Surface Plasmon-Polariton Resonance in Terahertz

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Abstract

We study the effect of the total suppression of the specular reflection (TSSR) caused by the resonance plasmon-polariton excitation on semiconductor in Terahertz. In our experiment the HCN laser radiation is incident from the air on the InSb surface with a periodic array of grooves and couples with eigenmode of the interface. The results obtained were compared thoroughly with the predictions of the numerical calculations, and rather well accordance was found.

1. Introduction

The numerous effects caused by the resonance excitation of the surface plasmon-polariton (SPP) are currently under thorough theoretical and experimental investigation. For metal gratings in visible and infrared regions the SPP resonance arises when at least one of the diffracted waves turns out close to the eigenmode of the metal-air interface. This coupling results in well-known effects such as the total suppression of the specular reflection (TSSR), redistribution of the incident wave energy between diffracted waves and polarization transformation [1], anomalous transparency of thick [2] and opaqueness of ultra-thin conducting films [3], etc. The SPP modes and related phenomena also exist in the low-frequency range such as THz and microwave range. THz band is under growing interest due to its very useful applications, especially for the biology and medicine. The plasmonic effects allow to construct new devices and stimulate the development of THz technology. It is known that for the most metals the propagating SPP mode does not exist for THz frequency. There are different ways to overcome this difficulty: making a holes array in the metal surface [4], using the metamaterials with composite structure, and the other way is using a doped semiconductor [5]. As it was shown in [6] for highly doped semiconductors all the effects that were mentioned above can be obtained in terahertz range. In current work we examine the most essential TSSR effect on semiconductor grating in Terahertz both experimentally and numerically.

2. Experimental results

For our study we prepared two InSb specimens with array of grooves on the surface fabricated by means of the standard optical lithography. The periodicity of grooves array is $d = 253$ μm and their form is close to semi-elliptical. The groove sizes vary in proportion to etching time: for specimens under study their widths are $130,\ 143$ μm and depths $20,\ 24$ μm correspondingly. To leave an opportunity for further adjustment of the grating depth we did not remove the photoresist. Fig. 1 shows the scheme of the specimens and geometry of the experiment. As a light source we use HCN (hydrocyanic) laser

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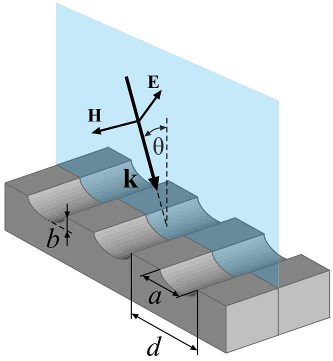

Fig. 1: Scheme of InSb specimens and diffraction geometry. Incidence plane is perpendicular to the grooves and radiation is p-polarized. SPP resonance occurs at the incident angle $\theta \simeq 17.5°$.

with frequency 0.89 THz and band width 10 MHz that generates linearly polarized quasi-monochromatic light beam of wavelength $\lambda = 336.9$ μm. The spot diameter of the beam is about 14 mm and it covers wholly the grating in transversal to the incidence plane direction. We chose the incidence angle close to the $\theta \simeq 17.5°$, so that the -1^{st} SPP resonance occurs (i.e. -1^{st} diffraction order couples with SPP). This condition can be written as $k \sin\theta - g \simeq -k\sqrt{1 + (\xi'')^2}$, where $k = 2\pi/\lambda$, θ is incidence angle, $g = 2\pi/d$ and two primes denote the imaginary part of surface impedance $\xi = 1/\sqrt{\varepsilon}$ (see Fig. 2 for geometry). In this geometry there exists only specular diffracted wave and we choose grating depth to achieve the total suppression of specular reflection. Before proceeding with experimental results we want

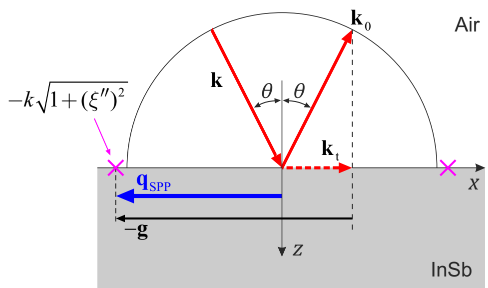

Fig. 2: Geometry of SPP resonance: -1^{st} diffraction order couples with the eigenmode of air-InSb interface with wave vector **q** via reciprocal grating vector **g**.

to discuss the numerical computations performed by means of Chandezon method [7]. For numerical experiment we use Drude conductivity model

$$\varepsilon(\omega) = \varepsilon_0 - \frac{\omega_p^2}{\omega(\omega + i\gamma)} \tag{1}$$

with parameters $\varepsilon_0 = 15.011$, $\omega_p = 0.04\ eV$, $\gamma = 0.00137\ eV$; these parameters were retrieved from experimental data [8] in the wavelength region $100 - 1000$ μm. In Fig. 3 we present the results of experiments and numerical calculations. In order to take into account the influence of the residual photoresist the numerical simulations were performed under the assumption that the grating surface is covered by thin continuous layer of the dielectric with permittivity $\varepsilon = 2.62$; this value is typical for positive photoresist on basis of PMMA. The best agreement between experimental and numerical results turned out when the layer thickness is approximately 10 μm. As one can see the suppression of the specular reflection for the specimen with $a = 143$ μm, $b = 24$ μm is almost total. Actually, the TSSR is unreachable in the case of the non-planar incident wave. In our experiment the beam divergence

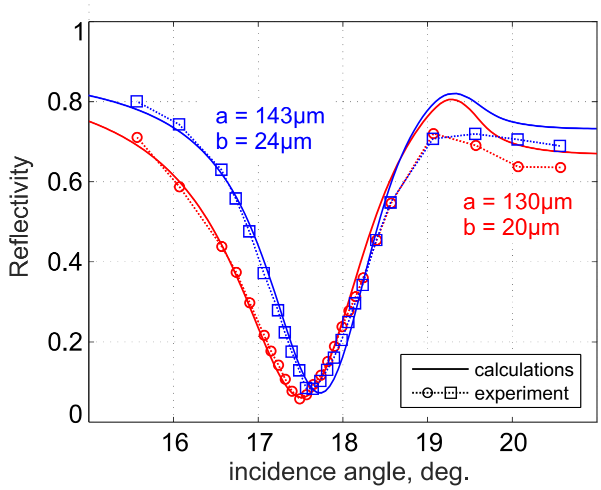

Fig. 3: Dependence of InSb reflectivity on the angle for different grooves sizes. Solid lines correspond to the numerical calculations and dashed lines with markers show the experimental results.

angle is about $0.5°$, and its intensity distribution is close to Gauss. Therefore we had to apply the Gauss smoothing with the same parameters to the numerical results. This fact explains that in our calculations we don't see cusp at Rayleigh point, $\theta_R = 19.37°$, but only its blurred trace. A discrepancy between the curves far from resonance most likely arise from groove irregularities, roughness of the specimens and possible re-reflections from the edges. In spite of these facts the experimental results agree quite well with the numerical calculations.

3. Conclusion

In this work we have experimentally studied the effect of TSSR under resonance diffraction at semiconductor (InSb) grating in terahertz range. The effect observed is analogous to that in optical and infrared regions of spectrum for a good metal. The results of the experiment justify previous theoretical assumption [6] and thoroughly agree with the results of the numerical calculations.

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