Terahertz Surface Plasmon Resonance with Dirac Electron Systems for Bio-Medical Applications

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Among the wide range of magneto-electric waves, a THz (Terahertz) band (0.1-10 THz) contains several important vibrational modes of intermolecular coupling. Therefore, non-labeling detection of intermolecular binding is expected to be realized [1]. On the other hand, the surface plasmon resonance (SPR) method is widely used as a highly surface-sensitive analysis method in the bio-medical fields. However, the conventional visible light SPR method only detects refractive index changes, making qualitative analysis difficult in principle. In this study, we aim to realize highly sensitive non-labeling detection of specific binding by THz-SPR with Dirac electron systems. We focused on Dirac electron systems topological insulator as one of the promising materials for SPR excitation in the THz band. Unlike metals (gold, etc.) used in conventional SPR methods in the visible light range, Dirac electrons are advantageous in terms of SPR generation range and sensitivity. Using topological insulator THz-SPR, we can expect a synergistic effect of two resonance phenomena, intermolecular vibrational resonance and surface plasmon resonance.

Bi_2Se_3 thin films (about 200 nm thick) were prepared on 0.5 mm thick sapphire substrates (c-plane) by pulsed laser deposition. XRD and ARPES measurements were conducted, and the results ensured that those films were high quality and had topological states. Bi_2Se_3 micro ribbon structures with widths W = 32, 48, 64 µm were then fabricated by photolithography and SF_6 ion etching to enhance SPR, and the transmittance of THz was measured. The transmittance was shown in Fig.1(a)-(c). Since Bi_2Se_3 has phonon mode in around 1.9 THz, the transmittance was fano-fitted. As shown in Fig.1(a)-(c), decreases in transmittance occurred at lower frequencies as the array width increased, so it is considered that an SPR-derived transmittance dip was observed. Q factor of the dip in each ribbon width (W = 32, 48,64 µm) was 2.27, 1.88, and 2.84 respectively. Especially for W = 64 µm, it is the world record among topological insulators or graphene in room temperature measurement below 1 THz, which is the suitable range for specific binding detection of biologically relevant molecules [2,3].

Finally, avidin-biotin binding and sugar chain-lectin binding detections were conducted. As for avidin-biotin detection, avidin/biotin mixture with biotin concentrations of 0, 0.1, 1, 5 10, 25, and 50 µM were prepared and each solution was dropped on a hydrophilic PVDF membrane. The membrane was dried and adhered to a Bi_2Se_3 micro ribbon structure with a width of W = 64 µm. Since the avidin concentration is 6.552 µM and four biotin molecules bind to one molecule of avidin, all binding should be completed at a biotin concentration of about 26 µM. Fig. 1 (d), (e) shows experimental setup and transmittance result. Fig. 1(f) shows that although the resonance frequency changes linearly when the biotin concentration is between 0.1 µM and 25 µM, the resonance frequency does not change above 25 µM, where binding saturation occurs. This suggests that the resonance frequency is affected by the oscillation of specific bonds. The same result was also seen in sugar chain-lectin detection. These results suggest that topological insulator-based THz-SPR can detect intermolecular specific binding.

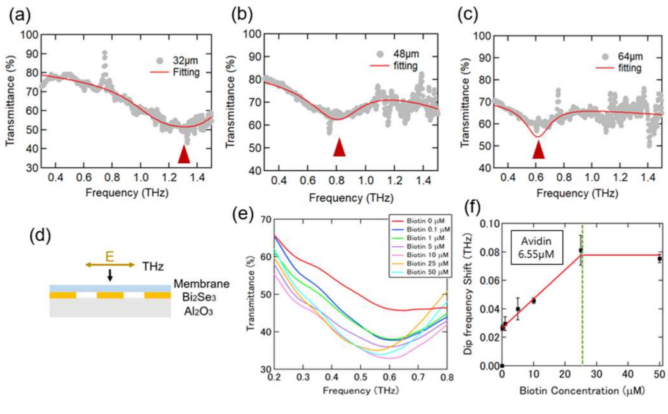

Figure 1. (a)-(c) THz transmittance of Bi_2Se_3 micro ribbon array. (d) Experimental setup of avidin-biotin binding detection. (e) THz transmittance of avidin-biotin solution and Bi_2Se_3 micro ribbon array. (f) Biotin concentration vs. dip frequency.

References

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