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Investigating Bi_2Se_3 Plasmons using Terahertz Near Field Spectroscopy

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Topological insulators (TIs) such as Bi_2Se_3 form topological surface states, which contain massless electrons that are confined in two dimensions. These electrons support surface plasmons, known as Dirac plasmons, with attractive properties for applications such as imaging and sensing owing to their robustness, surface confinement and sensitivity to refractive index changes. In proximity of the Bi_2Se_3 phonon line at ~1.9 THz, the plasmon excitation strongly couples to phonons. The spectral signature of this coupling has been observed in the far-field [1], [2], and very recently surface plasmons were imaged by the near-field using scattering near-field microscopy [3]. While the upper plasmon-phonon polariton branch was clearly observed, characteristics of the lower polariton branch are less certain. Here, we investigate Dirac plasmons in Bi_2Se_3 ribbons using aperture-type near-field microscopy. This technique is sensitive to THz plasmons and it enables spectroscopic (THz-TDS) analysis [4]. By placing an aperture probe in the near-field zone of the sample, the evanescent fields on the sample surface can couple through the aperture to be detected [4] (Fig. 1a inset). These field components decay exponentially away from the sample surface and are thereby lost in far field measurements. In addition, the aperture isolates the field and a sub-wavelength sized region, blocking background radiation which may reduce the contrast of the measurement.

We compare spectra recorded on Bi_2Se_3 ribbon gratings samples both in the far-field and in the near-field regions. Individual ribbons in the grating arrays have widths ranging from 12 – 40 μm, designed to support plasmons in the 0.5 – 2 THz spectral range. In both the near and far-field we observe the signatures of strong coupling between surface plasmons and the optical phonons (Fig. 1a). We map the dispersion relationship near the Bi_2Se_3 phonon line at ~1.9 THz using ribbons of different periodicity and find that the dispersion agrees well with theoretical predications confirming the surface nature of Dirac plasmons (Fig. 1b). We find a clear signature of the upper polariton branch in near-field measurements. In contrast, the lower polariton branch is practically undetected by the near-field aperture probe when it is positioned within ~5-10 μm to the sample surface, even though a broad band develops at the predicted lower polariton frequency.

These results show the potential as well as reveal difficulties in investigations of massless Dirac plasmons using THz time domain spectroscopy and aperture-type near-field techniques. Yet, the results provide unique data for experimental verification of theoretical Dirac plasmon dispersion in thin-film Bi_2Se_3 ribbon gratings.

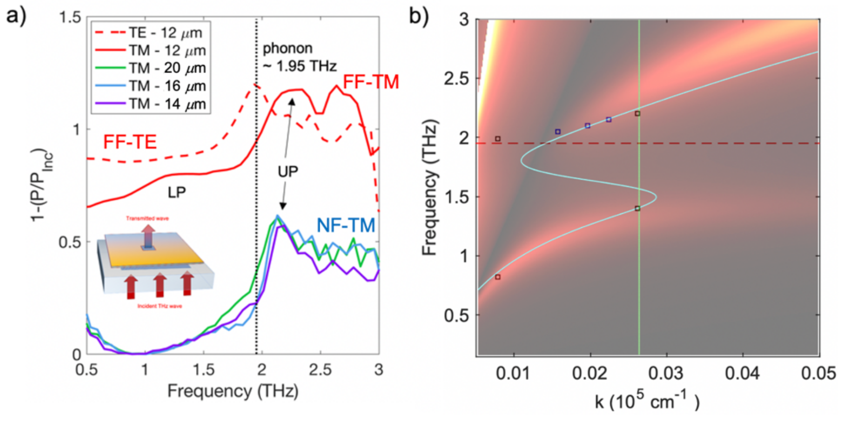

Fig. 1(a) THz spectra of Bi_2Se_3 ribbons: far-field measurements on 12 μm-width Bi_2Se_3 ribbon grating in TE and TM polarizations (red) and near-field measurements on gratings with ribbon widths 14 μm (purple), 16 μm (blue) and 20 μm (blue) in the TM polarisation. Inset: schematic diagram of aperture-type near-field measurement of BiSe grating sample. . (b) Calculated dispersion relationship of Dirac plasmon polariton with experimentally measured UP and LP branch frequencies overlayed. Measurements are taken from both far-field and near-field data.

References

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