Detection of Dark Plasmon Modes of a Single Gold Rod by Radially Polarized Terahertz Pulses

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1. Introduction

Radial beams have radially symmetric polarization distribution and generate longitudinal electric fields oscillating along the propagation direction at the focal point [1]. This characteristic electric field distribution can couple with modes that are difficult to couple with uniformly linearly polarized light, such as dipole-forbidden dark modes of plasmon resonance, and has been used for their excitation and detection [2, 3]. However, in previous reports, the optical response caused by the interaction between radial beams and matter has been observed through the detection of intensity of the light, which makes it difficult to separate the response of the longitudinal electric field from that of the transverse electric field. If direct observation of longitudinal electric fields of radial beams is performed with terahertz time-domain spectroscopy (THz-TDS) using broadband terahertz radial beams, it may be possible to selectively observe the optical response of dark modes as changes in the longitudinal electric field component [4]. In this study, we demonstrate the detection of dipole-forbidden modes by longitudinal electric fields.

2. Results

We performed THz-TDS measurement using terahertz radial beams. Figure (a) illustrates a schematic of the experimental configuration. A gold rod was placed at the first focal point of the confocal system in which terahertz radial beams generated using a half waveplate mode converter and a nonlinear crystal with threefold rotational symmetry [5]. The longitudinal electric fields at the second focal point were measured with electro-optic (EO) sampling using a (100) ZnTe crystal to investigate the changes brought by the interaction between the rod and the beams. Experiments with linearly polarized beams was also carried out for comparison, in which transverse electric fields were measured.

Figure (b) shows the experimental results for a rod of 1010 μm length and 100 μm diameter. These spectra show the relative electric field amplitude, the electric fields measured with the rod divided by the electric fields measured without the rod. When linearly polarized beams were irradiated, dips were observed only at the frequencies of the bright mode (0.38, 0.68, 0.96 and 1.24 THz), whereas when radial beams were irradiated, dips were also observed at the frequencies of the dark mode (0.50, 0.76, 1.07 and 1.38 THz), which cannot be excited by waves with uniform linear polarization. This shows that the dark modes can be excited by radial beams and detected by observing the longitudinal electric fields after propagation. Our results demonstrate that the electric field distribution generated by focusing radial beams is able to achieve non-contact excitation and detection of the dipole-forbidden modes. This technique has the potential to realize non-contact detection of plasmon modes, including non-radiant modes used for sensing and other applications.

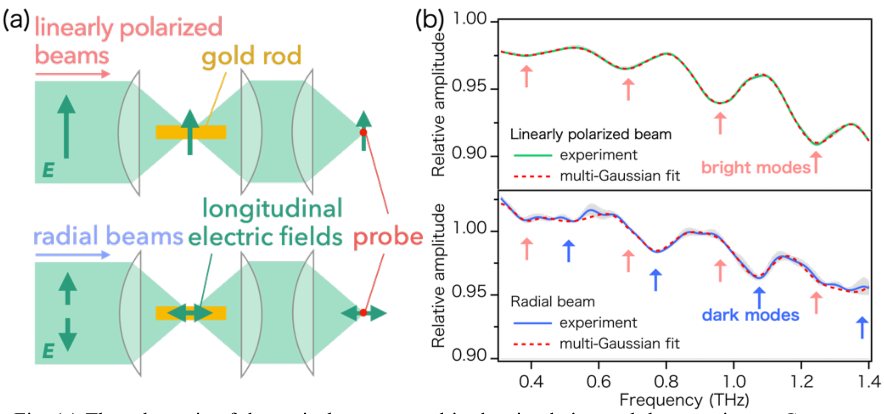

Fig. (a) The schematic of the optical system used in the simulation and the experiment. Green arrows indicate the direction of the polarization. (b) The relative electric field intensity, shown with the error width. Blue (Red) arrows indicate the frequencies corresponding to dark (bright) modes of the rod.

3. References

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