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Terahertz Near-Field Imaging of Subwavelength One-dimensional Plasmonic Structures

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Abstract: We have developed a terahertz near-field imaging system detecting both amplitude and phase of the electric field spatiotemporally. Imaging one-dimensional slits on metal substrate reveals both propagating and surface-bound waves, strongly dependent on the frequency.

OCIS codes: (240. 6690) Surface waves; (180. 5810) Scanning microscopy; (300.6270) Far infrared spectroscopy

In recent years, with remarkable growth of the meta-materials research [1] spanning the entire frequency range from gigahertz all the way to the visible, spatiotemporally capturing electrodynamics of light has become a formidable yet unavoidable challenge. Using a method [2] to measure a THz near-field with sub-wavelength resolution in a THz time-domain imaging system (0.1-2.5 THz), we show real-time near-field measurements of the time evolution and frequency dependence of terahertz (THz) fields transmitted through near-perfectly conducting films with slits. Our field imaging reveals the plasmonic behavior of one-dimensional metamaterials in both time and space domain.

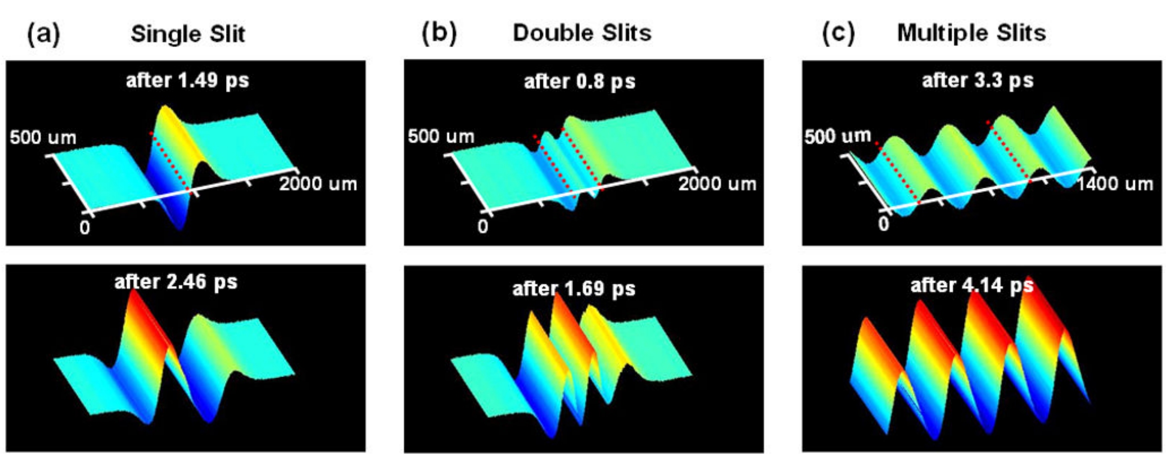

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Fig. 1. (a) Experimentally captured near-field images of the vertical (z-component) electric field at the surface of a single, (b) a double, and (c) multiple slit samples at two different times. Red dotted lines indicate slit positions, and the blue and red colors represent opposite phases.

We study one-dimensional structures with a single (slit width a=40 μm), double (slit width a=40 μm, separation s=400 μm), and multiple slits (slit width a=100 μm, separation s=500 μm) on aluminum, fabricated by femtosecond laser machining. Figure 1 shows one-dimensional cross sections of the z-component of the THz field, captured from time-domain movies for single (a), double (b), and multiple slits (c) at distinct times, which show the spatially varying phase of this component in the near-field.

Using the FFT method, the frequency-domain field distributions with multiple slits provide crucial evidence of surface-bound field as shown in Fig. 2(b). This surface-bound field can be thought of as the first-order diffraction, which is evanescent because the frequency is below the Rayleigh minimum at 0.6 THz. At a larger frequency of 0.996 THz, the Fourier-transformed images are dominated by the interference between the 0^{th} and 1^{st} order diffractions, as can be explicitly visualized in Figs. 2(c). We have shown that any frequency component over the broad terahertz spectral range can be imaged with full information on amplitude and phase.

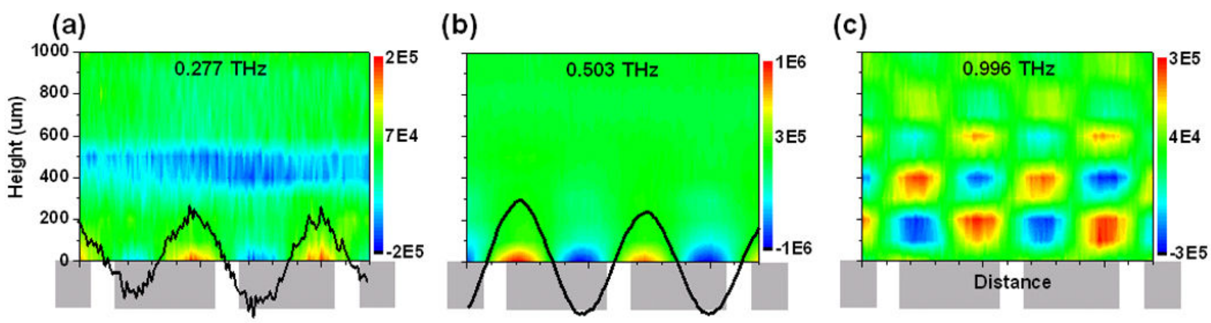

Fig. 2. (a) Height dependent near-field images for multiple slits at 0.277 THz, (b) 0.503 THz, and (c) 0.996 THz. Blue and red color represent opposite phases and black line denotes the cross sectional field distribution only at the surface of the slits.

Our measurements provide valuable insight into electromagnetic phenomena in real time and space, both in the near and the far-field regimes.

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