Miniature terahertz waveguides and the molecular sensing application in a micro-fluidic channel

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1. Introduction

Various waveguides have been developed in terahertz (THz) frequency region and well adopted as artificial photonic media in a time-domain-spectroscopic system for sensing the molecules. The dielectric materials of THz waveguides are too bulky to be used in a microfluidic channel because the corresponding modal field requires a sufficiently large length to work [1]. The THz Zenneck surface wave, i.e., THz surface plasmon, can be easily excited as the waveguide mode on a metal sheet, but the waveguide field is apparently delocalized from the metal medium [2]. THz surface plasmon thus have very low field strength or very low sensitivity to interact analytes in the microfluidic channels. Several solutions have been presented to control THz waveguide field confinement on the metal surface, including the THz spoof surface plasmon polaritons (THz-SSPPs) [3], and metal-tapered configurations of parallel-plate waveguides (PPWGs) [4]. The THz metal waveguides are more compact than that of the dielectric ones, but their waveguide mode sizes should be controlled by bulk assemblies, which also cannot be integrated with a microfluidic channel. In the presentation, one miniature THz waveguide is developed based on the metal-rod-array (MRA) structure and the molecular sensing application is experimentally realized with directly inserting MRA inside the microfluidic channel, where the array size is 3×12 and the waveguide length is only 1.4 mm, corresponding 1~2 λ.

2. Waveguide configuration and principle

A metal-rod-array (MRA) construction is presented as the solution of THz miniature waveguide, including the transverse-magnetic (TM) and transverse-electric (TE) modes. Figures 1(a) and 1(b) show the top view for the field orientation of TE and TM modes among the metal rods, respectively. The waveguide configuration with the geometry and the microscope photograph of MRA are illustrated in Fig. 1(c). The metal-rod diameter is fixed as 0.16 mm and the interspace can be modified to realize the modal field optimization, including the waveguide coupling efficiency, field strength and location along the rod axis. The research results show TE waveguide modes are more compact than those of TM modes because of their different waveguide principles. For TE modes, THz waves interacting the X-axial interspace perform spectral peaks based on the equation, $\lambda_c=2nd/m$, where λ_c, n, d, and m are, respectively, a resonance wavelength, an effective refractive index of waveguide, and a resonance mode number. For three-layer MRA propagation, strong waveguide dispersion with detectable transmittance is found in the experiment. Based on the observation of the electric-field oscillation through a microfluidic channel, the phase values of MRA-guided THz waves are obviously enhanced at the 2nd TE waveguide mode (0.4–0.5 THz), contrast to those of THz waves along the blank microfluidic channel.

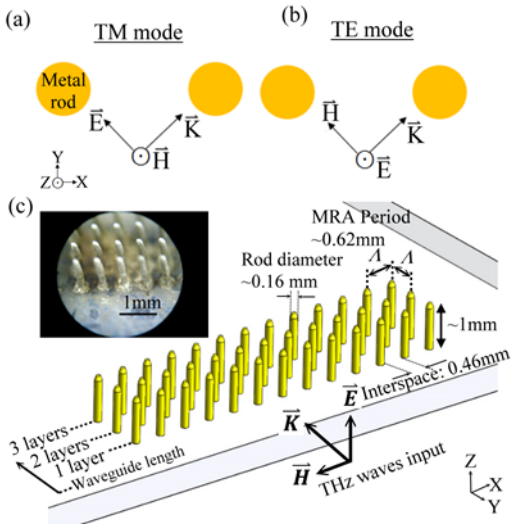

Fig. 1 THz field orientation of (a) TM and (b) TE waveguide modes. (c) Miniature waveguide based on an MRA. (Inset) Microscopic photograph of the MRA.

3. Microfluidic sensing results

Based on the phase enhancement of the 2nd TE mode, three kinds of colorless liquid analytes, namely, acetone, methanol, and ethanol, with different dipole moments are identified *in situ* using the MRA-based microfluidic sensor. The detection limit in molecular amounts of a liquid analyte is experimentally demonstrated to be less than 0.1 mmol, corresponding to 2.7 μmol/mm^2. The phase sensitive MRA-based sensor potentially has good adaptability in lab-chip technology for various practical applications, such as industrial toxic fluid detection and medical breath inspection.

References

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