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Meta-Atom Photonic Sensor for THz Detection of Organic Molecules

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The terahertz (THz) spectrum is a highly promising yet one of the least exploited regions of the electromagnetic spectrum, offering spectroscopically rich interactions with materials [1], and strong potential for sensing [2] applications due to its low photon energy, high penetration capability, nondestructive inspection properties. However, the long wavelengths of THz radiation, typically ranging from millimeters to tens of micrometers (0.1–10 THz), fundamentally limit the sensitivity of conventional sensors for detecting small or subwavelength molecules. This limitation has hindered the development of highly sensitive and compact THz functional sensing devices. Understanding and controlling interaction at the subwavelength scale is therefore a key requirement for advancing THz sensing technologies. Metasurfaces, a artifically structured media that are composed of an array of artificial meta-atoms, where each individual meta-atom is capable of confining EM fields to deep subwavelength light–matter volumes, achieving extreme field enhancement [3]. In this work, we demonstrated a photonic sensing platform based on a single planar meta-atom composed of concentric disk- and ring-shaped elements patterned on a freestanding metal film for the THz detection of organic molecules. Coupling the meta-atom to a α-lactose monohydrate layer resulted in enhancment of the resonances amplitudes and significant redshift of the resonances frequencies from 0.35 THz and 0.80 THz to 0.26 THz and 0.53 THz, respectively. Furthermore, the characteristic absorption feature of lactose at 0.53 THz [4] produced a pronounced transmission dip at the second resonance, providing direct evidence of molecule-specific detection. These results demonstrate that the planar meta-atom can serve as a compact and highly sensitive THz sensor, offering a approach for the identification of small volumes of organic and biomolecules promising for future miniaturized THz spectroscopy applications.

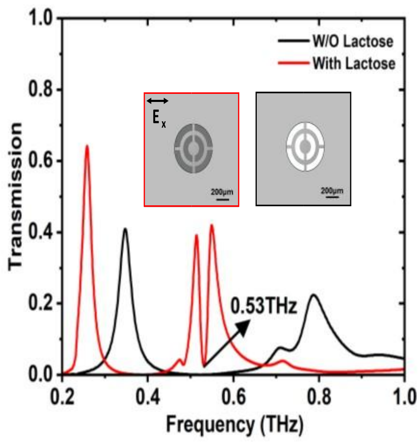

Fig. 1 Transmission spectra of a single planar meta-atom with (red) and without (black) a 60 μm αlactose monohydrate layer using FDTD simulations. Inset: schematics of the corresponding structures.

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