Mid-infrared surface phonon polaritons probed with scattering-type scanning near-field optical microscopy

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1. Introduction: Mid infrared (MIR) is a fingerprint region for spectroscopy and sensing of various materials including solid state materials, liquids, and gases. However, since the typical wavelength is in the order of micrometers, the interaction between MIR light and nanomaterials is inefficient due to the large difference in their scales. To enhance this interaction, a field concentration beyond the diffraction limit is needed. Surface phonon polaritons (SPhPs) enable the sub-diffraction field concentration with photonic nanostructures of polar semiconductors. In this study, we observed the MIR SPhPs excited in a phase change material deposited on SiC and their confinement with cavities. Scattering-type scanning near-field optical microscopy (s-SNOM) visualizes the distribution of the SPhP field with a high spatial resolution (~ 20 nm) [1] and verifies the SPhP confinement quantitatively.

2. Experimental setup: The s-SNOM setup is based on the AFM system combined with a MIR tunable quantum cascade laser (QCL) and a liquid-nitrogen-cooled photodetector as shown in Fig. 1(a). The laser light illuminated a metallized tip of the AFM cantilever. The scattering light from the tip, which is interfered with a reference light, is detected and demodulated for phase-sensitive detection and suppression of background signals. The scattering signal is proportional to the local field of the SPhP at a position of the tip. The structured gold film was fabricated on the 40-nm-thick phase change material film ($Ge_3Sb_2Te_6$, hereafter GST) deposited on a SiC substrate.

3. Results and discussion: Figure 1(b) shows the near-field maps at the vicinity of a gold edge with different excitation frequencies. The periodical bright fringes show the local fields of the SPhPs. The laser light illuminating the sample excites the SPhPs through light scattering at the gold edge while compensating the momentum mismatch between the laser light and the SPhPs [2]. The smallest wavelength of the SPhP (~500 nm) is around 1/20 of the free-light wavelength (~11 μm). As the excitation frequency increases, the SPhP wavelength becomes larger, which indicates the negative dispersion of the SPhP. These SPhPs with the small wavelengths originate from the slow-guided mode excited in the high-index GST film [3]. Furthermore, we achieved strong SPhP confinement by using metal hole cavities.

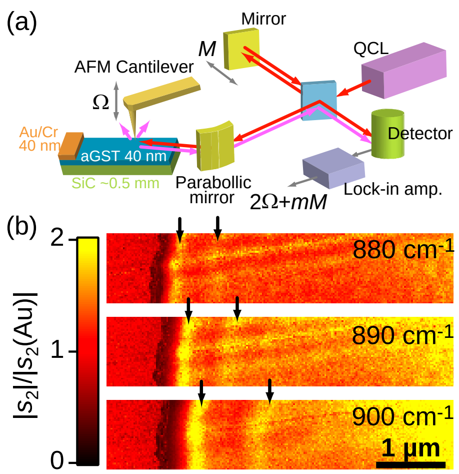

Figure 1 (a) Configuration of the s-SNOM setup. The scattering signal (pink arrows) is interfered with a reference light (red arrows). (b) Normalized near-field maps of the SPhPs excited at the gold edge with three different excitation frequencies.

Reference: [1] Hillenbrand et al., Nature **418**, 159 (2002). [2] Huber et al., Appl. Phys. Lett. **87**, 081103 (2005). [3] Li et al., Nat. Mater. **15**, 870 (2016).