Active Control of Surface Plasmons

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Motivation—Advances in mid-infrared (mid-IR, 3-12μm) sources and the growing field of mid-IR photonics make this wavelength range very attractive for plasmonics research. Although less work has been done in this range, meshes and periodic structures utilizing surface plasmons and designed for the mid-IR have been shown to have similar properties to structures in the visible. It has also been shown that chemical attachment to the mesh surface can enhance the sensitivity of molecular absorption measurements by several orders of magnitude. Beyond applications, the mid-IR is also an interesting regime for fundamental plasmonics research as propagation lengths can be orders of magnitude longer than in the near-IR/visible.

Background—Surface plasmons (SPs) are propogating waves tied to the interface between a metal and dielectric. The SP dispersion relation is

$$k_{sp} = \frac{\omega}{c}\sqrt{\frac{\varepsilon_s \varepsilon_m}{\varepsilon_s + \varepsilon_m}}\ , (1)$$

where k_{sp} is the SP wavevector and ε_s and ε_m are the relative permittivities of the dielectric material and the metal, respectively. When photons are incident on a metal surface that is corrugated or perforated with holes, the momentum conservation for coupling to light is

$$k_{sp} = k_{xphoton} \pm \frac{2\pi}{a_o} m, k_{xphoton} = k_{photon} \sin\theta\ , (2)$$

where a_o is the period of the surface modulation, and m is a mode index. The coupling of light to SPs can lead to interesting effects. For example, a lattice of holes in a metal film can exhibit *extraordinary transmission* that causes light in specific frequency bands to transmit through the films at much higher levels than expected.

Accomplishment—While working with tuning the mid-IR transmission properties of perforated metal films (square mesh on GaAs) we have found a condition for launching a long-range SP excitation. The transmission bandpass peak of the mesh is first split by rotating the sample slightly (eq. 2). This splitting can be seen in Fig. 1a as the red trace. A 9.7 μm laser is then focused to a 50 μm spot size and the light transmitted through the mesh is spatially resolved. This is seen as the bright spot in Fig. 1a,b positioned at x=0.

The dielectric constant of the mesh substrate was tuned through heating the sample. In comparing the red traces in Fig 1a and Fig 1b, one can see a distinct shift in the bandpass spectral position (from about 1020 cm^{-1} to 1005 cm^{-1}). The striking feature in Fig. 1b is that the laser, which was propagating through the sample (out of the page) now has a tail streaking off to the left, the expected direction for SP propagation. The key result here is, with very little dielectric tuning (only a 15cm^{-1} shift in the bandpass), we are able to switch light from a transmitting mode, to a laterally propagating SP mode tied to the metal surface. As shown in Fig. 1c, the decay length for the mid-IR excitation we observed is 384 μm. This is in agreement with theory and significantly longer than propagation lengths in the near-IR (few μms).

Significance—The ability to control and direct light on chip opens up many possible applications, such as circuits that use light to transmit information as opposed to electrons. Our result is one step towards this realization and demonstrates that the mid-IR is a valuable spectral range for plasmonics research.

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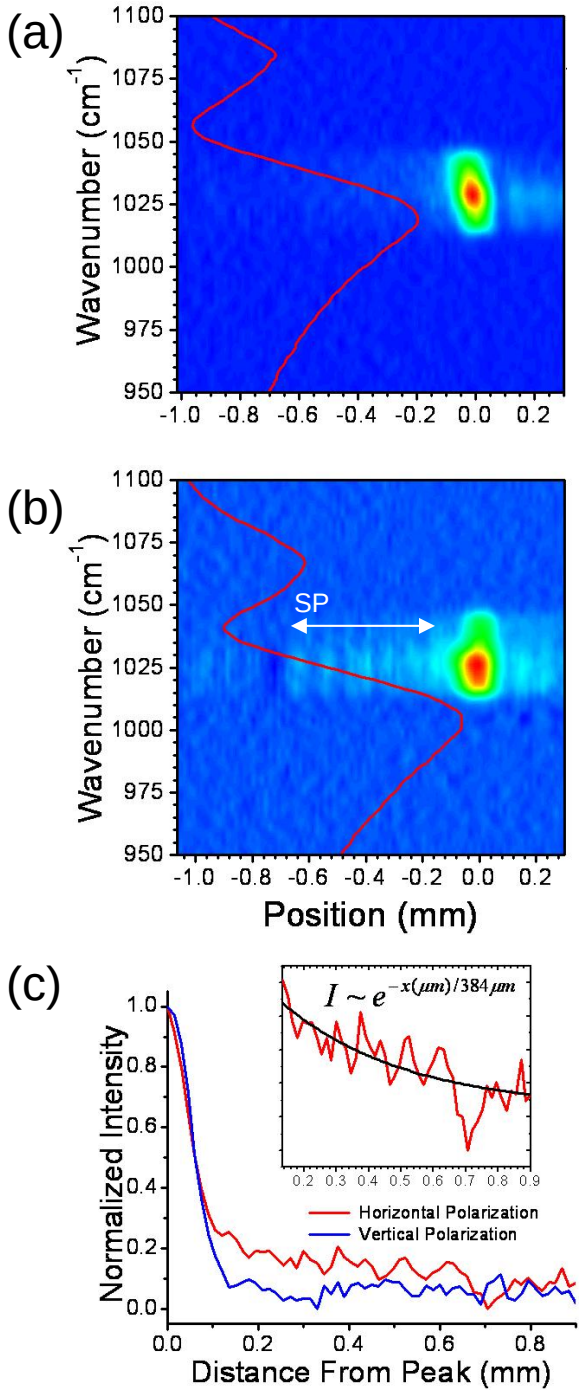

Figure 1: Spatially resolved laser excitation of a surface plasmon on a perforated metal film. The metal film on GaAs is 60nm thick and patterned with 1.4 μm holes spaced by 2.8 μm. The red trace in (a) and (b) shows the bandpass transmission characteristics of the mesh. In (a), the sample is at room temperature, while in (b), the sample is heated to 235°C in order to temperature tune the GaAs dielectric constant and shift the bandpass structure. When the 9.7 μm laser (bright spot in a,b) aligns with the bandpass peak in (a), it simply transmits through the sample. However, when it lines up on the falling edge of the bandpass, in (b), it launches a surface plasmon wave that propagates laterally on the sample surface. In (c) a comparison is made between vertically polarized light, which does not excite a surface plasmon in this geometry, and the horizontally polarized light, which does. An exponential fit was used to determine a surface plasmon decay length of 384 μm.