Focusing surface plasmon polaritons through a disordered array of nanoholes in thin metal film

Eunsung Seo¹, Joonmo Ahn², Wonjun Choi¹, Hakjoon Lee¹, Young Min Jhon², Sanghoon Lee¹ and Wonshik Choi¹

¹Department of Physics, Korea University, Seoul 136-701, Korea
²Sensor System Research Center, Korea Institute of Science and Technology, Seoul 136-791, Korea
*E-mail: wonshik@korea.ac.kr

Abstract
Control of near-field waves is the key to going beyond the diffraction limit. Here we present the focusing of plasmonic waves, a type of near-field waves, by the wavefront shaping of far-field waves. We coupled far-field illumination to a disordered nanoholes on a thin gold film to generate speckled plasmonic waves. By controlling the phase pattern of the incident waves at the excitation wavelength of 637 nm, we demonstrated the focusing of surface plasmon polaritons (SPPs) down to 170 nm at arbitrary positions. Our study shows the possibility of using disordered nanoholes as a plasmonic lens with high flexibility in the far-field control.

Experimental setup
We constructed an experimental setup (Fig. 1) in which the wavefront shaping of an incident wave was incorporated into the near-field scanning optical microscope (NSOM). The output beam from a laser illuminated a digital micromirror device (DMD), which shaped the phase pattern of the laser beam.

![Diagram of experimental setup](image)

Fig. 1. Experimental setup. HWP: half wave plate, DMD: digital micromirror device. L₁–L₄: lenses with focal length of 500, 100, 200 and 200 mm, respectively. P₁: aperture allowing for the first-order diffraction by the DMD. P₂: 50 μm-diameter pinhole conjugate to the NSOM aperture. TL: tube lens. OL₁–OL₂: objective lens, 40x, 0.6 NA. OL₃: objective lens, 10x, 0.28 NA. BS: beamsplitter. PMT: photomultiplier tube (Hamamatsu H8259-01).
We generated a binary grating pattern in each group and chose the first-order diffracted wave using a pinhole (P1). By shifting the grating pattern, we controlled the phase of the reflected wave for each group.

The reflected wave from the DMD was reduced in size by an objective in the microscope, which then illuminated the sample from the bottom. The overall magnification from the DMD to the sample was 1/1000; in other words, each group on the DMD corresponded to 300 × 300 nm² on the sample.

**NSOM Images of focused surface plasmons**

We put the NSOM aperture near the center in Fig. 2(a) and controlled the phase pattern of an incident wave using the DMD in such a way to maximize the signal detected at the PMT.

We controlled the phase of far-field illumination by using feedback iteration. As can be seen in Fig. 2(b), a strong spot appeared at the target point where optimization was performed, confirming that the final phase map lead to the increase in the intensity of SPP waves at the target point. Figure 2(c) shows the signal intensity detected at the PMT with the increase of iteration number. We observed about 30 times increase in the intensity after 2,000 iterations. Figure 2(d) shows the phase map after completing the iterations.

**References**