FABRICATION OF LARGE ARRAYS OF ORDERED 3D NANOCUPS FOR PLASMONIC APPLICATIONS

Joanne C. Lo[1,2], Richard J. Anderson[1], David A. Horsley[2], and Jack L. Skinner[1]
[1]Sandia National Laboratories, Livermore, CA; [2]University of California, Davis, CA

Here we present a novel method for fabricating large, ordered arrays of 3D nanocups for plasmonic applications (Fig. 1). Previously, it has been demonstrated that nanocups provide a unique method for bending scattered light by creating “magnetic plasmon” responses in optical frequencies [1]. This light bending property can be further enhanced by placing nanocups in an ordered array [2]. However, creating large, ordered arrays of nanocups has remained a significant challenge [1]. Here we have overcome this limitation by constructing a large (0.5 cm X 1.0 cm), ordered array of nanocups via nanoimprint lithography (NIL), soft lithography, and shadow evaporation. The array of nanocups have interparticle spacing that allows coupling between grating diffraction and localized surface plasmons to achieve large electromagnetic field enhancements [2]. This methodology enables high user control over the shapes and optical properties of asymmetric nanocups, and bypasses the limitations associated with the structure of nanospheres. For plasmonic-based applications, such as ultra-efficient solar cells and optical cloaking, our 3D light-bending nanocup array offers a novel technique for achieving high control over the plasmonic response.

Figure 2 illustrates the fabrication process of the gold nanocups. The NIL master was fabricated via interference lithography, and a copy of the master was made with NIL. A composite polydimethylsiloxane (PDMS) stamp was used to replicate the NIL nanopatterns. First, a layer of hard PDMS (h-PDMS) was first spin-coated onto the NIL template and then partially cured. Next, a layer of soft PDMS (s-PDMS) was spin-coated on top of the h-PDMS layer and cured for 120 min. To prevent the collapse of the nanopillars, the composite stamp was supported with a glass slide. The array of nanocups was fabricated by shadow evaporating 20 nm of gold onto the PDMS nanopillars at a 10° angle while rotating the stamp, creating nanocups on the tips of the pillars. Figure 3 shows the silicon NIL master template and the fabricated PDMS nanopillar array.

Figure 4 shows the optical response of the nanocup array. Extinction measurements of PDMS nanopillars with nanocups were measured using an Ocean Optics QE65000-FL spectrometer. As shown, even though the magnitude of the response varied, the peak extinction wavelength did not shift as the incident angle varied. Rather, the peak wavelength remained at approximately 700 nm for each incident angle. This demonstrates that the far-field scattering pattern of light transmitted through the nanocups depends only on the direction of the nanocups, not on the direction of the incident light. This phenomenon is shown conceptually in Figure 1. Thus, our methodology for constructing large, ordered arrays of 3D nanocups offers a promising technique for redirecting light in plasmonics applications.

REFERENCES:

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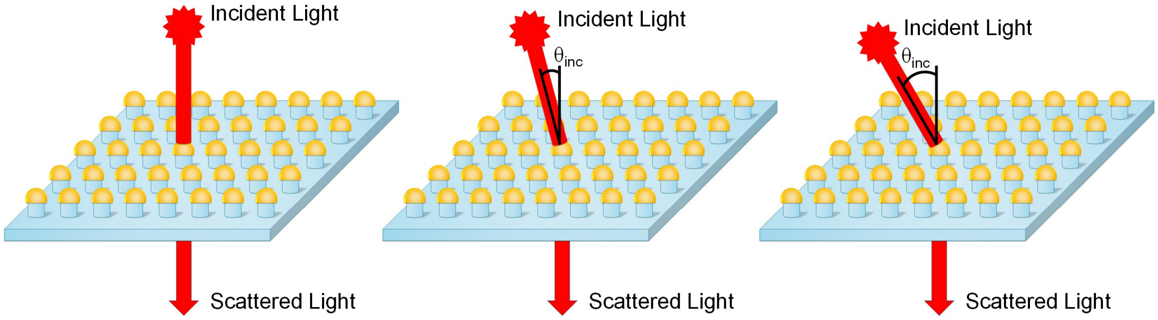

Figure 1. Conceptual illustrations of the light-bending property of the large array of ordered nanocups. Regardless of the angle of incidence (θ_{inc}), the nanocups redirect scattered light to the direction that the cups are facing.

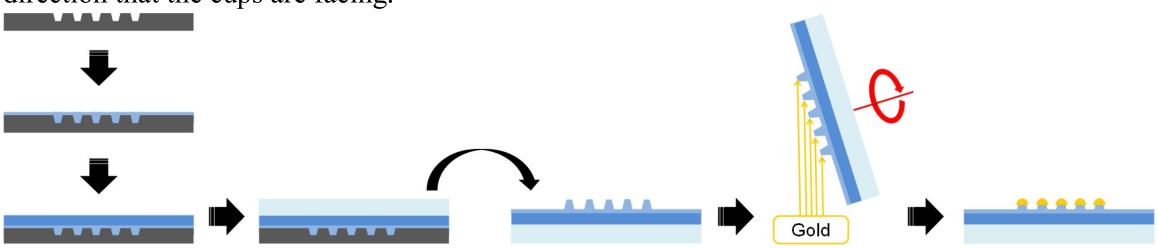

Figure 2. Fabrication process for the gold nanocups. A composite stamp was used to create nanopillars from the NIL master: (i) the NIL master was coated with a layer of h-PDMS, (ii) a layer of s-PDMS was then spun-on top of the h-PDMS, and (iii) glass was bonded to the s-PDMS. The nanocups were fabricated by shadow evaporating gold onto the nanopillars at a 10° angle while rotating the substrate (*red line*).

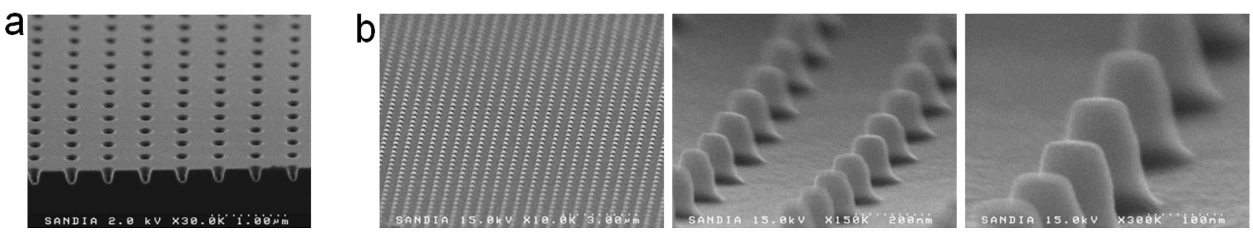

Figure 3. Fabrication results. (**a**) NIL master and (**b**) the nanopillars (90nm diameter, 120nm height, and 440nm pitch) fabricated from the master.

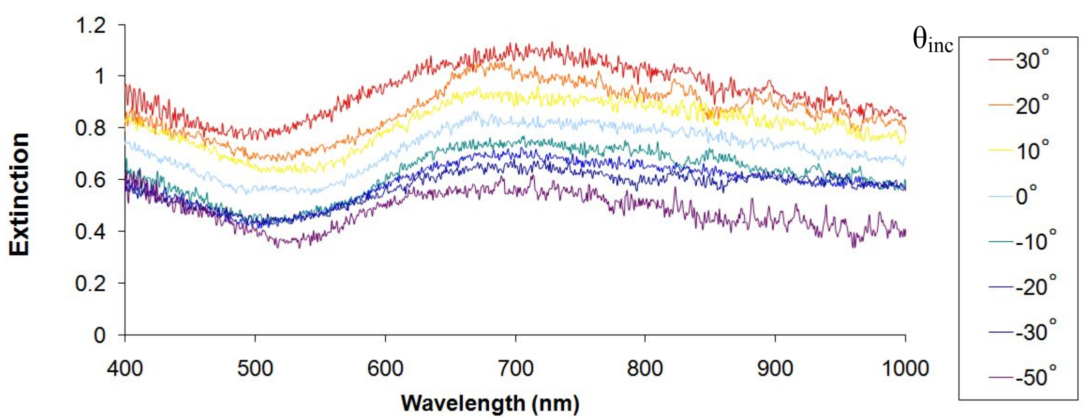

Figure 4. Experimental results. Extinction measurements are made at different incident angles for the nanocup array. The extinction spectrum exhibits angular independence.