Optical transmission properties of corrugated nanoscale hole arrays in thin gold films

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We present the characterization of short-range ordered hexagonal arrays of subwavelength holes in thin gold films. The hole arrays are fabricated by a low-cost technique using convectively self-assembled polystyrene beads as an initial pattern template. Our results suggest that corrugated, short-range ordered hole arrays allow the excitation of resonant surface plasmons. This opens the door to inexpensive, large-scale and high throughput fabrication of nanophotonic devices.

The investigation of sub-wavelength hole arrays in thin metal films has been of significant interest since the publication on extraordinary optical transmission (EOT) by Ebbesen *et al*. in 1998 [1]. Applications of EOT include enhanced performance of optical sensors, new types of optical switches and filters [2,3,4]. Focused ion-beam milling (FIB) is the technique commonly employed for the fabrication of hole arrays when studying how array parameters influence their optical properties. FIB, although versatile, has the intrinsic disadvantage of being a slow, linear and expensive technique. In contrast to this, the hole arrays presented here were fabricated using an upscalable, low-cost method. Despite the long-range disorder and corrugated shape of the arrays, we can, with surprising accuracy, excite surface plasmon polaritons at wavelengths observed for long-range order systems.

The hole arrays (Figure 1) are fabricated by a combination of nanosphere lithography [5] using convectively self-assembled polystyrene beads ($Ø_{Beads}$ 508 nm) [6] and Ar plasma etching. 300 nm thick Au films on borosilicate glass serve as a base substrate. The pitch *p* of the fabricated hole arrays is ~510 nm. The holes have tapered sidewalls (c.f. insets in Figure 1) and an increased roughness after etching. The samples were subject to different etch times, yielding arrays with different fill factors *ff* (area of holes/unit cell) of 10% (A) and 22% (B), and an average gold film thickness of 290 nm (A) and 215 nm (B). Note that the tapered sidewalls were not taken into account when calculating *ff*. Doing so would result in a larger effective hole diameter, and thus larger *ff*.

The surface plasmon (SP) wavevector $k_{sp} = 2\pi/\lambda_{sp}$ is excited when its momentum is matched to that of the incident photons combined with the array momentum [1]. The array momentum is obtained from its reciprocal lattice vector, and this leads to a direct relation between λ_{sp} and *p*. Figure 2 shows the transmission spectra for arrays A and B obtained under low illumination N.A. and a collection N.A. of 0.65. Each array was measured at three different locations. I/I_0 is the absolute transmission, η is the transmission normalized by the *ff*. Both arrays show a modulation of the transmitted light, but their transmissions differ in intensity and peak wavelength. It should be noted that, despite the long-range disorder, the spectra taken at three different locations vary only slightly. The first order resonance at the gold/air interface (Au/Air (1,0)) is centered at λ = 565 nm for A, whilst for B shows a clear peak at λ = 550 nm. The first order resonance at the gold/glass interface (Au/Glass (1,0)) has its maximum at λ = 765 nm for A, whereas for B, a rise of the transmission can be seen, but the peak itself is out of the measurement range. The difference between the theoretically predicted (λ_{sp} < 500 nm for Au/Air (1,0) and 700 nm for Au/Glass (1,0)) and measured transmission peaks is a phenomenon commonly observed for hole arrays [e.g. 7], and may be explained by a change in the effective refractive index of Au due to the *ff*.

We have shown that short-range ordered hole arrays fabricated by a low-cost technique with the potential for high throughput fabrication show similar optical properties as compared to structures fabricated by cost-intensive and low throughput FIB milling. A more critical analysis of the influence of degree of order of the array and cross-sectional shape on their optical properties is under way.

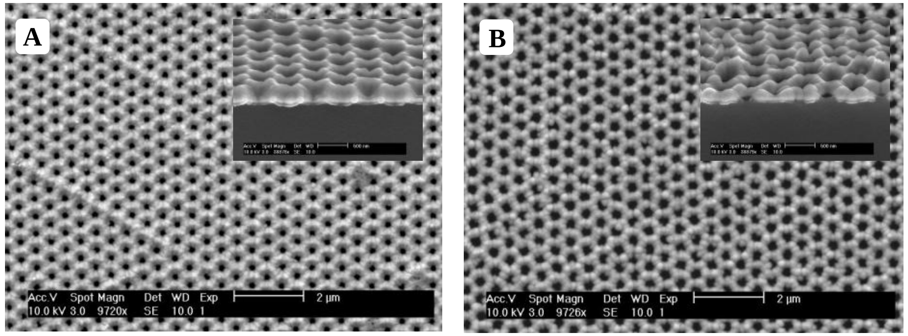

Figure 1. SEM micrographs of hole arrays in thin gold films on a glass substrate. A 20° angled view is shown in the insets. Both arrays were fabricated with the same initial PS bead template (Ø 508 nm). A and B were subject to different etch times. The fill factor is ca. 10% and 22% for A and B respectively. The average thickness of the gold layer after etching is 290 nm for A and 215 nm for B.

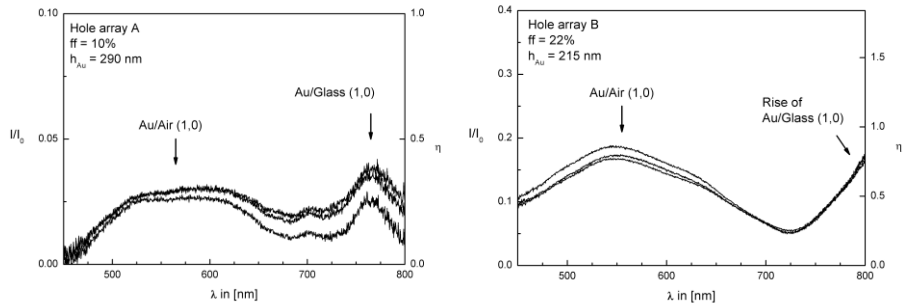

Figure 2. Transmission spectra I/I_0 for hole array A (left) and B (right). Three different measurements were taken within vicinity of 1 mm for each array. η is the transmission normalized by the *ff*. The measured first-order SP resonances are indicated by vertical lines for each interface.

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