Numerical Investigation of Optical Behavior of Nano-hole Array with Non-vertical Sidewall Profile

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Transmission enhancement of light through nanoscale hole arrays in noble metal film has been an active research area back to 1998 when extraordinary optical transmission (EOT) phenomenon was observed by Ebbesen et. al[1]. Due to the limit of nanofabrication methods, the nano-hole array (NHA) always has a non-vertical sidewall profile, whose effect is somehow ignored so far in numerical studies. Here we investigated the effects of the tapered angle on the transmission of light through non-vertical cylindrical nano-hole array using finite difference time domain (FDTD) simulation. The NHAs were fabricated on the 100 nm optically thick gold film by electron beam lithography (EBL) followed by a double liftoff process[2,3].

Fig.1a shows the SEM micrograph of fabricated NHA with a hole depth and radius both of 100 nm, period of 500 nm, and measured taper angle of approximately 10^0. As it is clear from this figure the upper radius of the NHA is larger than the bottom one (called positive profile), which is due to lateral deposition of gold film during evaporation. In Fig.1b, the measured and FDTD calculated optical transmissions of fabricated structure are compared. As can be seen, there is an excellent agreement between the FDTD calculated optical transmission and the measured one. Other fabrication methods such as FIB milling will also result in significantly tapered profile due to re-deposition of sputtered material and milling by the tail of the Gaussian ion beam, and the taper angle increases with the ion beam spot size.

Fig.2 shows the FDTD calculated optical transmission of NHAs with positive and negative (upper radius of the NHA is smaller than the bottom one) profile at different tapered angle ranging between 0^o and 16^o. The (1,0) surface resonance mode positions were shifted towards larger and smaller wavelengths on increasing the tapered angle in NHAs with positive and negative profile, respectively. Note that negative profile typically results from the noble metal coating onto free-standing Si_3N_4 membrane patterned with etch-through nano-hole array, and like the lift off process, the taper angle depends on the lateral deposition rate relative to the vertical rate.

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2. A. Hajiaboli, B. Cui, M. Kahrizi, V. V. Truong, Phys. Status Solidi A **206**, 976, (2009).
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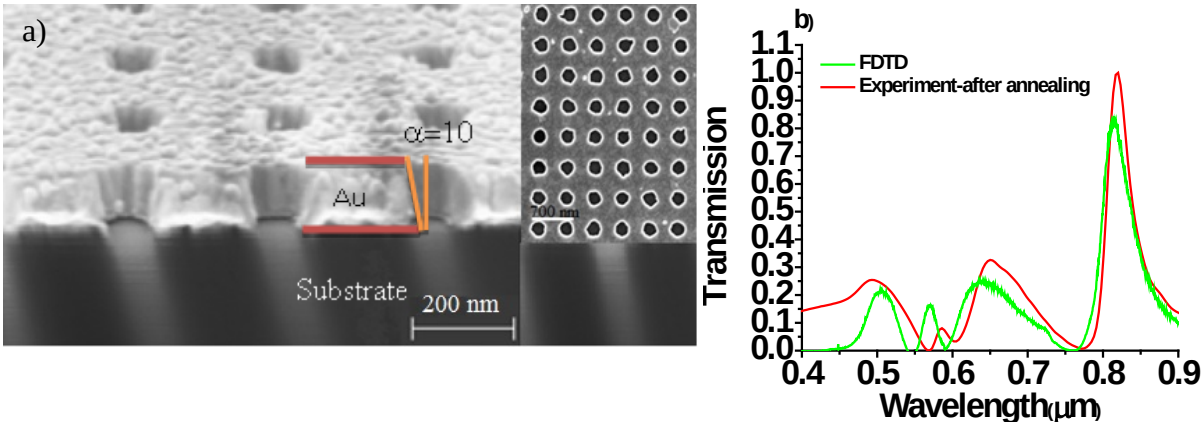

Fig.1. (a) SEM image of nano-hole array in 100 nm thick Au with positive tapered sidewall profile of taper angle of approximately10^0. (b) FDTD calculated and measured transmission spectra of nano-hole array with the hole depth and radius both of 100 nm, period of 500 nm, and tapered angle of 10^0.

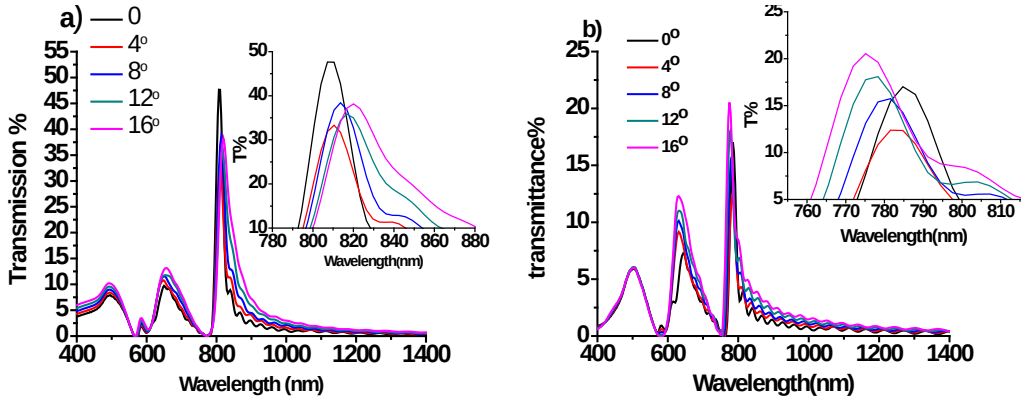

Fig.2. FDTD calculated optical transmission spectrum of (a) NHA with positive tapered profile, and (b) negative tapered profile at different tapered angles. The hole depth and radius are both 100 nm and periodicity 500 nm.