Theoretical study of the effects of substrate material refractive index on the optical transmission of nano-hole arrays

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Surface plasmon (SP) is collective oscillation of metal free electrons excited by incident electromagnetic field and confined in the metal surface. According to the SP resonance theory [1] for the nano-hole arrays (NHAs), the relative permittivity of the surrounding material strongly affects NHAs' resonance wavelength position and intensity. Though there have been a number of experimental and theoretical studies on free-standing and substrate-supported NHAs [2], the effect of using different substrate materials on the transmission properties is yet to be investigated.

The effects of varying of hole diameter in the range of 100 to 350 nm at different refractive index of the substrate on the optical transmittance spectra in NHA structure are compared in figure 1a. As can be seen from this figure, on increasing hole diameter, the optical transmission intensity was increased and maximum transmission of 40% was achieved at hole diameter of 350 nm. A red shift of 180 nm in the resonance peak position of the first transmission diffracted order at the film/substrate interface, $\lambda_{(1,0)}$, was observed on increasing the hole diameters as shown in figure 1b. The transmission intensity of the $\lambda_{(1,0)}$ SP mode was increased on increasing the refractive index from 1 to 1.3, and then decreased on further increasing the substrate index of refraction to 1.7 as is shown in figure 2a. The effects of different refractive indices in the range of 1 to 1.7 on the FWHM values of the $\lambda_{(1,0)}$ of SPR of the NHAs at different hole diameters are compared in figure 2b. As can be seen from this figure, the FWHM values of the $\lambda_{(1,0)}$ resonance peak were increased on increasing the hole diameter from 100 to 350 nm, whereas the FWHM values of the $\lambda_{(1,0)}$ of the SPR in a NHA of fixed hole diameter were decreased on increasing the refractive index from 1 to 1.7 and the maximum and the minimum FWHM for all hole diameters occurred when the NHAs were used with a substrate material of refractive index of 1 and 1.7 respectively.

In conclusion, it was found that transmission properties were strongly affected by the refractive index variation in NHAs. It was also found that, on increasing the index of refraction, the FWHM values were decreased. However, they were increased on increasing the hole diameter of the NHA and as a result, using supported medium of high index of refraction and smaller hole diameter in the perforated structure could increase the sensitivity of the NHA structure which is promising new approaches in sensing application.

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[1] S.A. Maier, Plasmonics: Fundamentals And Applications. Springer, 2007.
[2] L.Martín-Moreno ,F.J. García-Vidal ,H.J.Lezec, K.M.Pellerin,T.Thio,J.B.Pendry,T.W.Ebbesen, Physical Review Letters 86 (6):1114-1117 (2001)

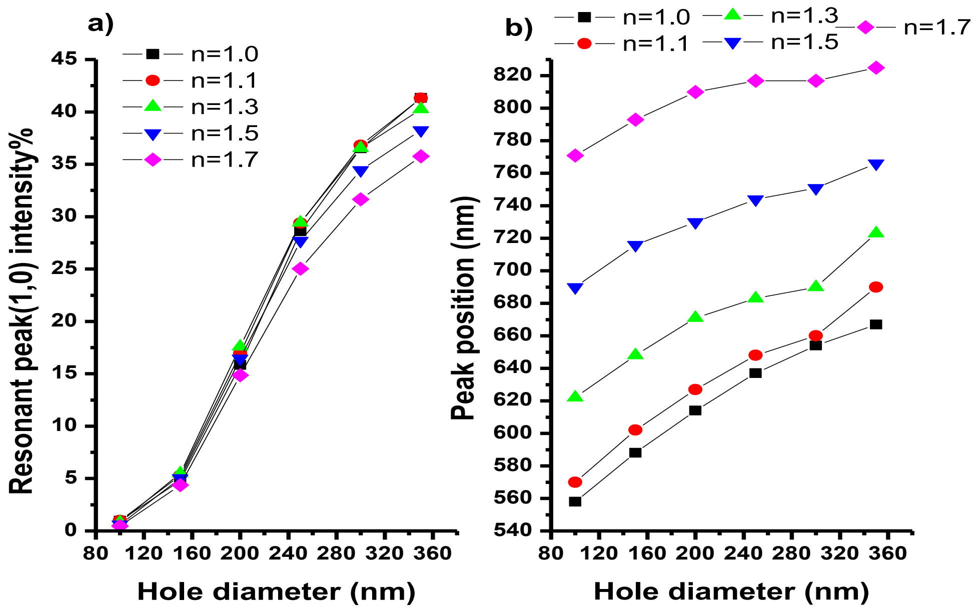

Figure 1: The effects of varying of hole diameter on the a) resonance intensity and b) resonance peak position of the nano-hole array supported with different materials. Hole depth is 100 nm and array periodicity is 400 nm.

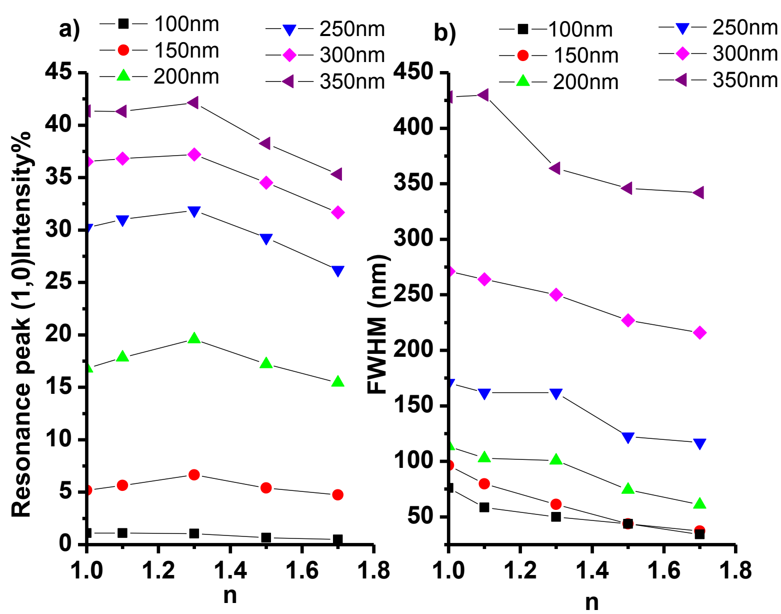

Figure 2: The effects of varying supporting material index of refraction on a) resonance peak intensity; and b) resonance line-width of the NHAs with different hole diameters. Hole depth is 100 nm and array periodicity is 400 nm.