Plasmonic Nanopillar Arrays for Enhanced Biosensing, Spectroscopy and Optical Trapping

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Nanoplasmonic structures have been used for ultrasensitive biosensors with high multiplexing characteristics [1], spectroscopy with high enhancement factors [2] and high nm-size precision optical tweezers [3]. However, most of these structures operate for single operations. Biosensors with refractive index sensitivity are lack of near field enhancement and spectroscopic structures with enhanced near field capabilities do not possess sharp reflection characteristics. Optical tweezers with high directional optical gradient force works under either no sharp resonance behavior or near field characteristics.

In this work, we proposed a structure which consists of arrays of gold nanopillars for biosensing, nanospectroscopy and optical trapping at the same time. Geometry of the structure is shown in Fig.1a. The SEM image of the structure is shown in Fig.1b. The structure shows two dips; the sharper and small ones correspond to the excitation of Au/Air(1,0) and Au/Air(1,1) modes respectively as shown in Fig.1c. The periodic structuring of the structure plays the dominant role in the resonant behavior of the structure. Fig.1d shows the shift in the resonance dip respect to solutions with different refractive indices, n. The refractive index sensitivity ($\Delta\lambda/\Delta n$) of the structure has been calculated as 675 nm/RIU. The Full-Width-Half-Maximum (FWHM) is 6 nm and preserved for different solutions. Figure of merit is calculated as 112.5. These values are higher than most of the nanoparticle and metamaterial biosensors. The structure operates under zero incident angle unlike most of the periodic nanorod structures designed for similar operations.

Fig.2a/b shows that the field focus at top surface of the nanopillar with 9000 times more intensity than the illumination source. This behavior is suitable for the vibrational spectroscopy applications. In addition to that, the near-field gradient provides enhanced optical force from the system. Fig.2c shows the 2D illustration of the nanopillar system with different beads (dielectric spheres with radius = 50 nm and refractive index, 1,5). All beads, center-to-center, 200 nm above the z direction. All beads are positioned at an arc with radius 200 nm. The strongest force is found for the bead located at (iii) at z-direction, 350 pN/W/μm^2 due to the direction of the propagation and polarization as shown in Fig.2d. The strongest force found for the bead located at the direction parallel to the direction of the polarization, in our case, x-polarized light results in a hot spot with highly enhanced field in the corner of the nanopillar. Hence, we can control the direction of the maximum force we can achieve from the system by changing the direction of the polarization.

In conclusion, we have proposed a gold nanopillar array system for biosensing, nanospectroscopy and optical trapping. Structure shows high refractive index sensitivity desirable for high-precision biosensing applications, high enhancement factor desirable for spectroscopy applications and high optical force depend on the polarization of the source.

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[2] V. Liberma et al, Adv. Mater **22,** 4298-4302 (2010).
[3] A. N. Grigorenko, N. W. Roberts, M. R. Dickinson and Y. Zhang, Nature **2,** 365-370 (2008).

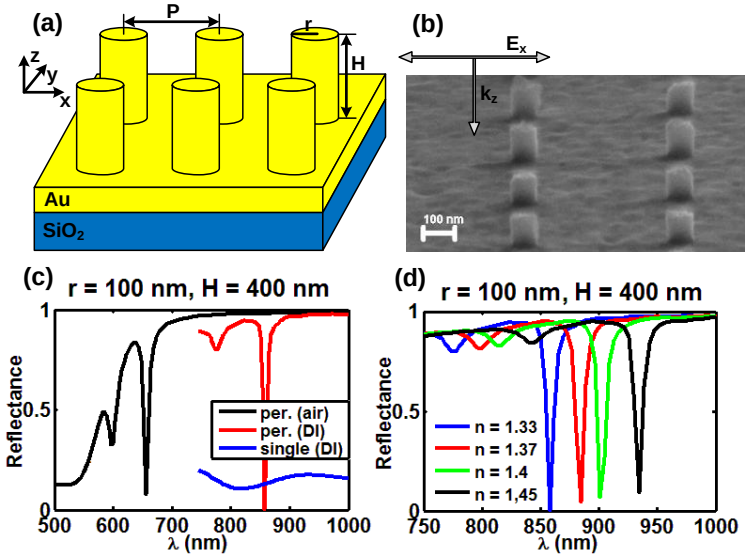

Fig. 1. (a) Geometry of the nanopillar arrays. (b) SEM image of the nanopillar array with r = 50 nm, H= 100 nm and P = 500 nm. The direction of the propagation and polarization of the illumination source is indicated in the figure. (c) The comparison of the free standing periodic system (r = 100 nm, H = 400 P = 600 nm) with the single and periodic nanopillar systems in DI water. (d) Nanopillar arrays embedded in solutions with different n for corresponding parameters, r = 100 nm, H = 400 nm and P = 600 nm

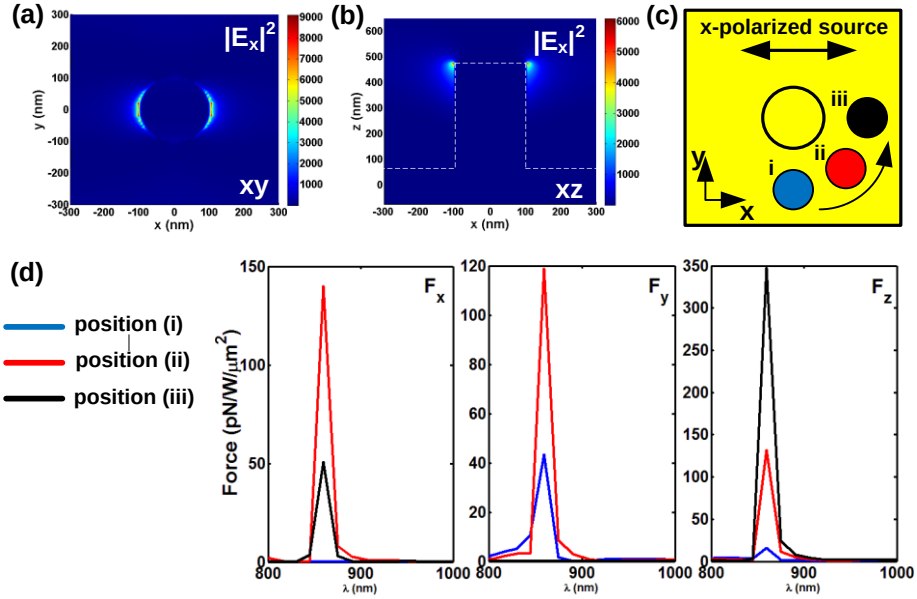

Fig. 2. Intensity distributions of the system embedded in DI water for the x-component of E-field for different cross-sections. The corresponding parameters are r = 100 nm, H = 400 nm and P = 600 nm. (a) xy-cross-section is determined at the top surface of the nanopillar. The position of the rod is indicated by white dashed line for (b) xz cross-section. (c) 2D-schematic view of the structure with three beads with n = 1.5 positioned differently inserted in DI-water. (d) x-, y- and z-components of the optical gradient force for three beads. The corresponding parameters are r = 100 nm, H = 400 nm and P = 600 nm.