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Original research article

Extraordinary optical transmission properties of a novel Bi-layered plasmonic nanostructure array

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A B S T R A C T

The optical transmission properties of a novel bi-layer plasmonic nanostructure array (BPNA), consisting of an array of gold nanoholes, glass and an array of gold nanodisks, was investigated by the finite element method. A well-defined localized surface plasmon (LSP) resonance peak appeared in the transmission spectra due to the coupling between the LSP of the metal nanoholes and the LSP of the nanodisks. The position and the intensity of the coupled LSP resonance peak depended strongly on the distance between the nanohole and the nanodisk arrays, the diameters of the arrays and the thickness of the nanohole or nanodisk arrays. The coupled LSP resonance peak exhibited a higher figure of merit compared to that for either the nanohole array or the nanodisk array. Results indicated that the bi-layer nanodevice was a highly sensitive detector for tunable plasmas, and should aid in better understanding of the mechanisms for extraordinary optical transmission phenomena.

1. Introduction

Extraordinary optical transmission (EOT) was observed by Ebbesen who first studied the optical transmission properties of a periodic sub-wavelength rectangular hole in a thin metal film and found that the light transmission rate was higher than the area ratio of the hole and the film when the aperture was smaller than the incident wavelength [1]. In addition, EOT also offers strongly localized field enhancements. Therefore, many applications are associated with EOT, including integrated optics [2], highly sensitive biological sensing and detection [3], surface-enhanced Raman scattering [4], and other nonlinear optical effects [5].

Theoretically, the EOT phenomenon originates from the coupling of incident light with surface plasma polaritons (SPPs) on a metal surface [6]. The underlying physical mechanism behind EOT has been explored by some researchers and more efficient sub-wavelength nanohole structures with higher transmittance have been reported [7–15]. For the sub-wavelength hole array within a metallic film, when the reciprocal lattice vector of the corresponding hole array period matches the momentum of the SPPs, strong electron oscillation results in excitation around the hole. The strong electron oscillation formed between the two sides of the hole results in a larger transmittance being funneled through the smaller aperture and propagates to the other side of the film. In addition, the localized surface plasmon (LSP) of the sub-wavelength hole also plays an important role in the EOT phenomenon [8,11,14,8–15]. For the metallic sub-wavelength particles, when the dimensions of the metallic sub-wavelength particles match the wavelength of the LSP excited on the metallic sub-wavelength particles, strong electron oscillations are excited around the metallic sub-wavelength particles [4]. The resulting strong electron oscillations then confine the energy on the surface of the metallic sub-wavelength particles forming a valley in the transmission spectra. To gain a better understanding of the contribution of SPPs and LSPs to the EOT

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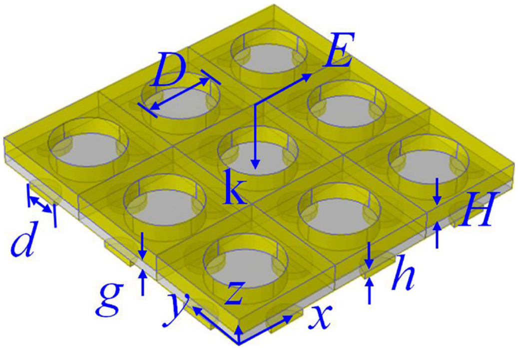

Fig. 1. The proposed bi-layer plasmonic nanostructure array consisting of gold nanohole arrays in film, glass and gold nanodisk arrays and the irradiation conditions.

phenomenon, researchers have altered the structural period parameters of the nanostructure and have fixed the shape and size of the hole [8]. Previous studies have shown the importance of both LSPs and SPPs for the EOT phenomenon, and for the situation when the LSP and the SPP exhibit a similar energy the nanostructure becomes conducive to transmission [16].

Recently, researchers investigated the optical transmission properties of nanoholes with circular [17], spheroidal [18] and triangular structures [14]. In our research group, the optical transmission properties of periodic X-shaped plasmonic nanohole arrays in a silver film are being investigated [19]. When the shapes of nanoholes or nanoparticles become more complex, novel transmission properties emerge [20–25]. Different nanostructures have been proposed to achieve highly sensitive and high figures of merit (FOMs) in plasmonic sensing [26]. The FOM has been defined and evaluated by Sherr et al. for sensing and comparing values for a variety of nanoparticle structures. However, such nanostructures are typically composed of single layer naonoholes or nanoparticles, but novel transmission properties and higher FOMs may be achieved in hybrid and more complex nanostructures.

To enhance nanodevice performance and sensitivity, the optical transmission properties of bi-layer plasmonic nanostructure

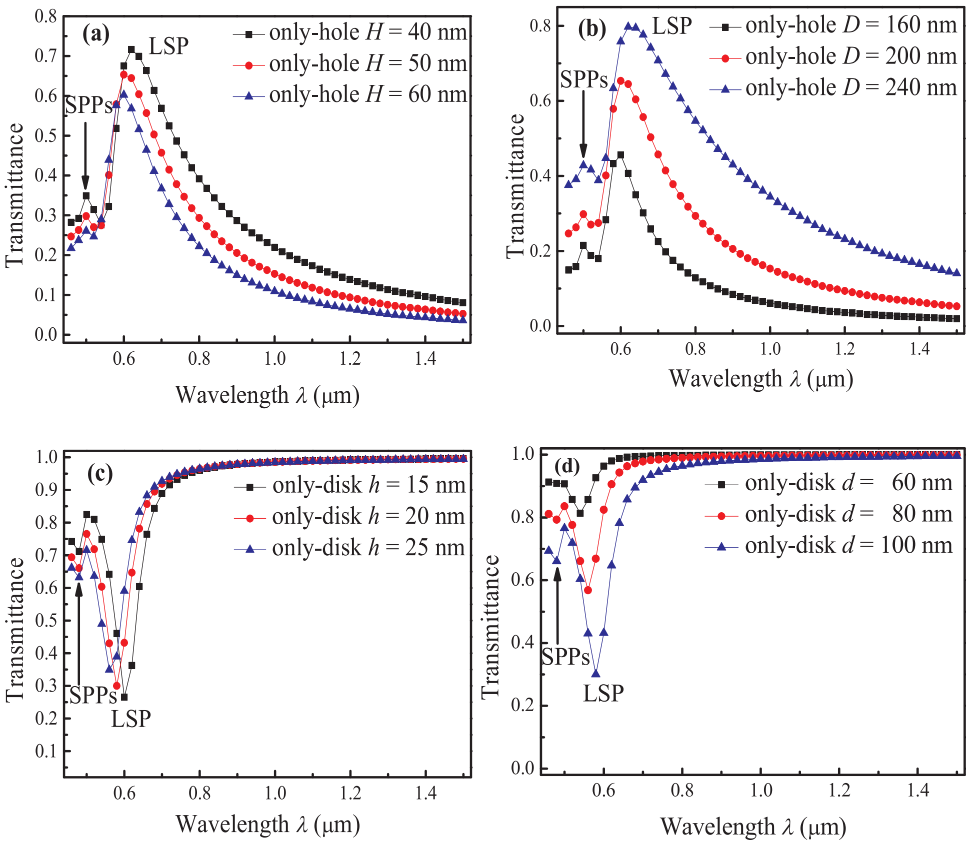

Fig. 2. Calculated transmission spectra of only hole or only disk for different heights and diameters, respectively. (For interpretation of the references to colour in the text, the reader is referred to the web version of this article.)