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Absorption enhancement in non-coplanar silver nanowire networks

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ABSTRACT

We propose non-coplanar silver nanowire (AgNW) networks placed on a SiO_2 layer. A notable absorption peak is observed in our proposed structure, and compared with the absorption of coplanar periodic AgNW networks and periodic AgNW gratings, the absorption performance of the non-coplanar AgNW networks demonstrates obvious advantages. It could be determined that the absorption ratio in this non-coplanar AgNW networks can reach 95%. In addition, several parameters that have important effects on the absorption of the non-coplanar AgNW networks are discussed in detail. Our research may provide guidance for the fundamental exploration of plasmonic absorption device applications.

1. Introduction

Surface plasmons (SPs) can be generated by metallic nanostructures under excitation of incident light [1]. In recent years, localized surface plasmon resonance (LSPR) [2] and surface plasmon polaritons (SPPs) [3], which are the two primaries research focuses of SPs, have been widely investigated. It was concluded that SPs can lead to certain abnormal optical behaviors in nanostructures, such as breaking through the diffraction limit of light [4,5], extraordinary optical transmission (EOT) [6–8], plasmon induced transparency (PIT) [9–15] and extremely sensitive sensing properties [16,17]. These behaviors are closely related to the shape, dimensions, and distribution of the nanostructures, as well as the surrounding dielectric environment. Thus, various types of structural models, such as a nanometallic particle [18,19] and nanowires [20–23], have been detailed within the literature, with both simulated and experimental results. In these structural models, nanowires (NW) with a small mode volume, localized resonant modes, and long photon life-times have enabled diverse optoelectronic applications. In particular, silver nanowire (AgNW) networks, which support both LSPR and SPPs, are emerging as promising substitutes for conventional transparent conductive oxide films. The optical properties of AgNW gratings and meshes freestanding in air [24], on glass [25], and on photovoltaic solar cells [26,27] have all been previously reported. The periodic subwavelength of the NW networks were also optimized for absorption in the metal NWs [21]; however, the absorption was still far less than our ideal effects. In addition, non-coplanar AgNW networks, which can effectively enhance absorption, have rarely been investigated.

In this paper, we study the absorption performance of unique, non-coplanar AgNW networks on glass. Comparing with the absorption of coplanar periodic AgNW networks and periodic AgNW gratings, the absorption performance of the non-coplanar AgNW networks demonstrates obvious advantages. The absorption ratio in this non-coplanar AgNW network can reach 95%. Our research may provide guidance for fundamental research on plasmonic absorption device applications.

2. Structure model and simulation method

Fig. 1(a) shows a periodic AgNW grating on the SiO_2 layer. Fig. 1(b) shows periodic AgNW networks on the SiO_2 layer. Fig. 1(b1) and 1(b2) shows the x-y view and x-z view of our proposed structure, respectively. And $w = 200$ nm is the thickness of the SiO_2, r is the radius of the AgNW, d is the distance between the two middle axes of the crossed AgNW, Px is the period of the AgNW at the direction of x, and Py is the period of the AgNW at the direction of y. The permittivity of silver is described by the Drude model $\varepsilon(\omega) = 3.7 - \omega_p^2/(\omega^2 + i\omega\gamma_p)$, with $\omega_p = 1.38 \times 10^{16}$ rad/s and $\gamma_p = 2.73 \times 10^{13}$ rad/s [28]. The permittivity of SiO_2 is obtained from the Handbook of Optical Constants in Solids Academic [29]. The absorption spectral responses of the structures are observed through the finite difference time domain (FDTD) method [30]. The spatial and temporal steps are set as $\triangle x = \triangle y = \triangle z = 1$ nm and $t = \triangle x/2c$ (c is

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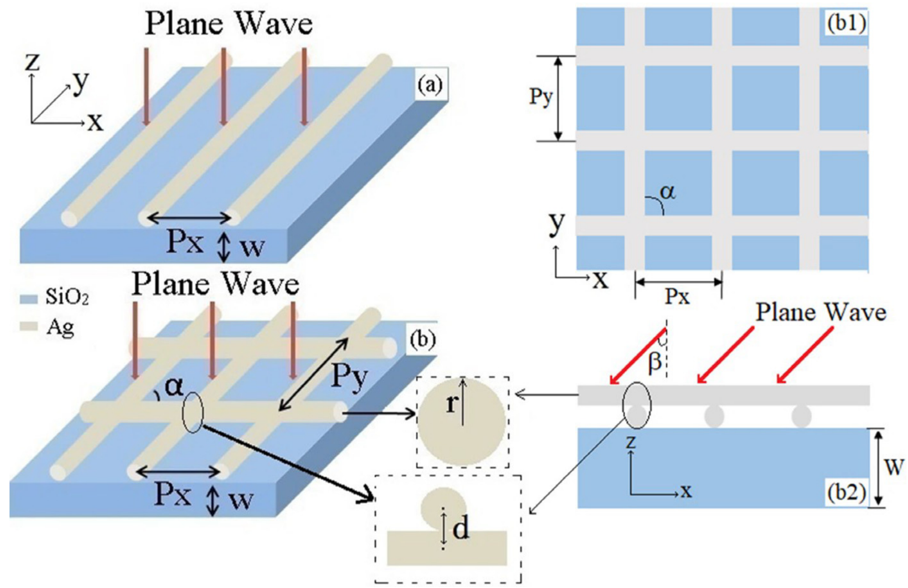

Fig. 1. (a) Schematic of periodic AgNW gratings on the SiO_2 layer. (b) Schematic of periodic AgNW networks on the SiO_2 layer. (b1 and b2) *x*-*y* view and *x*-*z* view of periodic AgNW networks on the SiO_2 layer.

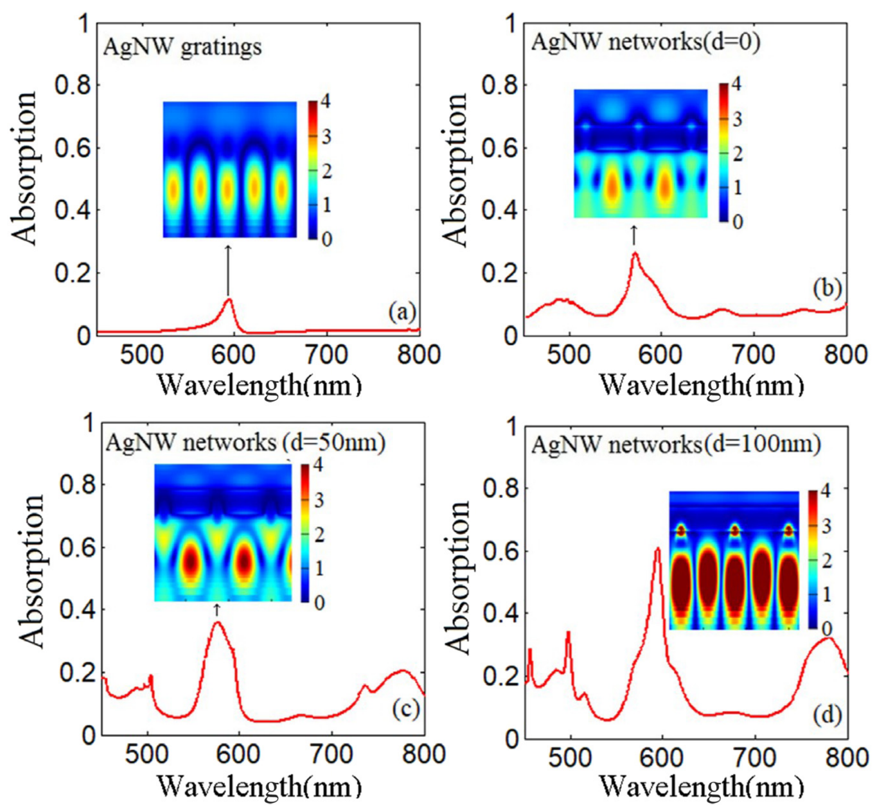

Fig. 2. (a) Absorption spectra of AgNW gratings, (b–c) Absorption spectra of AgNW networks on the SiO_2 layer with $d = 0, 50$ and 100 nm, respectively.

the velocity of light in a vacuum). We performed the FDTD simulations with a perfect matched layer boundary condition at the *z* direction and periodic boundary condition at the *x* and *y* direction.

3. Results and analysis

Fig. 2 shows the absorption spectra of AgNW gratings or AgNW networks on the SiO_2 layer. The Fig. 2(a) denotes the absorption spectra of AgNW gratings with $Px = 500$ nm, $r = 50$ nm, a low absorption peak is observed at 595 nm. When the periodic AgNW networks ($Px = Py = 500$ nm and $r = 50$ nm, $d = 0$ nm) are arranged on the SiO_2 layer, we can see that the absorption peak has a slight enhancement as shown in Fig. 2(b). When the $d = 50$ nm, the absorption peak also increases in Fig. 2(c). However, when the distance between the two middle axes of the crossed AgNW is $d = 100$ nm such that the AgNW networks are a non-coplanar structure, the absorption spectrum has a significant overall increase. Our results show absorption enhancements in the non-coplanar AgNW networks (when $d = 100$ nm) and may provide guidance for