Asymmetrical Stepped-Junction Nanoantennas

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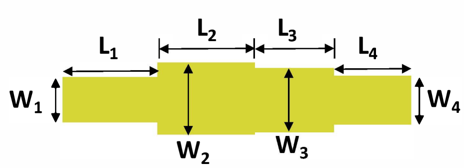
Abstract: We investigate optical nanoantennas featuring asymmetrical stepped-junction structures. By breaking the symmetry of the conventional optical nanoantennas, the performance of them is improved in many aspects. Experiments have been conducted to validate the proposed design.

1. Introduction

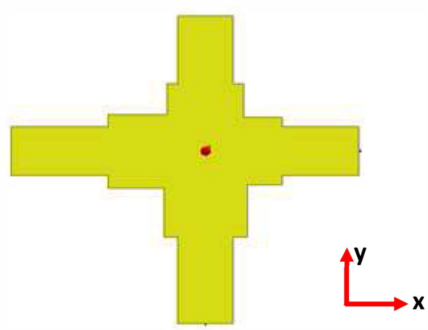
Various plasmonic nanoantennas have been developed to manipulate light below the diffraction limit, enhance the intensity of local electromagnetic waves, or direct the light propagation [1-4]. Among the nanoantennas, the bowtie-shaped structures [1] have been widely studied; however, their performances are still limited, especially when stringent design rules, such as wide bandwidth, need to be fulfilled. To address these challenges, innovations in both antenna design and nanofabrication techniques are highly demanded. For example, Babinet-inverted Yagi-Uda nanoantennas are designed to achieve unidirectional radiation of light [2]; the so-called fan-rod nanoantennas [3] are proposed to enhance the electric field intensity; and a J-pole nanoantenna [4] is demonstrated to enhance the angular emission pattern of quantum emitters. To further enhance the performance of nanoantennas, we present a novel stepped-junction nanoantenna. Different from the conventional nanoantennas, the stepped-junction nanoantennas feature asymmetrical structures, which lead to improved performances in terms of spectrum responses and polarizations. To verify the design concept, a prototyped stepped-junction nanoantenna operating at the near infrared (NIR) range has been successfully fabricated and characterized. The experimental results agree reasonably well with the simulations.

2. Nanoantenna design

The schematics of the proposed nanoantenna are shown in Fig. 1. The key building block of the designed nanoantenna is a stepped-junction structure as shown in Fig. 1 (a). It consists of four sections with different lengths and widths. The left two sections (with dimensions of L_1, W_1 and L_2, W_2) can be treated as one branch and the right two sections (with dimensions of L_3, W_3 and L_4, W_4) are treated as the other branch. The two branches are fused together to form the stepped-junction structure. The proposed nanoantenna is then formed by combining two orthogonally oriented arms as shwon in Fig. 1 (b). The stepped-junction structure is adopted for both arms. The new nanoantenna design offers several benefits. First, due to its asymmetrical feature, the stepped-junction nanoantenna can operate at multiple optical frequency ranges. Second, since the two consituting antenna arms oriented along the x and y directions are identical, the performance of this nanoantenna is independent of the polarization of the incident waves.



(a)



(b)

Fig. 1 General schematics of the proposed nanoantenna. (a) the asymmetrical stepped-junction structure and (b) the proposed nanoantenna.

3. Results and Discussion

To verify the performance of the proposed nanoantenna, we have designed a prototype nanoantenna operating at the near IR range. Full-wave electromagnetic simulations using the finite element method (FEM) are conducted to facilitate the design. The detailed geometrical dimensions of the stepped-junction structure are: $L_1 = L_2 = 70$ nm, W_1

= 40 nm, W_2 = 60 nm, $L_3 = L_4$ = 55 nm, W_3 = 55 nm, and W_4 = 40 nm. An array of designed nanoantennas was patterned on an ITO-coated glass substrate using an electron beam lithography (EBL) system. After EBL, the gold nanoantennas were formed by a vacuum deposition of 5 nm titanium and 50 nm gold followed by a lift-off process using an acetone bath. The scanning electron microscopy (SEM) images of the fabricated nanoantenna array are shown in Fig. 2. The fabricated stepped-junction structure has, on average, $L_1 + L_2 \sim 166$ nm, $L_3 + L_4 \sim 120$ nm, $W_1 = W_4 \sim 45$ nm, and $W_2 = W_4 = 60$ nm. The period of the nanoantenna array is 500 nm.

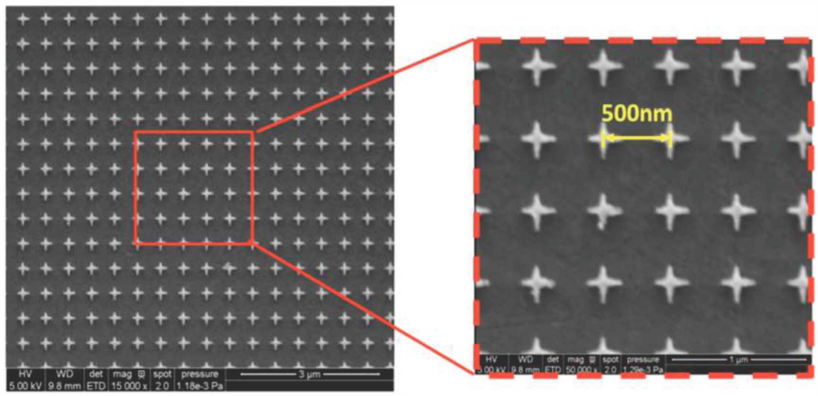


Figure 2. Top view SEM images of nanoantenna array fabricated on the ITO-glass substrate. The right image shows the zoomed in view of the representative nanoantennas.

The fabricated sample was characterized using a dark-filed microscope for its optical response. The measured extinction cross sections of the designed nanoantenna array are plotted in Fig. 3, where the simulation results are also shown. It is observed that the measured results are blue-shifted comparing to the simulation results, which are due to the fabrication errors during the EBL process. Also, two extinction peaks are observed in the simulation (λ_1 = 1300 nm and λ_2 = 1100 nm as marked in the figure), and thus enables multiband operation of the proposed nanoantenna structure. It is worth noting that only one peak ($\lambda \sim 1050$ nm) presents in the measured spectrum because the other extinction peak falls out of the range of the spectrometer.

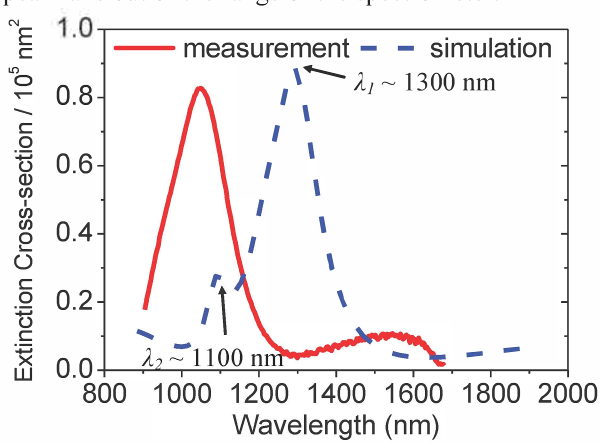


Figure 3. Experimental and simulated extinction spectra for the array of stepped-junction nanoantennas.

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