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Short communication

Fabrication and characterization of plasmonic nanorods with high aspect ratios

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ABSTRACT

Metallic nanostructures with high aspect ratios are important for developing devices in photonics and integrated optics. However, fabricating well-aligned plasmonic arrays is challenging due to the difficulties of etching metals. In this work, we investigate the feasibility of constructing high aspect ratio nanorods with desired shapes and controllable geometric parameters using direct focused ion beam etching. The whole fabrication process only involves a metal-deposition step and a single milling of designed patterns. Detailed characterizations of the fabricated devices are also experimentally demonstrated.

1. Introduction

With the rapid development of nanofabrication technology, plasmonics has become an important research branch in nano-optics and photonics [1–6]. By coupling light to coherent electronic excitations, numerous optical devices which show unique properties have been developed. Thanks to their capability of confining light in ultrasmall volumes, many useful applications have been enabled which pave the way for engineering optical signals at the nanoscale. Devices with high aspect ratios are of special importance since they have found extensive applications in waveguiding [7–13], color filtering [14–19], and sensing [20–36]. It is well known that metallic surfaces patterned on subwavelength dimensions exhibit spectacular optical properties which allow manipulating light at nanoscales at different frequency bands from visible to infrared. High aspect ratio structures have generated special interest due to their promising potential in a wide range of applications. Cylindrical nanorods with high aspect ratios vertically aligned with the supporting substrate are particularly useful since they can enhance the local electric field intensity significantly, leading to new strategies and opportunities for sensing.

Here, we report on the fabrication of nanorod plasmonic crystals with various shapes and tunable structural parameters realized by focused ion beam (FIB) etching. Versatile and powerful etching strategies enable programmable tuning on array geometries. The fabricated nanorods with high aspect ratios are characterized. In particular, promising applications are experimentally demonstrated. The elegant approach achieved in this work may find new applications in nanophotonics and optics.

2. Nanorods with high aspect ratios *via* FIB etching

In this work, high aspect ratio nanorods were FIB-drilled in an optically thick (530 nm) gold film. The metal layer was previously deposited on a quartz substrate with a 9 nm thick chromium adhesion layer by electron-beam evaporation at 3×10^{-7} mbar chamber pressure. A single-beam FIB system was used to define patterns using a 70 pA probe current. Parallel milling was applied to ensure minimized redeposition effects, leading to fine features and smooth sample surfaces after the milling process. More details about the fabrication process can be found elsewhere [37,38]. As shown in Fig. 1(a), oblique scanning electron microscopy (SEM) image clearly demonstrates the profiles of the fabricated nanorods. The tapered sidewalls are resulted from materials redeposition. The rod array has 450 nm periodicity with 200 nm rod diameter and 530 nm height. Spectroscopic measurements were carried out at different incidence angles using a UVISEL (HORIBA Jobin Yvon Corporation) which has a 75 W broadband xenon source (*i*HR320). The transmitted and reflected spectra were measured with respect to the light through a bare quartz substrate and an aluminum

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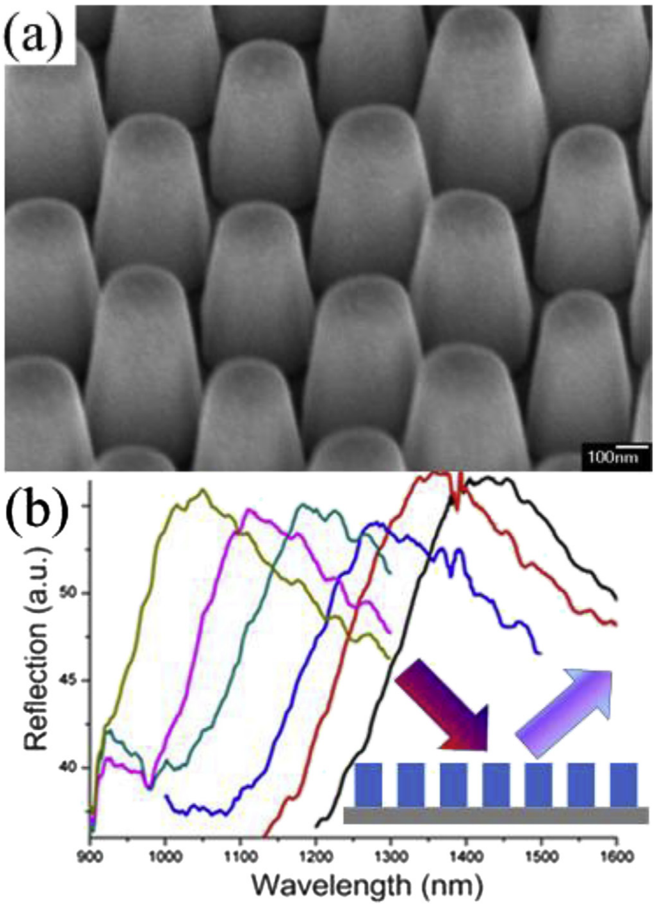

Fig. 1. (a) SEM showing the profiles of the fabricated nanorods. (b) Reflection of nanorods at different incident angles from 20° (left) to 70° (right). Tunable plasmon resonance is shown with different incident angles. The inset illustrates the schematic of the characterization setup.

mirror, respectively. As plotted in Fig. 1 (b), tunable plasmon resonance is shown with different incident angles. The inset illustrates the schematic of the characterization setup. As can be seen, the plasmon resonance redshifts with increasing incident angles (20° to 70° in 10° increments) from 1025 nm to 1425 nm. By accurately adjusting the array geometries, one can move the resonance response from near infrared to visible, enabling useful color tuning devices with incident-angle sensitive response [18].

3. Results and discussion

To further demonstrate the programmable feature of the fabrication method, rod arrays with varying geometric parameters were drilled. One can clearly observe high aspect ratios and smooth surfaces from Fig. 2. As typical examples, rods with different diameters and shapes are illustrated from Fig. 2 (a)–(d). The geometry of rods is approaching each other gradually from Fig. 2(a)–(c) and finally achieves uniform profiles in Fig. 2 (d). By design, it is feasible to obtain a wide range of plasmonic nanorods with high aspect ratios and various outlines. Strong contrast at the periphery of the rods is caused by redeposition during the etching process. It is worth mentioning that this can be depressed by using a dielectric layer as protection which can be removed subsequently by wet etching. One can simply fabricate more complex designs by precisely modifying the geometry of the patterns for FIB etching. Therefore, the fabrication process is monolithic.

The measured extinction spectra as a function of wavelength for different incident angles are shown in Fig. 3 (a). It is obvious that a new resonance reveals at 630 nm when the incident angle is changed from normal to 5°, as labeled as Peak I. The intensity increases and the resonance redshifts with larger incident angles. For the other resonance mode labeled as Peak II, the amplitude gradually decreases with increasing incident angles. Moreover, Peak I has smaller full width at half maximum (FWHM) than Peak II, implying higher impact factors. Resonant modes observed in the extinct spectra can be attributed to the excitation of Drude-type currents in the rod arrays. Under oblique incidence, the

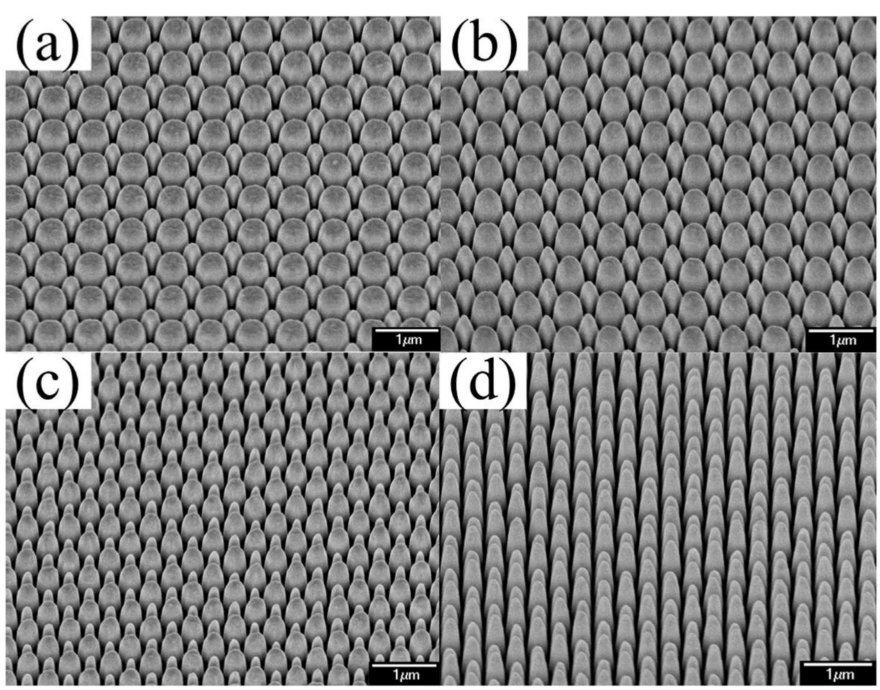

Fig. 2. (a)–(d) SEM images showing four different nanorod designs. The diameters of rods are approaching each other from (a) to (d).