Fabrication of Large-area Plasmonic Nano-cavity Antenna Array for High Efficiency Mid-and-Far Infrared Sensing

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To achieve efficient high-sensitivity infrared sensing, high absorption is needed. Conventionally, this has been achieved by large resonant cavities[1] which are bulky and complex (hence expensive). Recent periodic plasmonic nanoantenna arrays have been proposed and demonstrated for high absorption for near-infrared detection[2,3]. Here, we present a new plasmonic nanoantenna array structure of high absorbance but only 120 nm thick (<5% of the wavelength), which is much simpler to fabricate and good for mid and far IR, and demonstrate a low-cost and high-throughput nanoimprint-based method to fabricate them.

The new high-absorbance periodic plasmonic nanoantenna array structure consists of a transparent substrate (fused silica) with a pillar array, a thin metal bar on top of the pillars, and a thin metal film covering the pillar feet and substrate (hence the metal bars are perfectly aligned to and block the holes in the thin metal film, Fig. 1a). The fabrication of such array has only three key steps: nanoimprint lithography to pattern Cr bars (Fig. 1b-c), etching the bar-shaped pillar array (Fig. 1d), and a metal evaporation (Fig. 1e).

The bar-shaped molds over a large area was fabricated by a novel method, which uses two cycles of nanoimprint of grating mold and etching, with the second imprint orthogonal to the first, to form the periodic bars (Fig. 2). A triple layer resist scheme of nanoimprint resist (NXR-1020)/ SiO_2 (15 nm)/crosslinked polymer XHRiC-16 (50~150 nm) on Si mold substrate was used. The first grating was imprinted in NXR-1020 and transferred to the SiO_2 by RIE (but no etching of XHRiC-16). Then a second nanoimprint with a new NXR-1020 resist layer created the second grating normal to the first. Both the SiO_2 grating and the second grating acted as mask in RIE of XHRiC-16, creating rectangle openings. A Cr (15 nm) layer was evaporated, and a lift-off of the entire triple layer resists left Cr bars (length/width as 175/25 nm for 200 nm pitch, and 750/250 nm for 1 μm pitch, Fig. 3) on the mold surface. Finally a single RIE created the final patterns on the mold surface.

For mid-infrared sensing test, 1 μm pitch nano-antenna arrays were fabricated on fused silica (Fig. 4a); and the bar-shaped Au disks together with the backplane Au forms a 3D cavity antenna array of high absorbance (70 nm trench depth, 50 nm thick Au, and hence 20 nm size gap).

The samples were measures using the Fourier transform infrared spectroscopy (FTIR) spectra (tested in air). The measurements show that the bar-shape structures had high absorption of ~55% (at 3.8 μm, Fig. 4b). Compared to single bars (10% at 3.6 μm)[4] or bar arrays (~30% at 1.7 μm)[2], our result showed much higher peak absorption, which could be further increased by optimizing the cavity gap size and other parameters. Besides, the sensing wavelength could also be optimized by tuning the nano-bar lengths, periods, and aspect ratios.

Reference:
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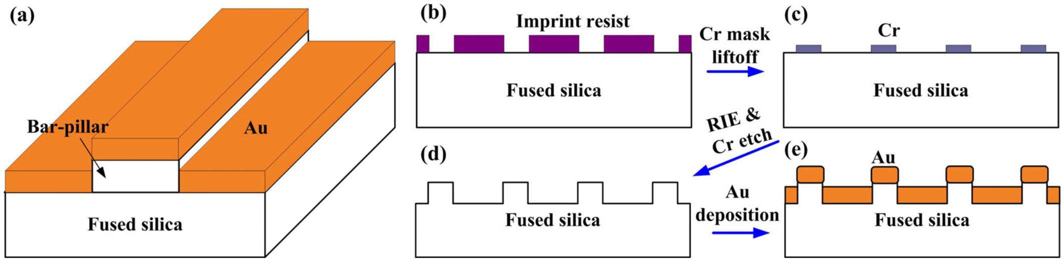

Fig. 1. Schematic and fabrication process of an infrared detector. (**a**) Schematic of the detector, made of a Au-capped bar-pillar with surrounding thin Au film. **b**-**e**, Fabrication process: (**b**) Imprint on fused silica and residual layer etching, (**c**) Cr deposition and liftoff, (**d**) RIE fused silica and Cr removal, (**e**) Au evaporation.

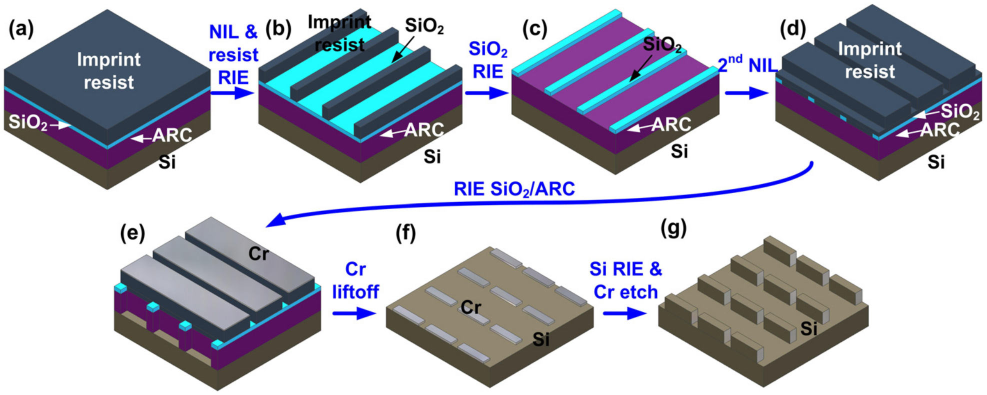

Fig. 2. Schematics of fabricating large-area bar-shape molds. (**a**) SiO_2 substrate with imprint resist/SiO_2/ARC tri-layer coatings; (**b**) First imprint and RIE residual resist to define the bar length; (**c**) RIE SiO_2 with the imprint resist stripped; (**d**) Second imprint to define the bar width; (**e**) Cr shadow evaporation and oxygen RIE of imprint resist and ARC; (**f**) Evaporation and liftoff of Cr; (**g**) RIE Si and Cr removal.

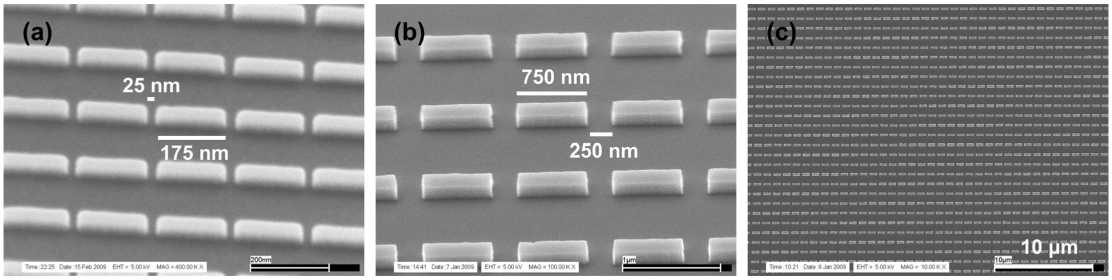

Fig. 3. SEM images of fabricated bar-shape molds. (**a**) 200 nm pitch bars with a length/width ratio of 7 (175/25 nm). (**b**) 1 μm pitch bars with a length/width ratio of 3 (750/250 nm). (**c**) Large area patterning of 1 μm pitch bars.

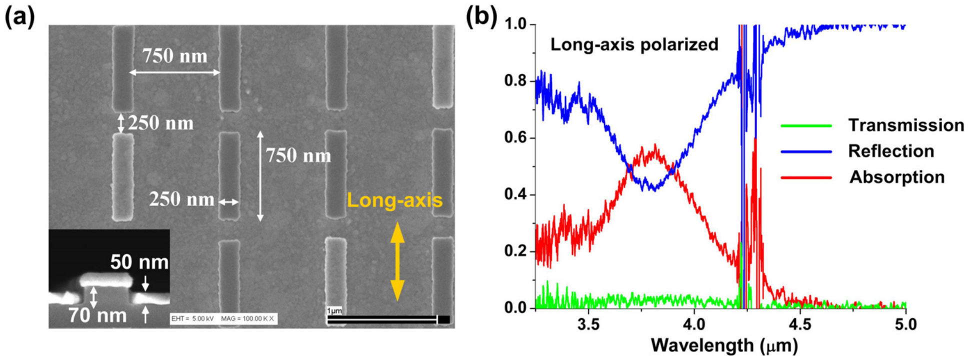

Fig. 4. Fabricated bar-shape nano-cavity antenna arrays and the infrared transmission, reflection, and absorption spectra. (**a**) SEM image of fabricated 1 μm pitch bars, with the insert showing the cross-section (70 nm trench depth, 50 nm thick Au, and 20 nm gap). (**b**) FTIR spectra of nano-bars, showing 55% absorption at 3.8 μm.