Controlled fabrication of plasmonic nanogaps using electron beam lithography and Helium-ion beam milling

Yudong Wang [ab], Martina Abb [a], S. A. Boden [b], C. H. de Groot [b], Otto L. Muskens [a]

[a] Physics and Astronomy and [b] Electronics and Computer Science, Faculty of Physical and Applied Science, University of Southampton, Southampton, SO17 1BJ, UK

E-mail: O.Muskens@soton.ac.uk

Keywords: E-beam lithography, He-ion microscopy, optical switch, plasmon, nanoantenna, asymmetric dimer

Plasmonic nanoantennas are receiving enormous interest for their capacity of controlling light on the nanoscale [1]. Like many other nanostructures, they sustain both radiative (bright) and nonradiative (dark) modes. Here, we present a comprehensive study of coupling and interference of plasmonic modes in dimer antennas with controlled nanogaps.

In our recent work [2], we have investigated plasmonic dimer antennas were the position of the nano-gap in the structure was tuned while keeping the total length fixed (Fig. 1). Plasmonic near-field coupling of high-order modes in these asymmetric dimer antennas result in hybridization of bright and dark modes of the individual nanorods, leading to an anticrossing of the coupled resonances. For two bright modes, hybridization results in a capacitive red shift and super-radiant broadening. We show that the properties of asymmetric dimers can be used for nonlinear control of spectral modes and demonstrate such a nonlinear effect by measuring the modulation of a hybrid asymmetric dimer, ITO antenna. Such asymmetric dimer antennas are of potential interest for a variety of applications in nonlinear optical control and optical sensing.

In addition to e-beam lithography of nanoantennas with sub-20nm gaps, we have explored the use of He-ion beam milling in fabricating plasmonic nanogaps with even smaller dimensions, and partial gaps where variable amounts of material is removed (Fig. 4). We achieve a very high, nanometer precision of incremental gap loading using a partially conductive junction, which is of interest for applications in nonlocal and quantum plasmonics.

References:

[1] L. Novotny, N. van Hulst, (2011) *Nat. Photon*. 5, 83–90
[2] M. Abb, Y. Wang, P. Albella, C. H. de Groot, J. Aizpurua, and O. L. Muskens (2012) *ACS nano* 6, 6462
[3] Y. Wang, S. A. Boden, D. M. Bagnall, H. N. Rutt, and C. H. de Groot (2012) *IOP Nanotechnology*, 23(59), 395302

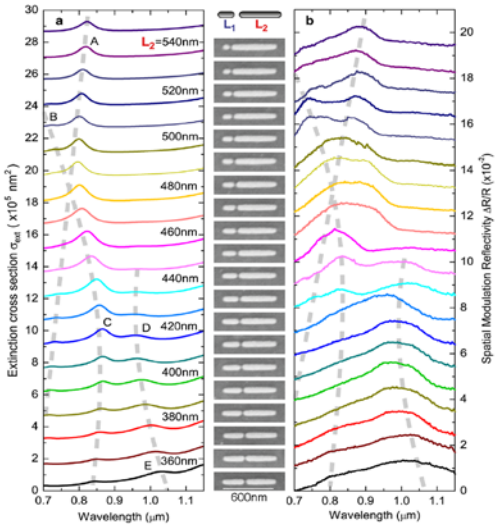
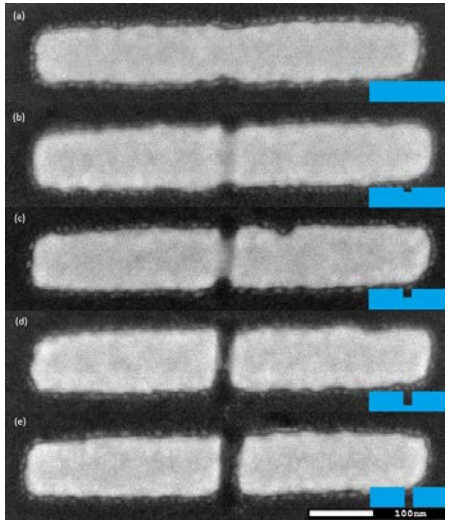


Figure 1. Theoretical (a) and experimental (b) extinction spectra of individual asymmetric antennas composed of metallic rods of different length L1 (short rod) and L2 (long rod). Corresponding SEM images are shown in the center.



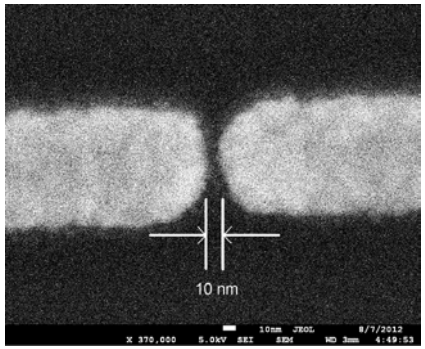


Figure 2. SEM image of the critical gap fabricated by E-beam lithography only. The dark area is SiO2 and bright area is 25 nm Au film fabricated by E-beam lithography and lift-off.

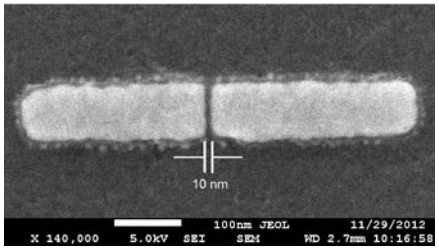


Figure 3. SEM image of the critical gap fabricated by E-beam lithography followed by He-ion beam milling. The dark area is SiO2 and bright area is 25 nm Au film fabricated by E-beam lithography and lift-off. The gap was milled by helium ion beam at a width of 10 nm.

Figure 4. SEM image of gold nano-antennas fabricated by e-beam lithography and He-ion beam milling. From (a) to (e) the repeat times of the base dose milling changes from 0 to 400 with a step of 100. The cross section schematic diagram shows the material being removed layer by layer from the top which has been proved by an electric resistance model in our previous work [3].