

Towards Sub-10 nm Nanofabrication of Plasmonic Devices using Multiple Electron and Ion Beams

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Direct write focused ion beam (FIB) machining represents the quickest, most flexible method to fabricate nano-devices for prototyping and research applications. The use of a FIB combined with SEM allows for immediate inspection and refinement steps in the patterning, assuring the desired fidelity. This technology has thus found wide-spread use in fields such as photonics, nano-fluidics, TEM sample preparation, integrated circuit modification, and MEMS. Conventional gallium FIB based on the liquid metal ion source (LMIS) has many notable drawbacks which include the lower limit for feature sizes that can be achieved and Ga implantation.

As an illustrative example of machining over multiple length scales, we show here an example of a double bowtie plasmonic device, inspired by the work of Zhang and co-workers. The device consists of four equilateral triangles patterned into 17 nm thick Au films by electron beam lithography. These elements face into one another giving a shape like two crossed bowties. The dimensions of the device are critical to determine the resonant wavelength. The requirements are that the triangles have a side length of approximately 85 nm, with a radius of curvature of 10 nm at the vertices, and a gap between the points of the triangles of about 30 nm. The gaps are varied to alter the plasmonic response of the device. To date, lithographic methods are necessary to form such small objects since traditional Ga FIB does not have the requisite machining precision.

The ORION NanoFab allows these devices to be made by direct write using three different ion species and completely obviating the need for lithographic processing. The critical dimension can in fact be reduced even further. A three step approach was used to fabricate a double bowtie structure in a 100 nm thick gold film on a glass substrate. During the first step, Ga FIB is used to open up a 1 μm square window into the film, while leaving behind a square island 200 nm wide in the center. The second step consisted of using the neon beam in the gas field ion source to machine slits in the island which form a cross, as demonstrated in Figure 1. The sidewall angle of the created features is 82° , this could be improved with trimming by helium [4]. Finally, helium ion milling is utilized to separate the four triangular elements as represented in Figure 2. A top-down view of the completed device is presented in Figure 2. The active area of the device had never been exposed to the Ga beam. The fact that the results can be inspected immediately in-situ, using helium ion microscopy (HIM), also provides the quick feedback and process control. Extremely tight dimensions can be maintained in the most critical area. Figure 3 shows the center of the bowtie structure. The image has been filtered to highlight the edges for measurement purposes. The distance between the triangle vertices is 10 nm (line drawn on image), and the radius of curvature of the vertices is also 5 nm (circle drawn on image).

References

- [1] Z. Zhang, et al., Nano Letters, 9, 4505 (2009)
- [2] J Notte, "Charged Particle Microscopy: Why Mass Matters", Microscopy Today, 20(5), 16-22 (2012).
- [3] <http://www.srim.org/>
- [4] Larry Scipioni, et al., J. Vac. Sci. Technol. B 28(6), C6P18 (2010).

Figures

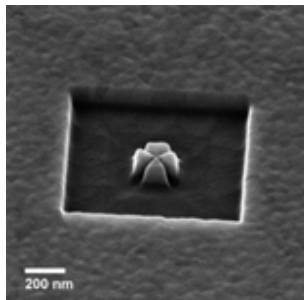


Fig 1: Machining of island with neon beam to form arms of double bow tie structure. Helium ion imaging

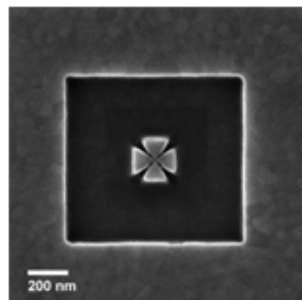


Fig 2: Top down image of final device. Helium ion imaging

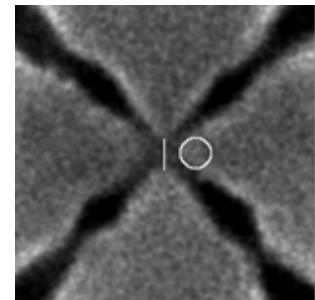


Fig 3: Edge-enhanced HIM image of center 100 nm area of double bow tie structure. Line drawn on image is 10 nm. Circle has radius of 5 nm.