Focused Ion Beam Lithography for Novel Nanofabrication Applications

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Focused ion beam (FIB) technology, and later dualbeam FIB-SEM, developed in the late 20th century alongside the microprocessor manufacturing industry as a tool for circuit edit and lithographic mask repair. The next "killer app", and the first to find acceptance outside of the fab, was the preparation of site-specific thin lamella for transmission electron microscopy. In the last decade, dualbeam instruments have become robust (and accessible) enough to be used as versatile tools for nanofabrication. Here we present our current research in FIB-fabrication of photonic devices, as well as future research directions using the new xenon-plasma source FIB.

Ever-increasing demands on telecommunications networks have fueled interest in high-efficiency, high-speed integrated optical devices such as switches, amplifiers, and laser sources. These devices generally have features on the order of hundreds of nanometers to a few microns. FIB machining is an ideal tool for rapid prototyping on this scale. Using a Zeiss NVision 40 gallium-source FIB, we have modified single-pass optical amplifiers to select a narrow wavelength band by milling a Bragg grating of specific pitch (see Fig 1). The milling of precise, smooth end facets as seen in Fig 2 aims to convert the optical amplifier into a narrow-band distributed feedback laser. Metamaterial-based optical devices such as the chiral infrared polarizer in Fig 3 often require features of variable depth. This is difficult to achieve using traditional lithographic methods but is well-suited to FIB direct writing.

The past few years has seen several new focused ion sources become commercially available, such as helium/neon, and more recently xenon plasma. The xenon plasma source is capable of beam currents two orders of magnitude higher than is possible with the gallium LMIS source, enabling much faster milling rates. Our current research is directed at utilizing the plasma-FIB to fabricate mesoscale devices for photonics, microfluidics, and MEMS. Figure 4 is an image of a microfluidic mixer fabricated using a multi-step process including electron beam lithography (EBL), chemical etching, and gallium FIB direct-writing[1]. The plasma-FIB will potentially be able to vastly simplify this fabrication process, machining the whole structure in a single step, with high resolution and in a reasonable amount of time.

As micromanufacturing moves beyond miniaturization associated with the semiconductor industry into more diverse materials and requirements, more adaptable fabrication techniques will need to be developed. A versatile candidate is focused ion beam milling. Capable of milling variable-depth structures on scales from under 100 nanometers to hundreds of micrometers with new plasma sources, FIB will become a key technique in device fabrication in coming years.

References

1 Leonidas E. Ocola and Edgar Palacios, Journal of Vacuum Science & Technology B **31** (6), 06F401 (2013).

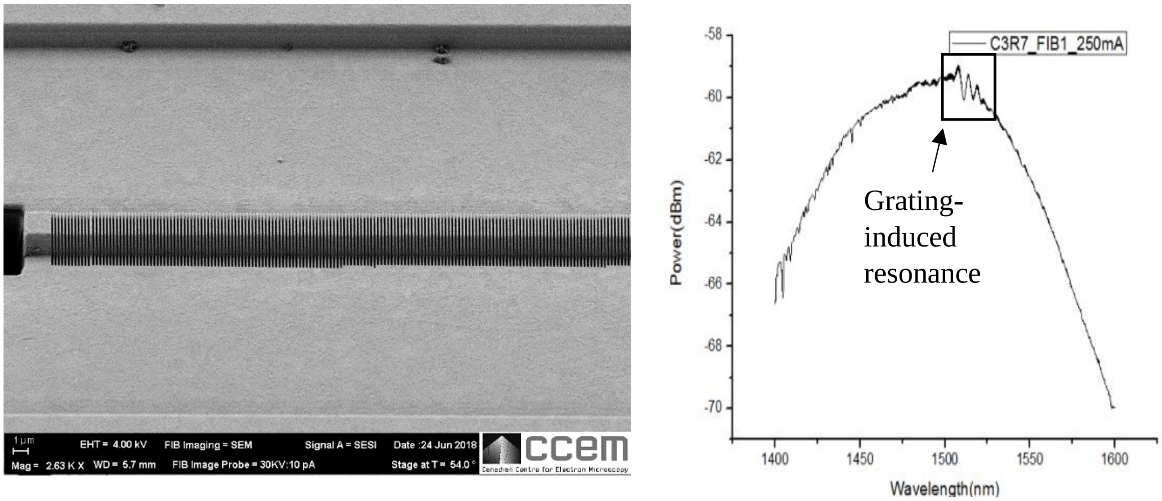

Figure 1: FIB-modified optical amplifier - narrow resonance band created by Bragg grating)

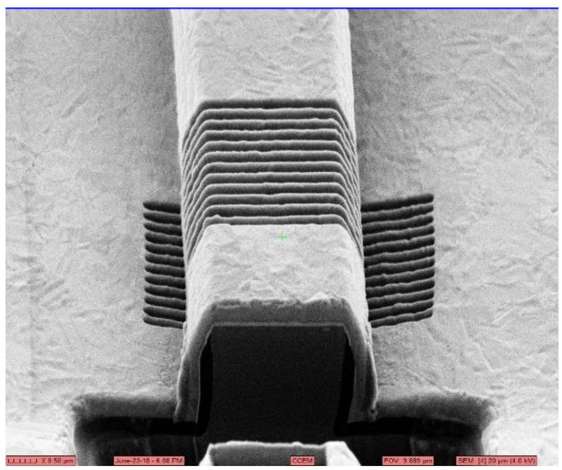

Figure 2: Waveguide end faceting to create DFB laser cavity

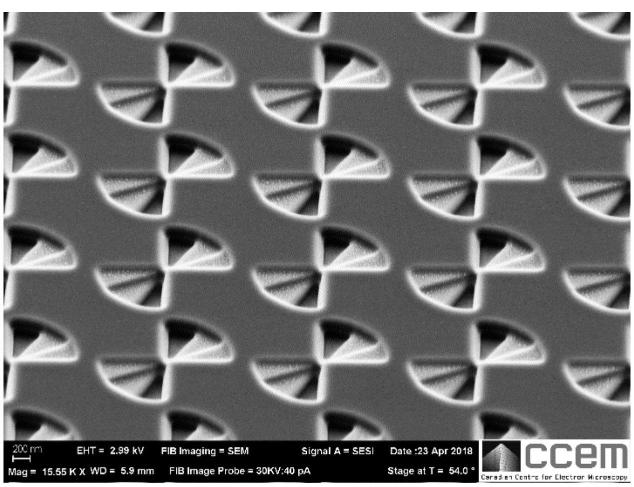

Figure 3: Variable-depth infrared-polarizing metamaterial

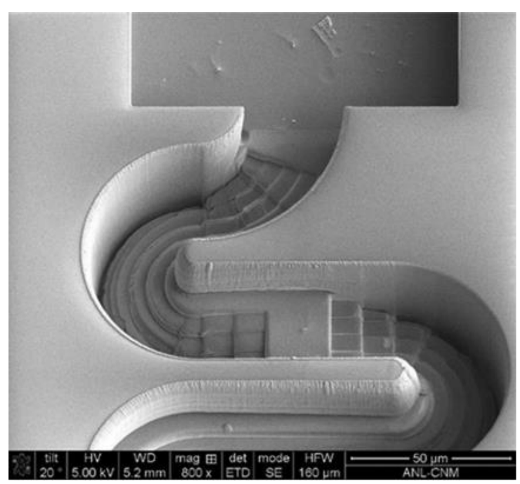

Figure 4: Microfluidic mixer fabricated with a multi-step process (Ocola et al)