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Towards Nanomagetomechanical Systems: Focused Ion Beam Milling of Ferromagnetic Garnets

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Ferromagnetic garnets ($R_3Fe_5O_{12}$) have attracted interest since their discovery over 50 years ago in part because of their magneto-optic properties [1]. These properties make them interesting candidates for nanosensors and nanomagetomechanical systems (NMMS). For example, a very creative recent proposal envisions the placement of a magnetic bit on a compliant nanomechanical element [2]. Controlled coupling between the magnetic and mechanical subsystems could be realized if the resonant frequencies of the mechanical and magnetic subsystems are designed to overlap. Experimentally, the dynamics of such systems may be investigated by means of stroboscopic interferometry [3,4]. Besides mechanically compliant structures such as cantilevers or bridges, isolated disks or pillars are also of interest as they permit the fingerprinting of magnetization states.

Significantly, and importantly for magnetic storage or logic applications, the three-dimensional shape of the interrogated structure figures prominently in the dynamics. For this reason the focused ion beam is potentially an invaluable tool for the prototyping of NMMS devices, since it is capable of milling three dimensional structures such as cantilevers, bridges, and pillars into virtually any material, thereby the avoiding some of the constraints presented by lithography. In addition, the physical dimensions of milled structure may be readily designed and varied as required. We are currently using a Zeiss NVision 40 Crossbeam® Workstation installed at NINT to create a variety of garnet structures; two examples are shown in Figure 1. Our three related objectives are: (i) the development of FIB fabrication techniques for creating NMMS systems; (ii) characterization of Ga induced damage and damping in FIB nanofabricated devices; and (iii) assessment of the performance of magnetic cantilevers as structure sizes are reduced.

We typically fabricate structures on the edges or corners of rectangular samples, as this method permits milling from multiple directions. In addition, structures residing on edges lend themselves easily to optical probing. Preparation of the garnet samples requires some care, and surface roughness and charging have both been identified as issues when working with these specimens. The bulk garnet is obtained in the form of thin wafers, coated with a protective film of Al. The wafers cannot be cleaved, and must be diced into small pieces of typical areal dimensions 1 mm x 2 mm. Because the dicing step leaves a rough edge, the samples are subjected to a polishing step using a 0.5 um polishing mat and water. Finally an etch step is performed to remove the protective Al layer and expose the garnet.

Before garnet specimens are milled, benchmark recipes are developed using single crystal Si wafers (orientation 100). This is an ideal material as it is easily diced into regular shapes, and Si and garnet exhibit comparable milling rates. We have milled Si cantilevers and measured resonance peaks in the MHz range using optical interferometry. These values are consistent with standard models for rectangular shapes [5].

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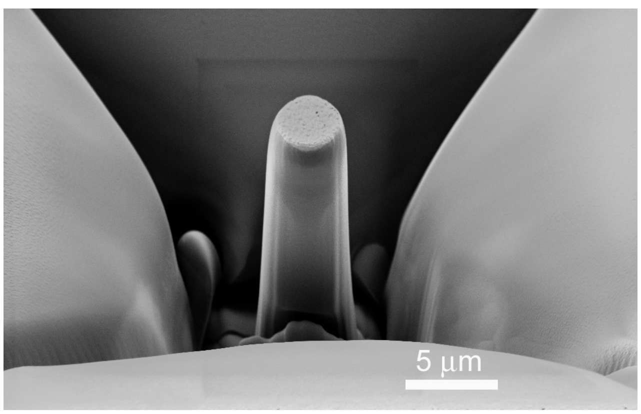

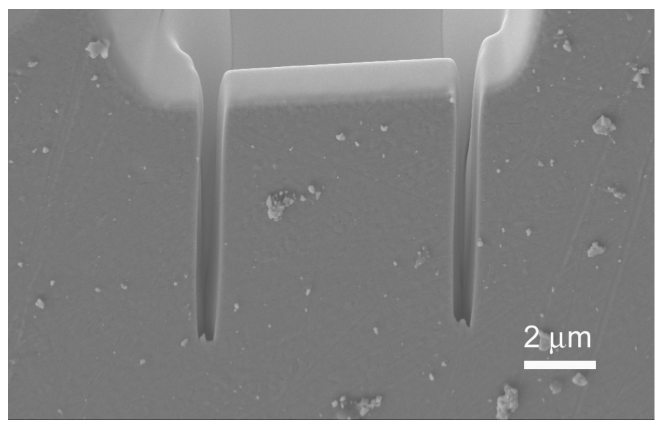

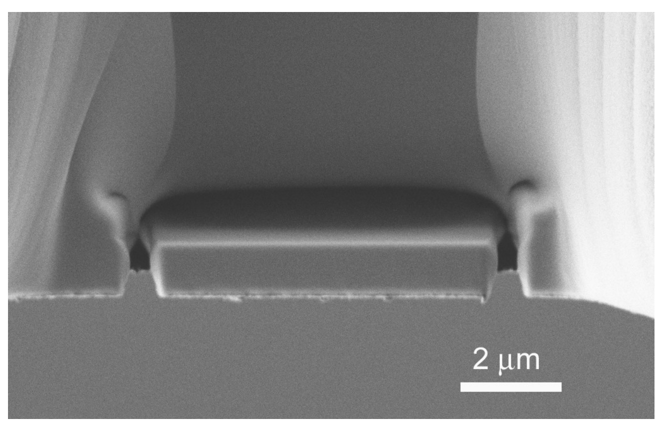

Figure 1: Micrographs of FIB-milled garnet structures for optical interrogation: (top left) SEM image of a pillar structure; (top right) SEM image of a cantilever; (bottom right) FIB image of the same cantilever, showing the end and undercut region.

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