Fabrication and Measurements of Arrays of Constriction-Based Spin-Hall Nano-Oscillators

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Principal Investigator(s): Gregory D. Fuchs
User(s): Yanyou Xie

Affiliation(s): Applied and Engineering Physics, Cornell University
Primary Source(s) of Research Funding: National Science Foundation
Contact: gdf9@cornell.edu, yx322@cornell.edu
Primary CNF Tools Used: JEOL 9500, MA6 contact aligner

Abstract:

Spin-Hall nano-oscillators (SHNOs) convert D.C. charge current to microwave frequency magnetic oscillations — enabling applications as highly agile microwave sources. The use of SHNOs for applications is still limited by the output microwave power and linewidth. The goal of this project is to synchronize SHNOs to generate larger power and narrower spectral linewidth. We are currently working on making arrays of SHNOs of different geometries and studying how they synchronize.

Summary of Research:

A spin-Hall nano-oscillator (SHNO) is a bilayer system containing a ferromagnetic layer and a metal layer with strong spin-orbit coupling [1], patterned as a nanowire or a nanoconstriction. SHNOs are based on spin-Hall effect, which converts a lateral charge current in the metal layer into a transverse pure spin current [2]. The spin current can provide sufficiently large spin transfer torque (STT) to the adjacent ferromagnetic layer to compensate the local spin wave damping, leading to auto-oscillations of the magnetic moment in the microwave regime [2]. For microwave oscillators, it is desirable to generate a larger power and a narrower spectral linewidth [3]. Arrays of synchronized SHNOs can reach these goals and the fabrication of arrays of constriction-based SHNOs is practical [1,3]. Here we fabricated arrays of two and four constriction-based SHNOs on 20.5 µm × 4 µm wires, with constriction width of 100 nm and 150 nm.

The fabrication process consists of three stages — sputtering, e-beam lithography and photolithography — as shown in Figure 1. We started by sputtering a bilayer of $Pt_{0.75}Au_{0.25}$ (5 nm)/$Ni_{81}Fe_{19}$ (5 nm) on a 2-inch sapphire wafer. Next, the SHNO devices were fabricated using e-beam lithography in JEOL 9500 to define constrictions with a 100 nm or 150 nm characteristic dimension. The SEM and AFM images of selected fabricated devices are shown in Figure 2 and 3. Finally, we fabricated gold bonding pads by photolithography. The process used the positive photoresist S1813 in the MA6 contact aligner. After developing, the we evaporated Cr (10 nm)/Au (90 nm) and performed lift-off.

Figure 4 shows spin-torque ferromagnetic resonance (ST-FMR) [4] measurements on one of the 4-constriction devices. In a ST-FMR measurement, a microwave-frequency (rf) charge current is applied to the SHNO, generating an oscillating transverse spin current and thus oscillating STT [4]. The oscillating STT induces magnetization precession in $Ni_{81}Fe_{19}$, which results in an oscillating resistance due to the anisotropic magnetoresistance of $Ni_{81}Fe_{19}$ [4]. Here we measure the generated D.C. differential voltage from the mixing of the rf current and the oscillating resistance [4], dV_{mix}/dH, as we sweep the external magnetic field. The occurrence of valley and peak (dark and light) combination indicates resonant excitation of spin wave eigenmodes [5]. Two significant valley and peak combination can be identified in Figure 4. By comparing with literature [5,6], we identified that at the same external magnetic field, the ones occurring at lower frequency are edge spin-wave modes, while the ones occurring at higher frequency are bulk spin-wave modes. The magnetization of the former mainly occurs near the edge of wire, while that of the latter mainly occurs in the interior of the wire [6]. To extract the mode profiles, we still need to perform micromagnetic simulations at the peak frequencies.

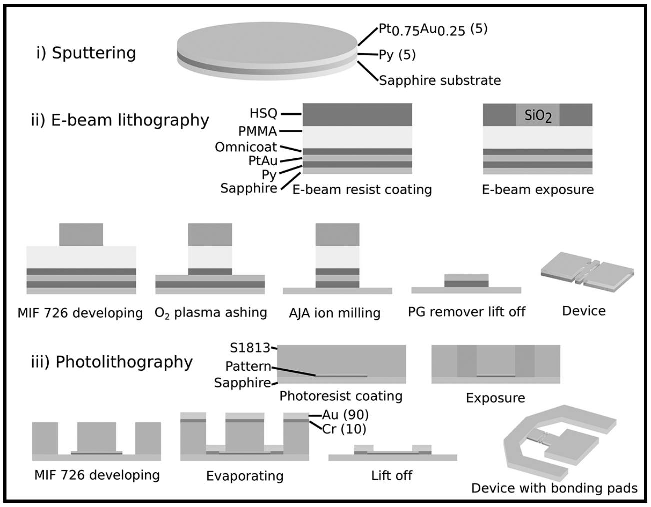

Figure 1: Fabrication process flow. (Find full color on pages xiv-xv.)

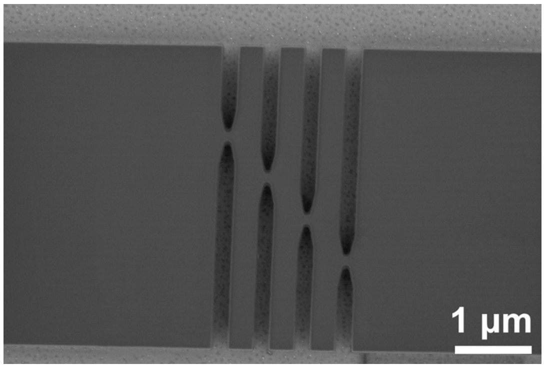

Figure 2: SEM image of one of the devices.

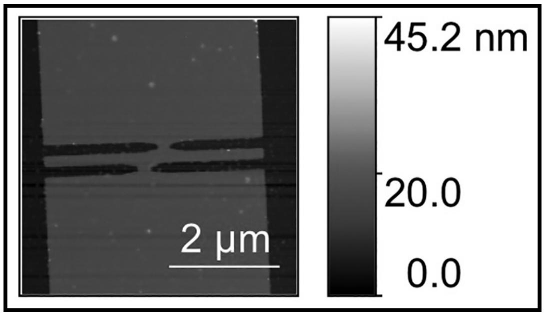

Figure 3: AFM image of one of the devices.

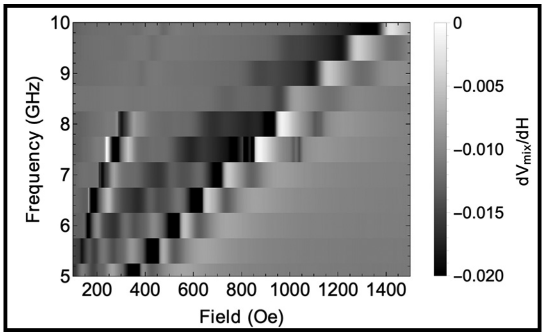

Figure 4: Density plot of spin-torque ferromagnetic resonance measurements sweeping along the external magnetic field. (Find full color on pages xiv-xv.)

References:

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