Spin-transfer torque switching in exchanged-biased spin valve nano-pillar fabricated by 3-D focused-ion beam lithography

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In 1996, Slonczewski and Berger predicted that a spin-polarized current, which is caused to flow between one relatively thick, and fixed, ferromagnetic layer through a non-magnetic layer to another free nanomagnetic layer could transfer spin momentum from the current to the free layer[1,2]. Depending on the direction of the spin current flow, the spin transfer effect can either force the free layer into parallel or antiparallel alignment comparing with the fixed layer when the spin transfer force is strong enough to overcome the coercive field of the free nanomagnet. The experimental evidence was proved by Myers[3] and Katine[4]. Since the spin transfer effect depends on the local spin current density, the effect dominates the self magnetic field generated by the current when the current perpendicular to the plane (CPP) device diameter is small enough. Furthermore, when a strong external pinning field is applied to such a nanoscale CPP structure, the effect of spin transfer can be the excitation of strong and uniform spin wave precessional modes in nanomagnet[5,6]. The nanomagnet precession could be a source of microwave radiation and possibly a source of a precessional spin current. Some experimental works have demonstrated the spin transfer torque switching and spin wave excitation effects[7,8]. The spin transfer phenomena open up the possibility of new types of nanoscale magnetic devices for memory such as MRAM and other spin electronics applications.

The spin transfer phenomenon has been observed in a number of device geometries, which include mechanical point contacts, lithographically-defined point contacts, and lithographically-defined nanopillars. These devices all share two characteristics, megnetoresistive readout of the magnetic state and small cross-sectional area. Most of the nanopillars were fabricated by e-beam lithography. Here, we report a novel 3-D focused ion beam lithography for the study of the spin transfer torque switching. This technology provides an efficient route to fabricate reliable CPP magnetic spin valve devices.

Our devices were fabricated using the following steps. First, a multilayer of Ta(5)/Cu(200)/CoFe(3)/Cu(6)/CoFe(6)/IrMn(10)/Cu(200)/Ta(5) (thickness in nanometers) were deposited onto a thermally oxidized Si substrate in an ultrahigh vacuum sputtering system with the base pressure below ~5x10^{-8} Torr. An external magnetic field of ~200 Oe was applied during the sputtering in order to induce an in-plane magnetic easy axis. Second, the multilayered thin film was patterned by optical lithography and then was etched by Ar ion milling through the film to the substrate. 4um wide tracks with 4um wide voltage leads are produced by those steps. Third, a course etching (width down to 300nm) is performed using 150pA Ga ion beam current. Then, a fine etching (width down to 150nm) and side wall cleaning process is performed using 11pA beam current. Side etching by 11pA beam current with a custom-built 45° wedge holder is performed. The geometry of the nanopillar is shown as Fig. 1. Transport measurements were conducted in a four-point contact geometry. An ac lock-in technique was used to measure the dynamic resistance (dV/dI) of the spin valves in an in-plane magnetic field applied along the geometric easy axis (long axis of the rectangle), with an ac current excitation of 200uA rms at 77Hz. A dc bias current was simultaneously applied during the dV/dI measurement, with the positive direction corresponding to electron flowing from fixed to the free layer. The dynamic resistance was measured as a function of magnetic field and dc bias current. The Fig.2 shows a megnetoresistance (MR) loop at 300K and zero bias current for a CPP exchanged-biased spin valve with a size of 150nm by 200nm. The external field aligns the moment of free layer and fixed layer to be either parallel (P) or antiparallel (AP), resulting in an MR value of ~0.5%, which is defined as MR=(R_{AP}-R_P)/Rp, where R_{AP}(Rp) is the resistance of the AP(P) state. The current induced magnetization switching (CIMS) can be clearly observed in zero external magnetic fields, as shown in Fig.3. The resistance switches to the Parallel (P) state at $I_{AP\rightarrow P}$= 10.1mA while it flips back to antiparallel parallel state at $I_{P\rightarrow AP}$= -1.2mA. The corresponding change in the resistance at zero bias dc current in Fig.3 is as the same as the change in the resistance at zero external applied fields in Fig.2, confirming that the magnetization is fully reversed by the spin-polarized current injection. The critical current density is estimated to be 3.4 x 10^7A/cm^2 (for $I_{AP\rightarrow P}$) and -4x 10^6A/cm^2 (for $I_{P\rightarrow AP}$). These agree well with the value estimated from Slonczewski's spin transfer model.

In summary, we have successfully fabricated an exchanged-biased spin valve nanopillar by 3D focused ion beam lithography for the study of spin transfer torque switching. We have observed the CIMS in the CPP nanopillar. The technique provides the fabrication of nanopillar for fast exploration of spin transfer torque effect in magnetic thin film.

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Figures:

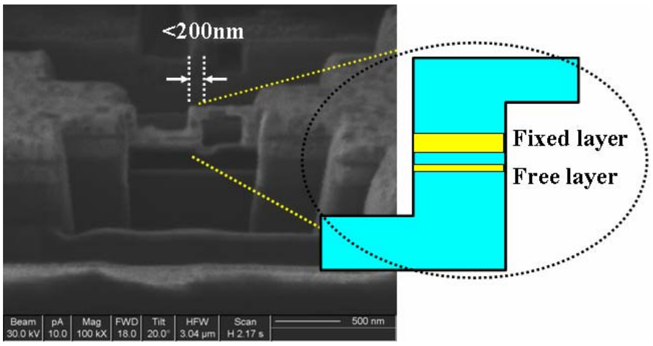

Fig.1 The geometry of the nanopillar fabricated by 3D focused ion beam lithography.

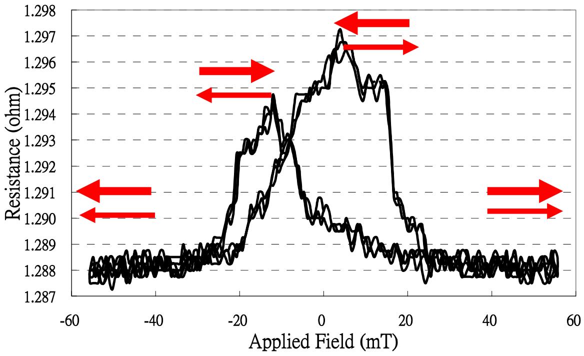

Fig.2 MR curve of the nanopillar

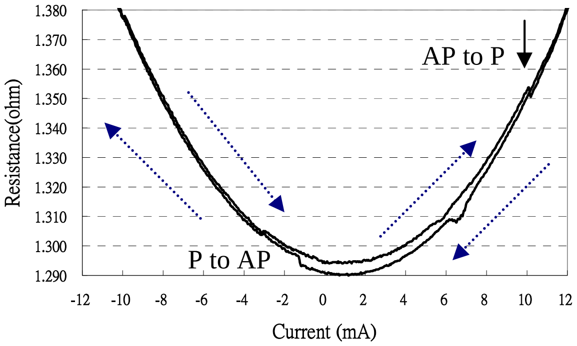

Fig.3 CIMS curve of the nanopillar