# Helium ion beam milling and Electron beam lithography to create sub-20nm sized domain wall magnetoresistance spin-valve

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We have fabricated and measured a single domain wall magnetoresistance spin-valve with sub-20 nm gap width using a novel combination of electron beam lithography and helium ion beam milling. The measurement wires and external profile of the spin-valve is fabricated by electron beam lithography and lift-off. The critical sizes of the spin-valve are the bridge length (or gap width) and bridge width [1]. However the size limit of the electron beam bi-layer lift-off resist is about 60 nm (gap width). In order to further reduce this gap width (so as the domain wall width), a helium ion beam microscope was used to create the bridge structure by milling through a nickel thin film fabricated by electron beam lithography.

The experiment was done with a Carl Zeiss OrionPLUS™ HIM. Four point probe resistance measurements and scanning electron microscopy are used to characterize the milled structures and optimize the He ion dose (Figures 1 & 2). The helium ion beam milling efficiency as extracted from electrical resistance measurements is 0.044 atoms/ion, about half the theoretical value (simulated by SRIM [2]). The helium ion beam dose required to completely mill through the 14 nm thick nickel film deposited on top of $SiO_2$/Si substrate was $3.69\times10^{18}$ ions/$cm^2$. The helium ion implantation happened at the same time of milling with an accelerate voltage 30 kV. At such high implantation dose, the helium ions' doping concentration inside the substrate can be as large as $2\times10^{21}$ atoms/$cm^2$. At this doping concentration, the helium atoms form nano bubbles with diameters 1 to 30 nm [3]. Due to the size of the implanted area, the bubbles whose calculated pressure can be as large as 0.44GPa result swelling in the bridge length direction. The swelling distance is proved to be proportional to the width of the milling pattern experimentally (Figure 3). This swelling changed the shape of the substrate permanently, which was proved by the SEM micrographs taken about one month after milling (Figure 4).

In this presentation we are going to introduce how to detect helium ion beam milling depth in a 14 nm-thick film by measuring resistance of the thin film. The advantage and drawback of helium ion beam milling (compared to the electron beam lithography) will be analyzed such as the minimum feature size and strain induced by substrate swelling. A typical step-like magnetoresistance curve has been measured proving that helium ion beam milling is capable of fabrication of spintronics devices (Figure 5).

References:

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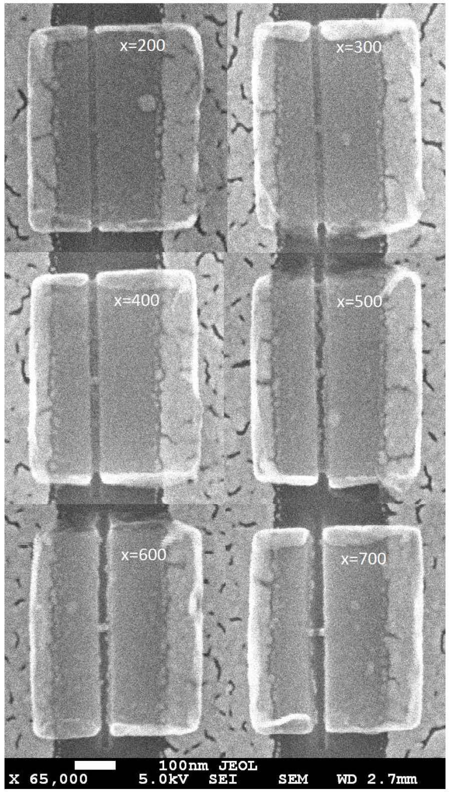


Figure 1. SEM micrograph of spin-valves milled by helium ion beam with x times base dose scan.

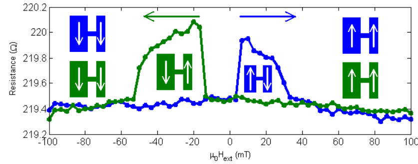


Figure 5. Typical step-like spin-valve R-H curve measured at room temperature. The external magnetic field was swept from -100 mT to 100 mT at a speed of 20 mT. The resistance was measured via a 4-point measurement and the current was 50 μA. The arrows inside pads indicate the orientation of magnetization inside domain pads.

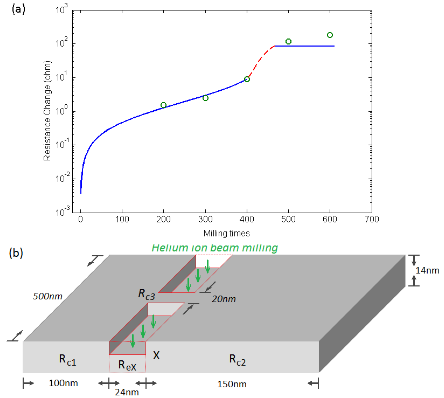


Figure 2. (a) plot of resistance versus helium ion beam dose. (b) 3-D sketch of helium milling.

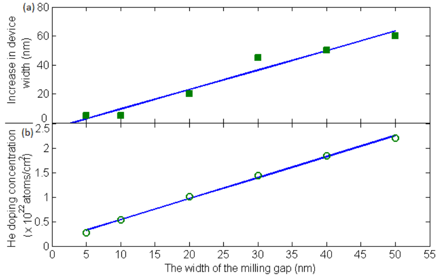


Figure 3. (a) plot of swelling distance to milling gap width (b) plot of He doping concentration to milling gap width.

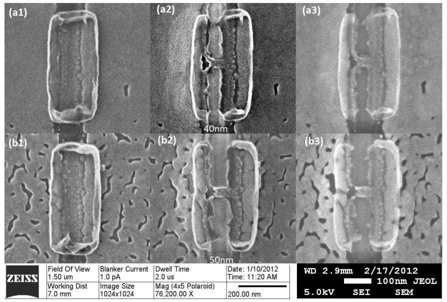


Figure 4. HIM & SEM micrographs of two milled samples with milling width 40 nm and 50 nm. **a** before, **b** just after, **c** one month after milling.