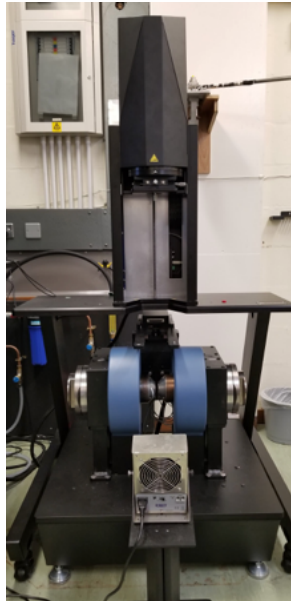


Instruction on Practicals in Information Storage and Spintronics

In the practical sessions of Information Storage and Spintronics, you are asked to determine the structure of your device provided using energy dispersive X-ray spectroscopy (EDX) and to characterise the corresponding magnetic properties using vibrating sample magnetometry (VSM), magnetoresistance (MR) measurements and magnetic force microscopy (MFM).

Your device consists of a ferromagnet dispersed in a non-magnetic matrix. A similar structure in amorphous states has been used as a magnetic sensor.

1. Vibrating sample magnetometer (VSM) (P/A 016):



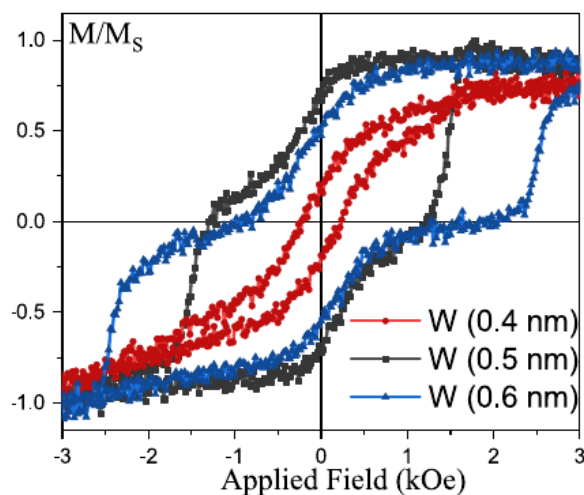
Magnetisation curves will be measured using VSM (Lakeshore 8600 Series VSM). The system can apply a magnetic field up to ± 27.6 kOe with the sensitivity of $< 1 \mu\text{emu}$, which allows highly sensitive magnetisation measurements within a few minutes.

A calibration sample needs to be measured first. A 5 mm square sample will then be placed on the VSM probe for the in-plane measurement using dedicated grease. Here, you need to make sure the sample does not move during the measurements. The VSM probe will then be attached to the VSM unit allocated above the magnet. Here, you need to pay special attention not to damage the probe. After setting the probe, you can start magnetisation measurements under an in-plane magnetic field by selecting measurement settings on the control screen.

For quantitative analysis, you need to measure the volume of your sample. You can measure precise area of the sample using the optical microscope next to VSM. In this study, you need to estimate the total thickness of the ferromagnetic layers by comparing the measured saturation magnetisation (unit in emu) and the saturation magnetisation of the ferromagnetic layer you derived in Section 1 in a literature. This estimation should be included in your report.

Once the measurement is finished, you can export the data as a text file. The magnetisation curve(s) against a magnetic field should be included in your report. You should discuss what is the coercivities of the ferromagnetic layers and how the magnetisations of these layers are switched by applying a magnetic field. You should also correlate the magnetisation configurations detected by the measurements with a spin valve (or magnetic tunnel) junction used in a magnetic random access memory.

In your report, you need to plot the magnetisation curve (see an example below). You first need to discuss how you calibrated the magnetisation. You then need to discuss the magnetisation reversal process of your device with a diagram showing the magnetisation configurations in your device. You also need to estimate the total thickness of the ferromagnetic layers by comparing your measured saturation magnetisation and literature value of the material derived from your XRD measurement. See Lakeshore web page for more details.



2. Energy dispersive X-ray spectroscopy (EDX) (Nanocentre):



EDX attached to a scanning electron microscope (SEM; JEOL, JSM-7800F Prime) will be used to determine the materials used in your spintronic device. This SEM can be operated under the acceleration voltages between 0.01 and 30 kV. It has angle resolution of < 0.8 nm at the acceleration of 15 kV and 1.2 nm at 1 kV. It can magnify up to 1,000,000 times with the working distance of 2~25 mm.

As detailed in the user manual, you need to place your sample on the sample holder using a conductive tape. Make sure the sample is stabilised well to avoid any vibration occurred during imaging. You then need to place the holder at the end of the transfer arm by venting the load-lock chamber.

After pumping down the load-lock chamber, you can transfer the sample into the main chamber by inserting the transfer arm. You then need to adjust the stigmatism and focus of the electron beam using the SEM controller for imaging. Once you choose the area to be investigated, you can run an EDX scan and obtain EDX mapping.

After completing the measurement, the EDX data and maps should be exported as image files. By analysing the EDX peaks, you can identify the ferromagnetic and non-magnetic materials used in your device. Note the device consists of a ferromagnet dispersed in a non-magnetic matrix.

In your report, you need to plot the EDX profile and index all the peaks associated with the ferromagnetic and non-magnetic materials. You then need to discuss the device structure with using the EDX maps. See Oxford Instruments users' manuals for more details.

3. Magnetic force microscopy (MFM) (P/Z 008):



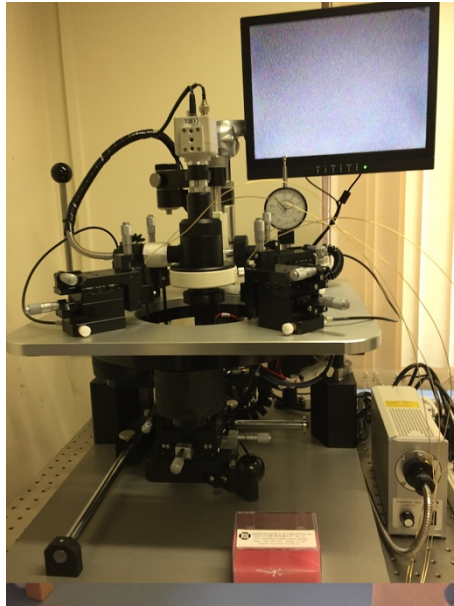
Magnetic domain structures will be measured using MFM. A magnetic tip will scan over the surface of your sample to detect the stray fields.

Your 5 mm square sample will be placed on the sample stage with facing upwards. A magnetised tip will be lowered on the sample surface with ~ 100 nm distance. The scanning conditions can be controlled on the computer screen. You need to change the height of the tip and scanning speed to optimise the image to clearly observe magnetic domain configurations.

You should export your MFM images as an image file. You should discuss the magnetic domain configurations depending on the contrast. You should also describe how the magnetic domains are reversed under a field application.

In your report, you need to include a MFM image. You first need to explain the type of magnetic domain configurations with magnetisation orientations. You then need to describe the magnetisation reversal process of your device with a magnetic field and compare it with the above results. See nanoscan manual for more details on the measurements.

4. Magnetoresistance (MR) (P/Z 008):



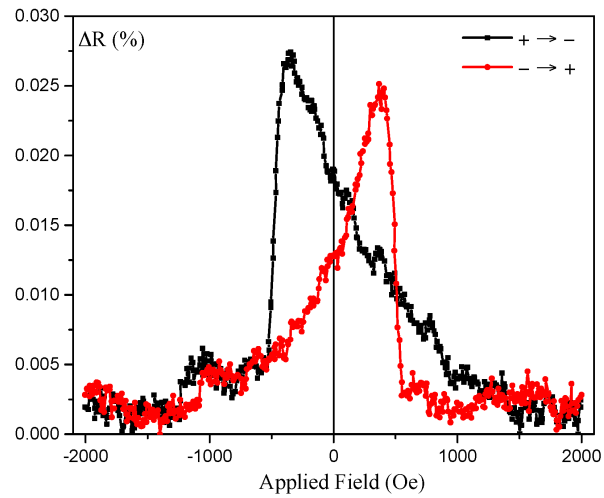
Magnetoresistance will be measured using a purpose-built MR measurement setup. Four probes to be pushed onto your sample will be used to apply an electrical current between the outer probes and to measure voltage drop across the inner probes. The Delta method will be used to achieve the sensitivity of nA at room temperature.

Your 5 mm square sample will be placed on the sample stage with facing upwards. The probes will then be lowered by a lever. The detailed setting for the measurement can be selected on the control screen. You will need to optimise the setting to avoid an open MR loop, which is typically due to the Joule heating by applying a large electrical current for a long time.

You should export your MR data as a text file and draw a graph of MR signals with respect to a magnetic field. You should compare the switching fields measured by the MR setup and those measured by AGFM. You should discuss the magnetisation configurations in each step of the MR curve. You should also consider why the measured MR is smaller (or larger) than that used in a read head of magnetic recording or a magnetic random access memory.

In your report, you need to plot the MR loop (see an example below). You first need to derive the MR ratio from the loop. You then need to compare the magnetisation switching fields and discuss the reversal process of your device with a diagram showing the magnetisation configurations in your device. You also need to discuss the amplitude

of the MR ratio estimated by comparing with the values required for magnetic recording and memories. See Keithley web page for more details on the measurements.



At the end of your report, you should make a guess at the multilayered sample structure based on the three measurements. You should also discuss how to improve the MR ratio for device applications.