Thermally assisted magnetisation reversal in a giant magneto- resistive junctions

In a modern computer, up to 40% of the power is wasted as heat generation, which requires cooling components. In order to ultilise some of the heat generated, thermoelectric devices have been widely investigated and implemented. In this study, we have focused on the spin Seebeck effect to convert heat generated by flowing an electrical current for the operation of a magnetic tunnel junction by encapsulating with a ferromagnetic insulator, which can assist current-induced magnetisation reversal via spin wave induced by the spin Seebeck effect. This in turn reduces the critical current density for the magnetisation reversal and further reduces the total power consumption for the operation.

The spin-caloritronic effects, such as the Seebeck [1], Peltier [2] and Nernst [3] effects, are gaining significant attention due to the potential to harvest previously wasted energy in the form of heat [4]. In ferromagnetic insulators like yttrium iron garnet (YIG) or Fe_2O_3, spin waves can be generated via the spin-Seebeck effect in the presence of a thermal gradient. For ideal efficiency this thermal gradient can be provided by the operation of the device itself via Joule heating. While the usual length scale for these gradients is micrometres, in this work a current-perpendicular-to-plane (CPP)-giant magnetoresistance (GMR) device has been insulated with Fe_2O_3 on a nanometric scale to evaluate the assistance of magnetisation reversal by a spin wave induced by the spin Seebeck effect.

A Heusler-alloy GMR multilayer, consisting of $Co_2Fe_{0.4}Mn_{0.6}Si$ (CFMS) (5)/$Ag_{0.78}Mg_{0.22}$ (5)/ CFMS (5) (thickness in nm), was grown via ultra-high-vacuum sputtering on a MgO(001) substrate with a Cr (20)/Ag (40) seed layer and was capped by Ag(2)/Au (5) layers. The seed and Heusler alloy layers were annealed at 650°C and 500°C respectively to aid crystallisation. Photo- and electron-beam lithography followed by Ar-ion milling were used to fabricate a series of elongated pillars with major axis lengths between 100 and 800 nm. As shown in Fig. 1, the milling was stopped ~1 nm into the bottom CFMS layer. For adhesion a Cr (1)/AlO (2) insulating layer was deposited underneath a 5 nm Fe_2O_3 channel around the GMR pillar.

Figure 2 shows a typical GMR behaviour for the pillars. When the field is swept from a positive to negative direction a 2.6% GMR ratio is observed, characterised by a broad rotation-controlled reversal followed by a sharper nucleation reversal. This is typical of a low-coercivity Heusler alloy such as CFMS. However, when the magnetic field is swept from negative to positive an 8% GMR signal is observed, four times greater than that in the opposite direction.

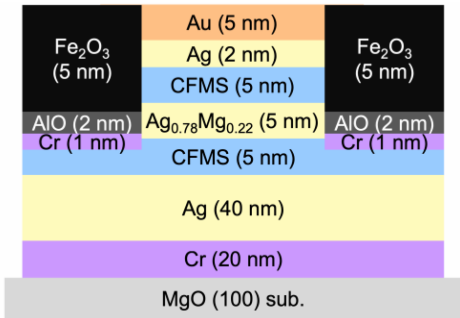

Fig. 1 Schematic of thermally assisted GMR device.

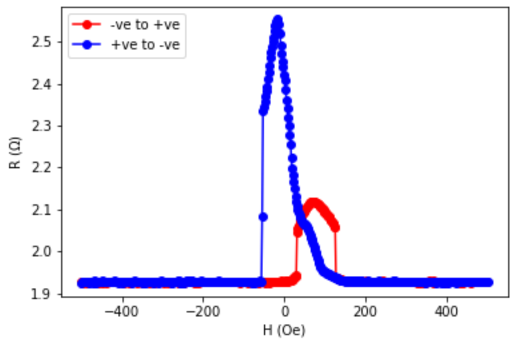

Fig. 2 Typical asymmetric GMR behaviour of spin-Seebeck enhanced GMR via Fe_2O_3.

The current application generates a thermal gradient in the Fe_2O_3 channel via Joule heating, which in turn creates a spin-wave via the Seebeck effect. This aids the magnetisation reversal of the free layer via the stray field from the Fe_2O_3. This thermal assistance is asymmetric due to the significant coercivity (~1 kOe) of the Fe_2O_3 layer compared to the soft Heusler alloy with coercivity <50 Oe.

The corresponding magnetisation switching induced by a current is also observed as shown in Fig. 3. We measured a clear switching along the current flowing from the bottom ferromagnet to the top ferromagnetic layer under a small in-plane magnetic field application of 15 Oe. The current sweep starts at 0 and increases to -20 mA (red curve), indicating antiparallel to parallel magnetisation switching. The magnetisation switching is observed at 13 mA, corresponding to the switching current density of (3~10) $\times 10^{-7}$ A/cm^2, which is almost one order of magnitude smaller than that for a similar device with the conventional AlO insulator. The current is swept to +20 (blue curve) and -20 mA (green curve) accordingly, which overlaps with each other and does not induce any magnetisation switching. This indicates that the spin wave induced by the spin Seebeck effect stabilises the magnetisation, requiring the optimisation of the pillar design for reversible operation. The critical current density for switching varies slightly, suggesting the instability of the thermally-induced spin wave in the device. This result demonstrates the magnetisation switching assisted by spin wave induced in the Fe_2O_3 insulator due to the spin Seebeck effect, which can be useful for the reduction in the power consumption of the magnetic memory operation.

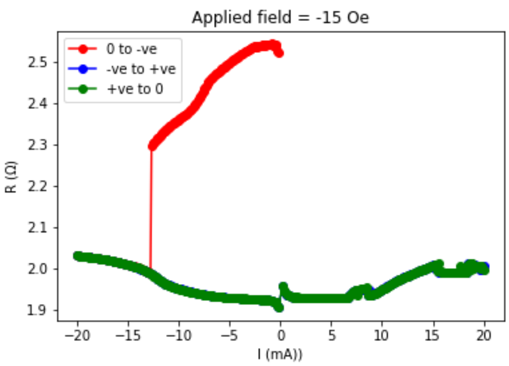

Fig. 3 Corresponding current-induced magnetisation switching behaviour of spin-Seebeck enhanced GMR via Fe_2O_3 under the in-plane magnetic field of 15 Oe.

References

[1] K. Uchida *et al.*, *Nature* **455**, 778 (2008).
[2] J. Flipse *et al.*, *Phys. Rev. Lett.* **113**, 027601 (2014).
[3] S. Meyer *et al.*, *Nature Mater.* **16**, 977 (2017).
[4] G. E. W. Bauer, E. Saitoh and B. J. van Wees, *Nature Mater.* **11**, 391 (2012).

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Atsufumi Hirohata (University of York)
E-mail: atsufumi.hirohata@york.ac.uk
http://www-users.york.ac.uk/~ah566/