Dot size dependence of magnetization switching by spin-orbit torque in antiferromagnet/ferromagnet structures

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Spin-orbit torque (SOT) induced magnetization switching, brought about by in-plane current in heavy metal/ferromagnet heterostructure with broken inversion symmetry, is expected to be a new scheme to switch magnetization in three-terminal spintronics devices [1, 2]. The main issue of the scheme is a necessity of external in-plane magnetic field application for bipolar switching. Recently, it was shown that antiferromagnetic materials can be used as both a source of SOT and exchange-bias in antiferromagnet/ferromagnet heterostructures, allowing for an external-field-free switching [3]. Another feature of studied micrometre-sized devices was analogue-like switching of magnetization with increasing current, which is potentially interesting for neuromorphic computing. Here, we study the field-free switching in smaller devices, aiming application-relevant nanometre-sized dots.

Stacks of Ta(3)/Pt(4)/PtMn(t_{PtMn} = 6.0, 6.8, 7.6, 8.4)/[Co(0.3)/Ni(0.6)]$_{2.5}$/MgO(1.2)/Ta(3) (thicknesses in nm) are deposited on Si substrates by DC/RF magnetron sputtering and processed into dots (diameter D = 60–1000 nm) with Hall bars. In-plane DC current with various amplitudes is applied to reverse magnetization and analogue-like behaviour is studied at room temperature. Magnetization state is detected through the anomalous Hall effect.

We find that at t_{PtMn} = 6.0 nm exchange bias is insufficient and at t_{PtMn} = 8.4 nm ferromagnetic layer has in-plane easy axis. We successfully observe external-field-free magnetization switching in perpendicular easy axis devices with t_{PtMn} = 6.8 and 7.6 nm and sizes down to 60 nm. As the size decreases, analogue-like behaviour transforms to the commonly-observed scheme with two magnetization states. The threshold size is between 300 and 500 nm for t_{PtMn} = 6.8 nm and between 200 and 250 nm for t_{PtMn} = 7.6 nm. The switching current density is roughly the same with that in our previous study on micrometer-sized devices (~ 1×10^{11} A/m^2) [3] and it gradually increases with the size reduction below the threshold size.

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