Observation of memristive domain patterns during spin-orbit torque switching in antiferromagnet/ferromagnet heterostructures

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Efficient field-free spin-orbit torque (SOT) magnetization switching has been achieved by use of antiferromagnet (AFM)/ferromagnet (FM) structures [1]. In addition, use of the AFM in them leads to formation of reproducible analogue-like (or "memristive") switching with multiple nonvolatile states. These properties allowed using such structures in an artificial-neural-network-based associative memory [2]. Additional electrical measurements suggested that the memristivity originates from separate switching of binary domains of 200 nm scale [3], which is nonsimultaneous due to exchange bias (EB) variation. The described picture differs from the conventional SOT switching in nonmagnet (NM)/FM heterostructures and its deeper understanding is important for fundamental research of SOT and EB as well as applications.

Here we use X-ray magnetic circular dichroism, an insightful tool for SOT switching studies [4], and couple it to photoemission electron microscopy to image ferromagnetic domains of an AFM/FM heterostructure in its intermediate memristive states. The measured stacks of Ta/ Pt/ PtMn/ $[Co/Ni]_2$/ Co/ MgO/ Ru were sputter-deposited and processed into 10-μm wide channels by photolithography and Ar ion milling. EB was induced by annealing at 300°C for 2 hr in the presence of 1.2 T magnetic field, collinear to the channel.

The experiment revealed domain patterns corresponding to different points of the hysteresis loop. In accordance with the electrical estimations, the domain structure is distinctly different from NM/FM cases and its feature size is of the order of 100 nm. We found that domains reproduce themselves in repetitive switching sequences and do not evolve between the applied pulses. When the pulses were applied in trains, they induced gradual switching by extending the domains. This is the first imagining of field-free SOT switching and it clarifies the way for achieving memristors and binary AFM/FM cells of desired properties.

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