Spin-orbit torque memristor, operated by pulsed currents

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Recently, analogue-like (memristive) spin-orbit torque (SOT) induced magnetization reversal at zero fields was demonstrated in antiferromagnet (AFM)/ferromagnet (FM) systems [1,2]. It was found that AFM plays a triple role: generates SOT, imposes effective in-plane field due to exchange bias (EB) [1] and gives rise to memristive behavior due to domain-to-domain variation of EB [3]. The system is attractive for neuromorphic computing [4]; however, only operation by dc currents was studied so far. Here we show that τ_p down to nanoseconds can be used for reliable operation of memristive devices.

We fabricated Hall bar devices with a PtMn/[Co/Ni] stack through sputter-deposition, electron beam lithography and Ar ion milling. To provide EB, fabricated devices were annealed at 300°C for 2 hours in the presence of 1.2 T magnetic field, collinear to the channel.

Hall resistance R_{Hall} versus voltage V (R_{Hall}-V) curves for τ_p in the range from 2 s to 1 ns are shown in Fig. 1. Three modes of switching are observed: for τ_p > 10 ms, R_{Hall}-V curves are independent of τ_p (Fig. 1(a)); for τ_p < 10 ms, average switching voltage $\langle V_{SW}\rangle$ increases with decreasing τ_p; for τ_p < 500 ns, both $\langle V_{SW}\rangle$ and the slope of switching region increase (Fig. 1(c)). We find that Joule heating is responsible for this behavior and enables new functionality, such as multiple pulses lengths integration. Reproducibility of short pulse operation is ensured by performing 100 write cycles at τ_p = 10 ns, 1 μs, 10 ms. The result indicates that reliable separation of R_{Hall} states can be achieved for all the studied τ_p. We conclude that SOT-induced memristive operation can be controlled by pulse length as well as pulse magnitude. The obtained characteristics can pave a way to go beyond digital computing and offer various opportunities such as counters/integrators and artificial synapses in neuromorphic computing.

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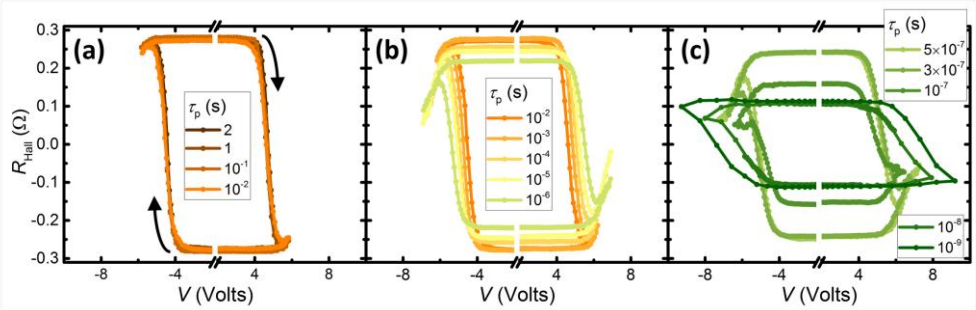

Fig. 1. R_{Hall}-V hysteresis loops. Three qualitatively different regimes are found for (a) 10 ms ≤ τ_p ≤ 2 s, (b) 1 μs ≤ τ_p ≤ 10 ms and (c) τ_p < 1 μs. Black arrows in (a) indicate direction of V sweep with start from 0 V.

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