Electric field control of spin-orbit torque magnetization switching in a spin-orbit ferromagnet (Ga,Mn)As single layer

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Current-induced spin-orbit torque (SOT) has been proposed as a promising method to control the magnetization of ferromagnetic materials, which can dramatically improve the performance of spintronic devices, such as magnetoresistive random access memory (MRAM). To achieve desirable magnetization switching and to realize the multifunctional spin logic and memory devices, efficient manipulation of SOT is important. It was reported that SOT magnetization switching can be manipulated by controlling the interfacial oxidization in bilayer systems and the density and type of surface carriers in topological insulators. However, the switching efficiency is limited and the switching process remains to be improved.

Here, we report successful control of full SOT magnetization switching via an external electric field in a single-crystalline ferromagnetic semiconductor (Ga,Mn)As with strong spin-orbit coupling [1,2]. As shown in Fig. 1a, the SOT switching is induced by sweeping a current with a density J along the $[\bar{1}10]$ direction with applying the gate voltage V_g of ±10 V in a perpendicularly magnetized (Ga,Mn)As single layer. The application of V_g = +10 V decreases the switching current density J_c to 7.6×10^5 A cm^{-2} and the negative V_g = –10 V increases the J_c to 8.7×10^5 A cm^{-2}. Therefore, the J_c can be changed with a large ratio of 14.5% by applying V_g, which is ascribed to the successful modulation of the interfacial electric field. Figure 1b shows the manipulation of the SOT switching at different V_g at 40 K, which indicates that the switching behavior is solidly modulated via the electronic field reversibly. Our finding will advance the development of energy-efficient gate-controlled spin-orbit-torque devices and help further understanding of the switching mechanism.

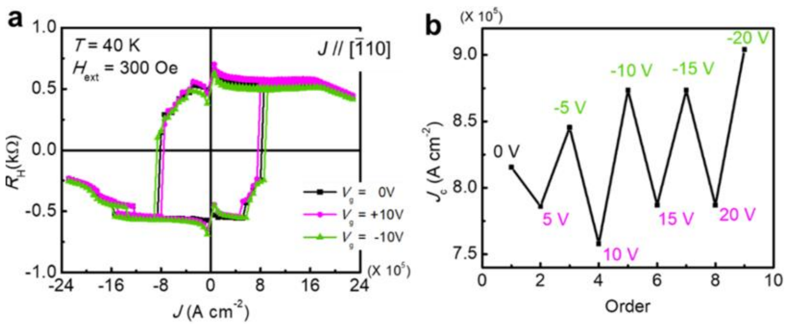

Fig. 1. Gate voltage (V_g) dependence of SOT switching in a (Ga,Mn)As single layer with J // $[\bar{1}10]$.

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