Magnetization switching by voltage controlled DMI

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Dzyaloshinskii-Moriya interaction is the anti-symmetric exchange interaction postulated by Igor Dzyaloshinskii in 1958[1]. Two years later Toru Moriya showed that the spin-orbit coupling is the microscopic mechanism of the antisymmetric exchange interaction [2]. The effects of the DMI on the magnetic properties of bulk materials have been extensively studied, e.g., the DMI is the source of the weak ferromagnetism of Fe2O3. Recently the voltage control of the DMI has attracted much attention as a tool for low power spin manipulation. One of the present authors showed that the Rashba spin-orbit interaction at the interface of the semiconductor nanostructures induces the interface DMI whose strength can be controlled by the gate voltage [3]. Very recently, Nawaoka et al. found that the DMI in the Au/Fe/MgO artificial multilayer can be controlled by application of a voltage [4].

The magnetic anisotropy (MA) is another magnetic property which can be controlled by the voltage. The voltage control of MA in a thin ferromagnetic film has attracted much attention as a key phenomenon for developing a voltage-controlled magnetic random access memory (MRAM) with low power consumption [5-9]. Shiota et al. demonstrated that the coherent magnetization switching is induced by application of voltage pulse to a few atomic layer of FeCo[4]. During the pulse application the magnetization coherently precesses around the effective magnetic field, and the magnetization switches if the pulse width is set to one-half period of the presession. However, since this is the toggle-mode switching, pre-reading is necessary for writing the MRAM. To avoid pre-reading it is necessary to develop a writing scheme based on the deterministic switching as shown in Fig. 1 (a), where the magnetization direction after the voltage pulse is determined by the polarity of the voltage and is independent of the initial magnetization direction.

Here we propose a new writing scheme of MRAM utilizing voltage-induced changes of MA and DMI. Based on the micromagnetics simulations we demonstrated that voltage-induced changes of MA and DMI can switch the magnetization of a perpendicularly magnetized right triangle deterministically; i.e., the magnetization direction is determined by the polarity of the voltage pulse

The system we consider is a perpendicularly magnetized right triangle (64 nm × 32 nm × 2 nm) shown in Fig. 1 (b). The micromagnetics simulations were performed by using the software package MuMax3[10]. The system is divided into cubic cells of side length 2 nm. The following material parameters are assumed: saturation magnetization Ms = 1.35 MA/m, exchange stiffness constant A = 10 pJ/m, Gilbert damping constant $\alpha = 1$. The external field of 100 Oe was applied in the x-direction. The anisotropy constant (K) and the DMI constant (D) are assumed to vary with the applied

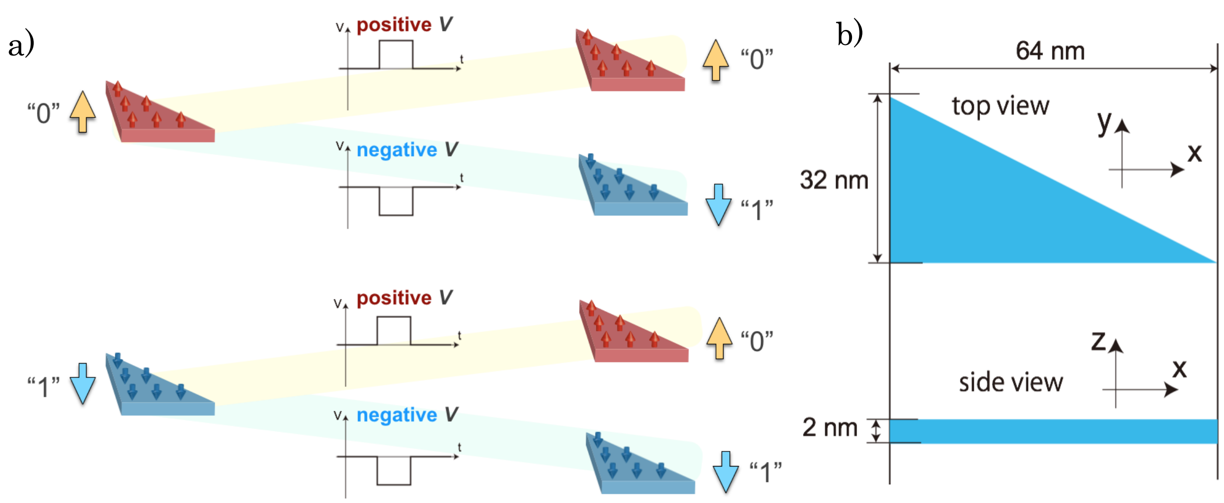

Fig. 1 a) Schematic illustration of the deterministic switching. The final magnetic state is determined by the polarity of the voltage pulse. b) Top and side views of the ferromagnetic triangle we simulated.

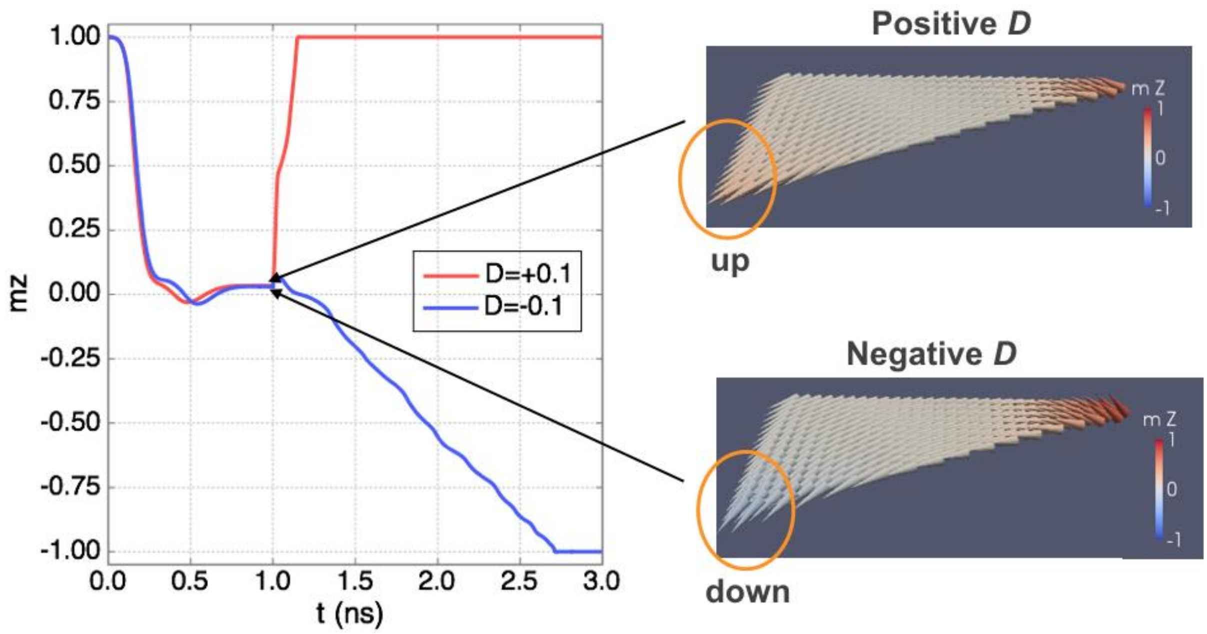

Fig. 2 Temporal variation of the z-component of the averaged magnetization, m_z, and snap shots of magnetization at the end of the pulse duration. The result for positive (negative) bias voltage is represented by the solid red (dotted blue) curves.

bias voltage in the different manner. In the absence of the applied voltage the anisotropy and DMI constants are K = 4 mJ/m2 and D = 0, respectively. When the positive (negative) bias voltage is applied they are K = 1.4 mJ/m2 and D = + (-) 0.1 mJ/m2. The width of the voltage pulse is 1 ns. The temperature is assumed to be zero.

The calculated results are shown in Fig. 2. The z-component of the averaged magnetization (m_z,) for the positive and negative bias voltage pulse are plotted by the solid (red) and dotted (blue) curves, respectively. The initial state is set as the perpendicularly polarized state with $m_z = 1$. Application of the voltage pulse for 1 ns tilts the magnetization to the in-plane direction and creates nucleation sites at the edges. The positive (negative) values of m_z are represented by red (blue) tones. The magnetization of the nucleation site at the left down edge points slightly down (up) for the positive (negative) bias voltage pulse due to the DMI as indicated by the circles on the snapshots. After 1 ns the bias voltage is turned off, and the magnetization relaxes to the perpendicularly magnetized state. The magnetization of the final state is the same as that of the nucleation site at the left down edge. Therefore the magnetization switches only if the negative bias voltage pulse is applied. For the initial state with $m_z = -1$ the magnetization switches only if the positive bias voltage pulse is applied. The systematic analysis for a wide range of parameters and conditions for switching will be presented.

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