Voltage-induced precessional switching at zero bias magnetic field in a conically magnetized free layer

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Voltage-induced magnetization switching[1] at zero bias magnetic field has become one of the key requirements in developing voltage-torque magnetoresistive random access memory (MRAM). In the conventional magnetic tunnel junctions (MTJ) with the perpendicular magnetization, however, voltage-induced magnetization switching has been demonstrated under a bias magnetic field having in-plane (IP) component.[2,3] Instead of bias magnetic field, the IP component of the shape anisotropy field, H_k, has been often used. Finite H_k is commonly obtained in a ferromagnet having an elliptic-cylinder shape. In the case of a perpendicularly magnetized free layer, however, the shape anisotropy field cannot move the magnetization from the equilibrium state because H_k is zero at $(m_x, m_y, m_z) = (0, 0, \pm 1)$ where m_x and m_y (m_z) are IP (perpendicular) components of the unit magnetization vector ($\boldsymbol{m}$) of the free layer (see Fig. 1(a)). Tilting the angle of the magnetization from the perpendicular direction is also necessary for switching of the free layer magnetization.

To tilt the magnetization, we propose the usage of a cone state. Cone state is the magnetization state (see Fig. 1(b)) where the tilted magnetization is stabilized by the competition between the first- and the second-order magnetic anisotropy energies, $K_{1,\mathrm{eff}}$ and K_{u2}.[4,5] Here $K_{1,\mathrm{eff}}$ is the effective anisotropy constant, where demagnetization energy is subtracted from the first-order anisotropy constant (K_{u1}). The MTJ we assume is illustrated in Fig. 1(a). x-axis is parallel to the major axis of the ellipse. In our case,[6] $(m_x, m_y, m_z) = (0.322, 0, 0.947)$ in the equilibrium state. The voltage-induced dynamics is analyzed with the following Landau-Lifshitz-Gilbert (LLG) equation, $\mathrm{d}\boldsymbol{m}/\mathrm{d}t = -\gamma_0 \boldsymbol{m}\times [\boldsymbol{H}_{\mathrm{eff}} + \alpha(\boldsymbol{m}\times\boldsymbol{H}_{\mathrm{eff}})]$, where t is time, γ_0 is the gyromagnetic ratio, α is the Gilbert damping constant, and $\boldsymbol{H}_{\mathrm{eff}}$ is the effective magnetic field defined as $\boldsymbol{H}_{\mathrm{eff}} = -(1/(\mu_0 M))\nabla E$. Here, E is the energy density of the free layer at a finite voltage given by $E = (1/2)\mu_0 M_s^2(N_x m_x^2 + N_y m_y^2 + N_z m_z^2) + K_{u1}(1 - m_z^2) + K_{u2}(1 - m_z^2)^2$, where μ_0 is the vacuum permeability, M_s is the saturation magnetization, and N_x, N_y and N_z are demagnetization coefficients. In Fig. 1(c), an example of the simulation results is shown. The oscillation of m_z extends from positive to negative region. It indicates that voltage-induced precessional switching at zero bias magnetic field is available in a conically magnetized free layer with the elliptic-cylinder shape.

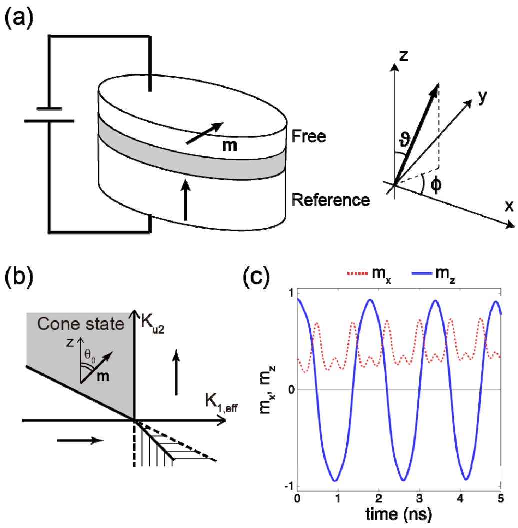

Fig. 1 (a) MTJ we assume. (b) Phase diagram of magnetic film with uniaxial anisotropy constants $K_{1,\mathrm{eff}}$ and K_{u2}. (c) Time evolution of m_x and m_z under application of voltage.

This work was partly supported by the ImPACT Program of the Council for Science, Technology and Innovation

Reference

1) Y. Shiota et al: *Nat. Mater.*, 11, 39 (2012).
2) S. Kanai et al: *Appl. Phys. Lett.*, 101, 122403 (2012).
3) Y. Shiota et al: *Appl. Phys. Express*, 9, 013001 (2015).
4) D. Apalkov and W. Butler, US Patent 8,780,665 (2014).
5) R. Matsumoto et al: *Appl. Phys. Express*, 8, 063007 (2015).
6) The example of the parameters of the conically magnetized free layer in this study: M_s = 1400 kA/m, α = 0.005, K_{u1} = 1081 kJ/m^3, and K_{u2} = 193 kJ/m^3 at zero voltage. K_{u1} = 1051 kJ/m^3, and K_{u2} = 43 kJ/m^3 under the application of a voltage. The volume of the free layer is 32 × 16 × π × 1 nm^3.