Interfacial multiferroics with perpendicular magnetic anisotropy

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Multiferroic materials have a great potential for low-power mannipulation of magnetization orientation using an electric field, where the cross coupling between the ferroic orders such as magnetization, electric polarization, strain, etc. plays a critical role[1–3)]. In general, the ferroic phase transition temperatures of single-phase multiferroics is lower than room temperature, requiring alternative material systems with multiferroic properties for spintronic applications. In this study, we investigate electric field driven magnetization switching of ferromagnetic/ferroelectric (ferroelastic) interfacial multiferroics with perpendicular magnetic anisotropy (PMA), where the multiferroic properties appear at room temperature[4–7)].

The first example which we study is [Cu/Ni] multilayer/ferroelectric $BaTiO_3$(001) interfacial multiferroics with PMA. Since there are two types of ferroelectric domains, i.e., $a-$ and $c-$domains, in $BaTiO_3$ at room temperature, different misfit strains are exerted on the [Cu/Ni] multilayer on $a-$ and $c-$domains. Such strain gives rise to a change in the magnetization orientation on each domain through the magnetoelastic coupling. This enables to control the magnetization orientation of [Cu/Ni] multilayers by driving the ferroelectric $a-c$ domain wall in an electric field. With this approach, we demonstrate electric field control of the magnetization orientation of [Cu/Ni] multilayers between out-of-plane and in-plane. Also, X-ray magnetic circular dichroism measurements show that modulation of the orbital magnetic moments of Ni layers occurs in an electric field while no visible changes in the spin magnetic moments are seen. These results clearly indicate that the orbital magnetic moment that could be manipulated by electric field induced strain is responsible for the magnetization switching in [Cu/Ni] multilayer/$BaTiO_3$ interfacial multiferroics.

Another example of interfacial multiferroics with PMA is [Cu/Ni] multilayer/ferroelectric $0.7Pb(Mg_{1/3}Nb_{2/3})O_3$-$0.3PbTiO_3$(001) (PMN-PT) heterostructures. PMN-PT has 8 equivalent $\langle 111 \rangle$ crystallographic orientations, along which the ferroelectric polarization favors to align. When an electric field is applied across the PMN-PT substrate, either 71°, 180°, or 109° switching of ferroelectric polarization occurs, thereby interfacial strain transferred from PMN-PT to [Cu/Ni] multilayer could trigger the magnetization switching. In this work, we demonstrate electric field modulation of the magnetic domain structures of [Cu/Ni] multilayer/PMN-PT using Kerr microscopy. When the out-of-plane magnetic field is swept from the positive saturation to a small negative magnetic field (~ -45 Oe), partial reversal of the magnetization occurs, thereby a maze-type domain structure appears. As an electric field is applied at the small negative magnetic field, a clear evolution of the reversed magnetic domains is observed. The result is compatible with separate Kerr magnetometry experiments, where multilevel magnetization states can be seen by an electric field. The underlying mechanism of the evolution of the magnetic domain structure will be discussed based on possible distinct interfacial strain for 71°, 180°, or 109° switching of ferroelectric polarization in PMN-PT.

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