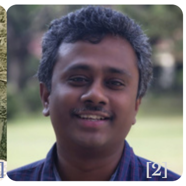
Magnetic Field Controlled Multistate Non-Volatile Random Access Memory



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Multiferroics are materials that simultaneously possess more than one order parameter, such as magnetization, polarization and/or strain. The magnetic and dipolar interaction gives rise to the magnetoelectric phenomenon, known for induced magnetization or polarization under an external electric or magnetic field, respectively. These materials can be either single-phase materials or composite materials, mostly made of a ferroelectric phase with spontaneous polarization and a magnetically ordered phase coupled via lattice strain. The magnitude of the magnetoelectric coupling coefficient of single-phase materials is weak and rare at room temperature. Hence, in most of the non-volatile memory devices such as RAM, sensors, and energy harvesting applications, magnetoelectric behaviour is achieved by composite materials.

The non-volatile memory technology in the market uses ferro/ferrimagnetic-based tunnelling magnetoresistance, in which low and/ or high magnetoresistance is read as 0 and 1 in binary codes. Current RAM research focuses on ferroelectric RAM (Fe-RAM) and resistive RAM (RRAM). Considering the magnetoelectric response of multiferroics, these materials are a potential candidate for a multistate memory device in which "+ ve" and "- ve" polarization as one binary state and new memory states will be created under a magnetic field due to magnetostriction-induced polarisation, leading to a multistate non-volatile memory device

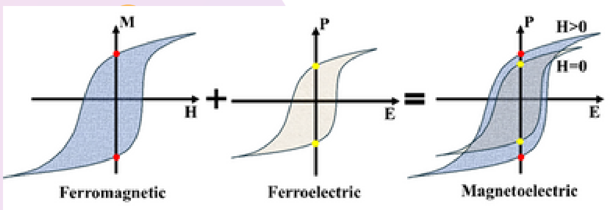

Figure 1. Schematic representation of the multistate polarization in multiferroics.

The most widely used combination of the magnetoelectric composite being the ferromagnetic phase composed of spinel, such as $CoFe_2O_4$ or $NiFe_2O_4$ and the ferroelectric perovskites like $BaTiO_3$, $Ba_xCa_{(1-x)}Ti_yZr_{(1-y)}O_3$. This combination is advantageous due to the immiscibility of these phases.

Imaging Polarization states under an applied magnetic field:

One of the methods to observe the coupling between FE polarization and magnetic domains is to study the change in the ferroelectric domains under a varying magnetic field using a piezoelectric force microscopy. The underlying sequence of coupling will be strain generated under a magnetic field in the ferromagnetic phase, which is transferred to the ferroelectric layer via the lattice, which in turn induces polarization rotation in the ferroelectric layer due to the piezoelectric effect.

$$\alpha_{ij}^{e} = \frac{\partial M_i}{\partial E_j} \qquad \alpha_{ij}^{m} = \frac{\partial P_i}{\partial H_j}$$

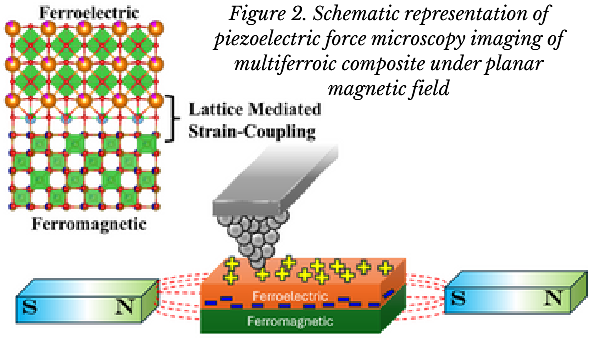

Figure 2. Schematic representation of piezoelectric force microscopy imaging of multiferroic composite under planar magnetic field

Also, since the ferromagnetic layer used has anisotropic magnetostrictive coefficients, new memory states can be created based on the magnetic field direction. The induced polarization rotation need not be always 180°. Instead, it can be gradual. The following figure confirms the magnetic field induced polarisation change and exhibit multistate non-volatile ferroelectric based memory of multiferroics under different magnitude and direction of magnetic field.

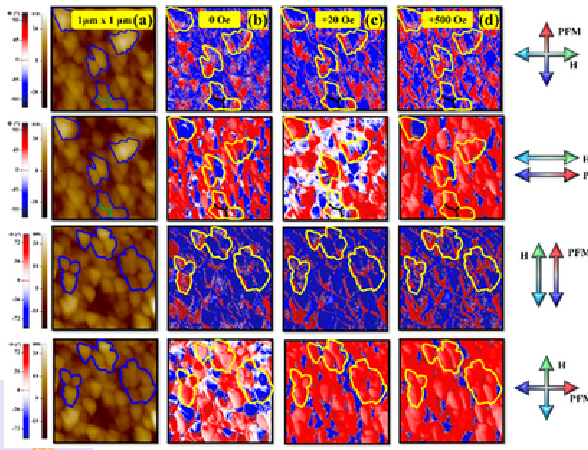

Figure 3 (a). AFM topology and PFM phase mapping of ME nanocomposite under the magnetic field of (b) 0 Oe, (c) 20 Oe, and (d) 500 Oe of different orientations. Horizontal arrows indicate in-plane field & vertical arrows indicate out-of-plane field. Red & blue

Figure 3 shows the change in FE polarization states in the presence of both planar and perpendicular magnetic fields. The studies were carried out in combination with the facilities available at the MSME department and the SATHI-CisCOM centre.

Hence, the observation of ferroelectric polarisation states using piezoelectric force microscopy under a magnetic field facilitates detailed studies on possible multi-state memory devices for memory applications.

[1] Mr Gowtham Velpandi
PhD Scholar
[2] Prof Ranjith Ramadurai
Department of Materials Science & Metallurgical Engineering