Room-temperature multiferroic superlattices

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Discovering multiferroic materials having an electrical polarization and being strongly ferromagnetic near room-temperature is a long-time-sought quest, due to the promise of novel spintronic devices. Strikingly, it appears that these two desired features are rather difficult to simultaneously co-exist. Using first-principle and Monte Carlo calculations, we demonstrate that two kinds of multiferroic superlattices do possess these two desired features [1,2].

![Figure 1](image_url)

**Figure 1.** (a) Predicted electrical polarization and (b) magnetic Curie temperature of La₂NiMnO₆/R₂NiMnO₆ superlattice as a function of the rare-earth ionic radius.

The first kind of superlattice is made by La₂NiMnO₆/R₂NiMnO₆, where R is a rare-earth ion. As shown in Fig. 1a, its electrical polarization increases when decreasing the rare-earth ionic radius. For instance, this polarization is about 9.2 μC/cm² at small temperature when R=Er (which is the rare-earth ion having the largest ionic radius). The origin of this polarization is the novel energy term \(-K\omega_R\omega_M u\), proposed in Ref. [3], where \(K\) is a constant, \(\omega_R\) and \(\omega_M\) characterize the in-plane antiphase and out-of-plane in-phase tiltings, respectively, and \(u\) is the displacement of the La or R ions with respect to their ideal positions. In both La₂NiMnO₆ and R₂NiMnO₆ bulks, the \(u\) of any two neighboring LaO or RO layers cancel each other, therefore making the whole polarization vanishing. On the other hand, in the La₂NiMnO₆/R₂NiMnO₆ superlattices, the \(u\) of neighboring LaO and RO layers, while still opposite in direction, are different in magnitude (because their \(K\) parameters are different). As a result, the polarization is finite in these superlattices, which naturally explains the so-called hybrid improper ferroelectricity [4-6]. Regarding the magnetic order of these superlattices, the ground state is ferromagnetic with a magnetization being around 2.4 μB per 5 atoms (since both La₂NiMnO₆ and R₂NiMnO₆ bulks are
ferromagnetic). As shown in Fig. 1b, the La$_2$NiMnO$_6$/Ce$_2$NiMnO$_6$ superlattice exhibits a magnetic Curie temperature of 290K, that is very close to room temperature [1], and this magnetic Curie temperature decreases when increasing the rare-earth ionic radius.

The second discovered type of multiferroic materials possessing a large polarization and a strong ferromagnetic order at room-temperature is made of superlattices combining a high Neel temperature anti-ferromagnet and a lower Curie temperature ferromagnet insulator, e.g., BiMnO$_3$/BiFeO$_3$ (BMO/BFO) superlattices. Indeed, our first-principle calculations show that BMO$_n$/BFO$_m$ can have an electrical polarization as large as 90 $\mu$C/cm$^2$ (similar to BiFeO$_3$ bulk) and are also ferromagnetic. The magnetic properties of these superlattices are strongly dependent on the thickness of BMO and BFO ($n$ and $m$), as shown in Fig. 2. In particular, the magnetization can reach large values of 0.3 $\mu_B$ per five atoms at room temperature in some cases (e.g., BMO$_1$/BFO$_3$), which is larger than that of BFO films by at least one order of magnitude. Thus, our works strongly suggest that the most promising commercial application of multiferroics (magneto-electric RAM) is indeed possible [2].

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