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PHYSICS

Towards two-dimensional room temperature multiferroics

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Multiferroic materials with coupled ferroelectricity (FE) and magnetism have long been sought for novel memory devices [1–3]. The co-existence of FE and magnetism is rare in nature, which can be attributed to their mutual exclusive origins (empty d shell for conventional ferroelectric order and partially filled d shell for magnetic order). Moreover, magnetoelectric (ME) coupling is weak in type-I multiferroics with FE and magnetism arising respectively from different mechanisms, while for type-II multiferroics with FE induced by magnetic ordering, their low spin-driven ferroelectric polarizations (mostly $<0.01\ C/m^2$) and Curie temperature (mostly <150 K) hinder their practical applications [4,5]. To date, almost all synthesized magnetoelectric multiferroics have been three-dimensional.

In a recent work, Zhong *et al.* [6] instead focused on 2D ferroelectrics [7] and predicted a room temperature multiferroic with a desirable co-existence of ferromagnetism (FM) and FE and strong magnetoelectric coupling. To be more specific, they investigated 2D thin-layer $CuCrX_2$ (X = S or Se). The Curie temperatures of FM and FE were both above room temperature, where the FM is stabilized by enhanced carrier density and polarization-driven orbital shifting. Moreover, the gradient of interlayer coupling parameter between adjacent layers gave rise to diversified types of magnetoelectric layers of different thicknesses. For example, tri-layer Cu-intercalated CrS_2, denoted as $Cu_2(CrS_2)_3$, is ferroelectric in-plane while ferrimagnetic vertically as shown in Fig. 1(a), with a net magnetization of 2.62 μ_B/f.u. For the ground state with polarization downwards, the middle layer is antiferromagnetically coupled

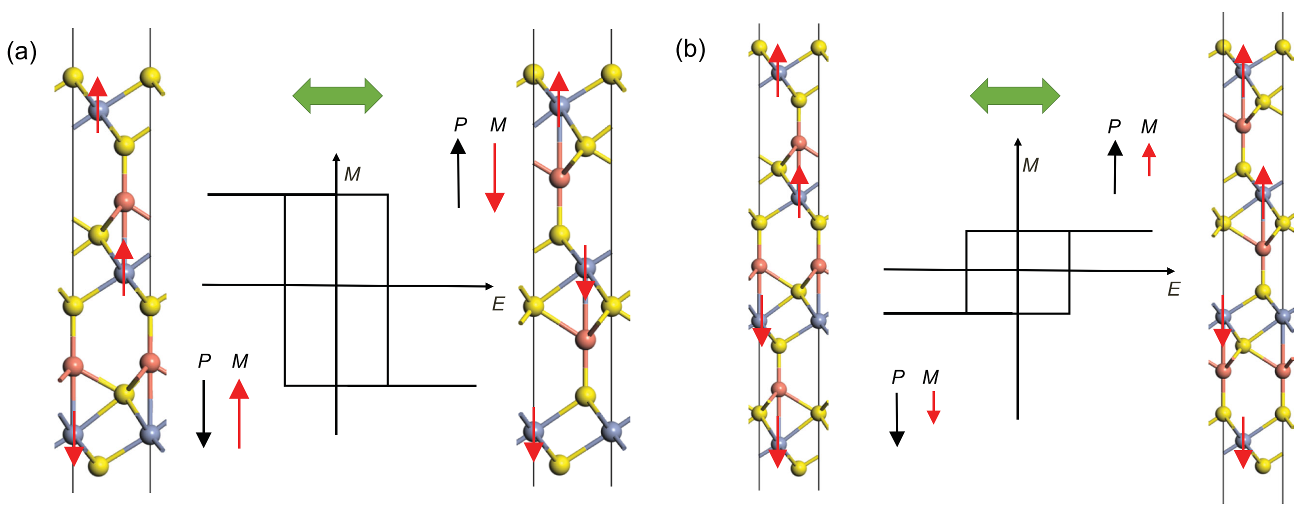

Figure 1. Spin configurations and multiferroic switching for (a) $Cu_2(CrS_2)_3$ and (b) $Cu_3(CrS_2)_4$ thin films. Black and red arrows denote the directions of polarization and magnetization, respectively. Adapted from Fig. 4 of Ref. [6].

with the down layer while ferromagnetically coupled with the top layer; when the polarization is upwards, the magnetization of the middle layer will be reversed, ferromagnetically coupled with the down layer while antiferromagnetically coupled with the top layer. Hence FE switching should enable a 180-degree reversal of a considerable magnetization of 2.62 μ_B/f.u. The ground state for four-layer Cu-intercalated CrS_2 denoted as $Cu_3(CrS_2)_4$ is shown in Fig. 1(b), where the upper two layers are ferromagnetically coupled while antiferromagnetically coupled with the two layers downwards. The net magnetization of 0.35 μ_B/f.u., which is much reduced, can also be reversed via polarization switching. The swapping of spin-up and spin-down channel in band structures during FE switching may result in a new type of 'electrical writing + magnetic reading' memory architecture.

The work by Zhong *et al.* [6] not only paves a new way to realize a room temperature ferromagnetic-ferroelectric multiferroic with strong magnetoelectric coupling [5,8,9], but may also stimulate more studies on multiferroicity in 2D systems. It remains to be seen whether the 2D multiferroic material or concept conveyed in this study can be experimentally confirmed or whether the predicted ME coupling can be confirmed in a more direct simulation of the FE switching process.

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INFORMATION SCIENCE

Exploring the electromagnetic information of metasurfaces

Din-Ping Tsai

Metasurfaces, a 2D counterpart of metamaterials, are made of planar subwavelength-scale meta-atoms with designed distributions. The meta-atoms of a metasurface can be used to couple incident waves to free space with controllable amplitudes, phases and polarizations, yielding many novel photonic devices such as optical meta-lenses [1–4]. In recent years, with the bloom of information technologies, efforts have been made to braid metasurfaces with digital and information science, rendering the emergence of a digital-coding metasurface, field-programmable metasurface, information metasurface and intelligent metasurface [5–7].

In 2020, Prof. Tie Jun Cui and team members Haotian Wu, Guo Dong Bai, Shuo Liu, Xiang Wan and Qiang Cheng from Southeast University and Prof. Lianlin Li from Peking University brought new physical insights into metasurfaces from an information perspective [8]. In this work, the researchers built on the concept of observation information from the information optics [9] and developed a generalized theory to characterize the information of the digital-coding pattern (I_1) and the far-field pattern (I_2) of metasurfaces. Here, the far-field information (I_2) of a metasurface is defined as the entropy difference between the normalized radiation function and the uniformly distributed pattern. Subsequently, by leveraging the generalized uncertainty relation between two non-commuting observables [10], it is revealed that the upper bound of the far-field information is determined by the size of the meta-surface and the working frequency (Fig. 1).

As an important application, the researchers adopted the established far-field information to predict the upper limit of the number of orthogonal radiation states generated by the digital-coding metasurface, thus providing guidance for metasurface-based computational imaging, for which orthogonal