Domain-wall nanoelectronics in ferroelectric memory

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Domain walls/boundaries in ferroic materials usually exhibit properties which do not exist in their bulks (e.g., superconducting, piezoelectricity, etc.) [1,2]. Ferroelectric domain walls with a size of several nanometers display exotic conduction [3–5] among their insulating bulk. Due to its electric-field controllable nature, ferroelectric/multiferroic domain walls could be a promising candidate for high-density data storage or logic devices with ultralow energy consumption. Such an interesting physics has been widely revealed and studied by probe-based microscopies, however a large domain-wall currents have not yet been extracted in a non-volatile prototype memory device. This technical demand gives people a strong stimulus to specially fabricate the nanoelectrodes so that this physical scenario can be designed towards scalable nanoelectronics down to 100 nm.

Recently, scientists are able to achieve a non-destructive read-out of the information stored in ferroelectric domain-wall resistance switching memories. Contrary to the traditional explorations of domain-wall conduction using scanning probe techniques (Fig. 1a), Jiang *et al.* fabricated domain-wall nanodevice in multiferroic BiFeO₃ thin films by taking advantage of the parallel nanoelectrodes (Fig. 1b) [6]. The “0” and “1” states can be written and read-out by creating or erasing the conducting domain walls with a high speed. Combining with the full character-

izations of the device figure of merit such as stability, retention, fatigue, etc., this three-terminal memory device can produce 14 nA readout currents at an operating voltage of 5 V, and it can also operate up to $T=85^{\circ}\text{C}$. Similar phenomenon has been also reported in BiFeO₃ heterostructures with such parallel electrode geometries [7]. These works demonstrate an important step toward the integration of non-volatile ferroelectric domain-wall memory.

Furthermore, these studies trigger a variety of scientific and technological questions. Such ferroelectric domain-wall devices with a lateral control would reduce the spatial density of the memory. How to achieve a stable write/readout process with a vertical geometry would be a significant milestone toward the high data storage density. Fundamentally, the physical origin of the domain-wall conduction in ferroelectric/multiferroic oxides are still obscure in that ferroelectric domain walls are natural defects with the discontinuity of ferroelectric polarization or crystal orientation, which indeed involves complicated physical and chemical structures in such a reduced dimension. Several main possibilities were already proposed in different domain-wall systems such as charge accumulation in head-to-head polarization, center of closure domains [8] and chemical-induced charge defects ($\text{Fe}^{3+}/\text{Fe}^{4+}$) [9]. Can people also succeed in creating conduc-

Figure 1 (a) Domain-wall conduction probed by a metallic tip, (b) domain-wall-based memory device. Reprinted with permission from Ref. [6]. Copyright 2017, Nature Publishing Group.

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tion in domain walls without crystal/chemical defects [10]? The complete understanding of the microscopic origin would help setup a framework to further increase the domain-wall conductivity (on/off ratio) and stability during the high frequency write/readout process in future devices.

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