NEWS AND VIEWS

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Room-temperature stable two-dimensional ferroelectric materials

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Ferroelectric materials, with spontaneous electric polarization that can be reversed by an external electric field, have many technological applications, such as non-volatile memories, field-effect transistors, and sensors. Ferroelectric polarization originates from an asymmetric distribution of atoms in a material's crystal structure, requiring the material to have two energetically degenerate ground state structures (two stable spontaneous polarization states) with inversion symmetry breaking[1]. Based on Landau-Ginzburg-Devonshire theory, a ferroelectric material below its transition temperature is described by a double well free energy (*F*) landscape as a function of the electric polarization (*P*)[2] as shown in Fig. 1. Thin-film ferroelectrics have the advantage to significantly scale down the dimensions of the devices. Moreover, the voltage used to flip the electric polarization can be much lower, satisfying the requirement for low-power consumption devices. However, in conventional thin-film ferroelectrics, the arrangement of atoms produces charges on the material's surface, generating a strong opposite depolarization field to suppress the polarization.

Recently, theoretical study predicted that the ferroelectric polarization in 2D semiconducting α-In_2Se_3 is driven by local covalent bonds (not by long-range interactions), which are strong enough to prevent the depolarization field from suppressing the polarization[3]. In addition, the two opposite electric polarization states only differ at the energetically degenerate positions of the central Se-layer atoms, enabling the locked in-plane and out-of-plane electric polarizations in the 2D α-In_2Se_3 (Fig. 1). Stimulated by this unprecedented interlocking of electric dipoles in α-In_2Se_3, intense experimental efforts were devoted with various techniques. Clear ferroelectric domains, ferroelectric hysteresis loop, and piezoelectricity have been observed in ultrathin samples with the thickness down to 2D limit by using Piezo force microscopy (PFM) and second-harmonic generation (SHG)[4–6]. The electric polarization of α-In_2Se_3 is observed to be stable at temperature up to 700 K. Besides, several prototype devices based on the few layer α-In_2Se_3, including switchable ferroelectric diode and ferroelectric semiconductor transistor were demonstrated.

The isolation of 2D layered materials allows to integrate distinct 2D materials into van der Waals (vdW) heterostructures. Recently, it was shown that ferroelectrics can have negative capacitance[7]. Negative-capacitance field-effect transistors (NC-FET) integrated of room-temperature stable ferroelectric α-In_2Se_3 with other 2D semiconducting channels (e.g. MoS_2) could bypass the Boltzmann tyranny of a metal–oxide–semiconductor FET (MOSFET)[8], which is highly needed for energy-efficient electronics beyond fundamental limits.

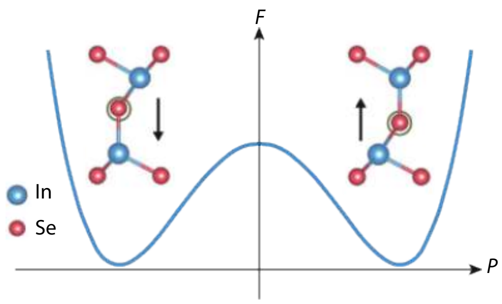

Fig. 1. (Color online) Double-well landscape of the free energy *F* in a ferroelectric as a function of the electric polarization *P*. Insets: the two energetically degenerate state with opposite electric polarizations of α-In_2Se_3. The size-view ball-and-stick schematic illustrations are cited from Ref. [3].

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