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Introduction to Multiferroics and Its Application

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This chapter gives an introduction to multiferroics including the concept, characteristics, advantages, and existing researches toward potential applications. Voltage-controlled ferromagnetism based on multiferroic heterostructures is focused here because of the capacity for low energy dissipation, high signal-to-noise ratio, etc. We discuss the basic understanding and potential applications.

1.1 Concept of Multiferroics and the Existing Magnetization Manipulation Methods for Practical Applications

Of late, multiferroic materials have been very popular in spintronics [1]. They simultaneously occupy ferromagnetic (FM) and ferroelectric (FE) orders, enabling magnetism to be manipulated by an electric field (E-field) or vice versa [2–19]. Therefore, multiferroic materials are very promising in producing multifunctional, miniature, high-speed devices [1]. So far, several methods (e.g. electric currents, voltages, thickness, or temperature) based on multiferroic materials have been well established to manipulate magnetization to realize applications like sensors, magnetic random access memories (MRAMs), radiofrequency (RF)/microwave systems, and so on [20–22]. Methods like electric currents manage to control high-anisotropy magnetic cells through the current-induced spin/strain-transfer torque (STT), thus holding out prospects for magnetic devices like information storage devices [23]. Multiferroic devices with voltage controlling techniques have low energy dissipation and high signal-to-noise ratio due to the absence of electromagnets [18, 22]. These methods can largely reduce the accumulation of heat as well as increase the integrated quality by substitutional magnetoelectric (ME) coupling [18, 20]. Meanwhile, accompanied by increasing memory density and decreasing mass,

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the voltage modulation is preferred for satellite, radar, and portable electronic devices where volume, mass, and energy consumption are precious [22].

1.2 Typical Multiferroic Heterostructures and Their Characteristics

Although extensive work has been carried out in single-phase multiferroic compounds like $BiFeO_3$, they are still limited in achieving controllable modulation with ME coupling while at room temperature [24]. On the contrary, multiferroic heterostructures that integrate individual magnetic and FE materials have strong room-temperature ME effects, and are more likely to be utilized in ME devices in the near future [24]. Besides, they are also favored for the flexibility of material choices and device designs [24]. Multiferroic heterostructures, like Fe_3O_4/PMN–PT (lead magnesium niobate–lead titanate), FeGaB/Si/PMN–PT, and YIG (yttrium iron garnet)/PMN–PT, have been explored on the basis of particular FE crystal material (PMN–PT) with a large piezoelectric coefficient [1, 5]. With the external electric field (E-field) applied along the PMN–PT substrates, these heterostructures should obtain strains and charge accumulations [1, 20]. It provides a great opportunity for the adjacent magnetic layers to achieve magnetic anisotropy and, eventually, to obtain a large change of ferromagnetic resonance (FMR) through the inverse magnetoelastic coupling [1, 20]. What is more, it is also demonstrated that FM/FE heterostructures are exceptionally useful in the applications of STT random access memory due to the strain-induced magnetostatic surface spin waves as well as the strain-controlled repeatable and nonvolatile magnetic anisotropy reorientation [20]. Here, we mainly focus on the voltage-controlled ferromagnetism based on multiferroic heterostructures and discuss recent progress in the fundamental understanding and the potential applications.

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