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A brief review of ferroelectric control of magnetoresistance in organic spin valves

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A B S T R A C T

Magnetoelectric coupling has been a trending research topic in both organic and inorganic materials and hybrids. The concept of controlling magnetism using an electric field is particularly appealing in energy efficient applications. In this spirit, ferroelectricity has been introduced to organic spin valves to manipulate the magneto transport, where the spin transport through the ferromagnet/organic spacer interfaces (spinterface) are under intensive study. The ferroelectric materials in the organic spin valves provide a knob to vary the interfacial energy alignment and the interfacial crystal structures, both are critical for the spin transport. In this review, we introduce the recent efforts of controlling magnetoresistance of organic spin valves using ferroelectricity, where the ferroelectric material is either inserted as an interfacial layer or used as a spacer material. The realization of the ferroelectric control of magneto transport in organic spin valve, advances our understanding in the spin transport through the ferromagnet/organic interface, and suggests more functionality of organic spintronic devices.

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1. Introduction

Giant magnetoresistance has been a successful example of nanotechnology in which transport of spin-polarized current through interfaces is manipulated in nanoscale to vary the resistance of the devices. Wide application of this effect, such as in the read heads of the hard disks for much larger information density, has been realized; the fundamental research was awarded Nobel prizes in 2007. The concept of manipulating the spin degree of freedom of electrons to control the electrical transport, has now evolved into a large active field of research and technology, i.e. spintronics, with emphasis more and more on spin transport and application potentials in information storage and processing, sensors, energy generation, etc. [1–5].

The effect of giant magnetoresistance can manifest in a trilayer junction shown in Fig. 1(a). The junction contains a non-magnetic

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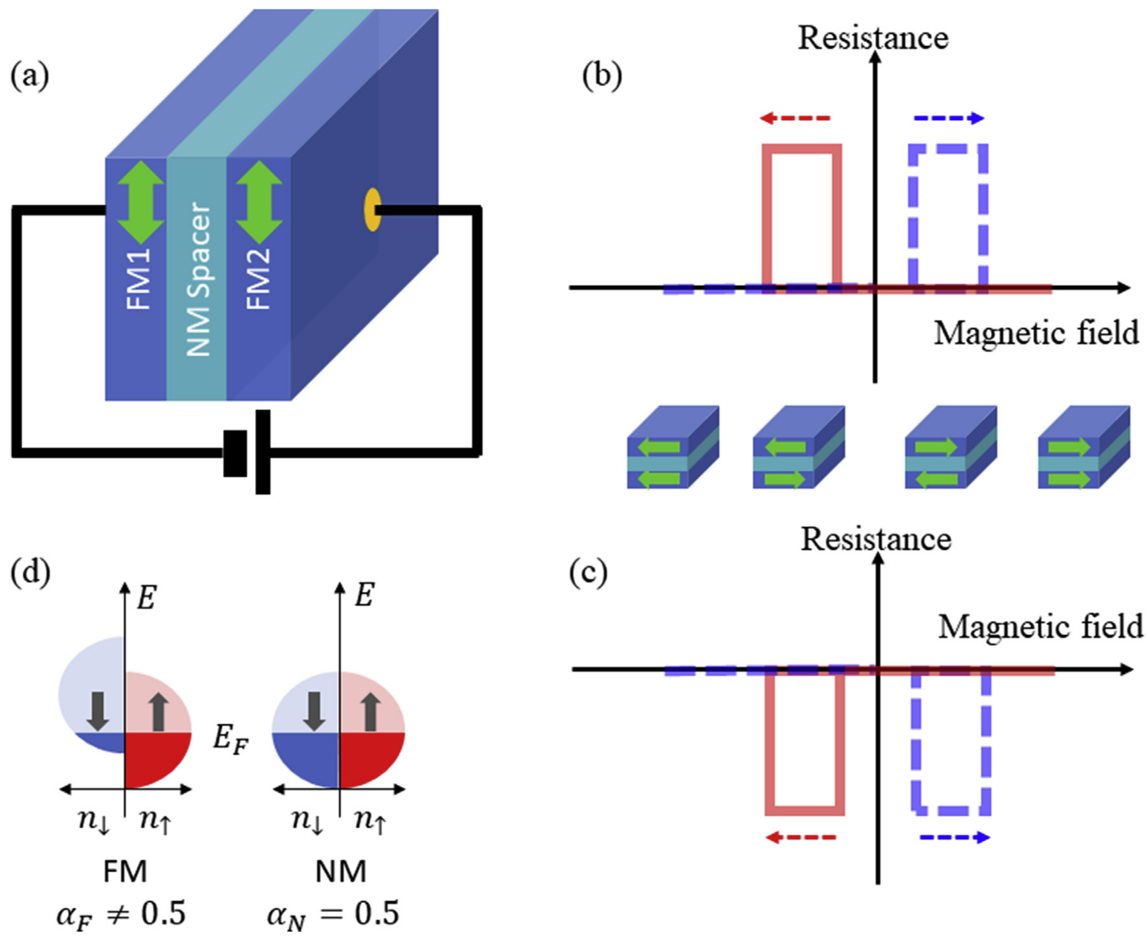

Fig. 1. (a) Schematics of an FM/NM/FM trilayer spin valve. (b) and (c) are the magnetic-field dependence of resistance of the spin valve for positive (normal) and negative (inverse) MR respectively. (d) Schematics of the electronic structure of the FM and NM materials, where $n_\uparrow$ and $n_\downarrow$ are the number of states of the up spin and down spin respectively.

(NM) spacer layer sandwiched by two ferromagnetic (FM) electrodes. Depending on the alignment of the magnetization of the two FM electrodes, the resistance of the junction changes between high and low values. The trilayer junction can then be regarded as a spin valve, in the sense that the electrical current can be turned on and off using the external magnetic field which controls the alignment of the magnetization of the two FM electrodes. Depending on the spacer materials and the thickness, three categories of spin valves are mostly studied. 1) If the spacer material is a metal, the magnetoresistance (MR) is expected to be small compared with the volume resistance [6]. Superlattice-fashioned structures were adopted to enhance MR by increasing the number of interfaces while keeping the thickness of the junction and the volume resistance constant [7–11]. In this case, the thickness of the spacer is often less than a few nanometers; the MR has to do with the indirect exchange coupling between the magnetic layers [12,13]. 2) If the spacer is a thick semiconductor, the two FM layers are magnetically decoupled and the transport through the spacer becomes diffusive. In this case, the MR hinges on spin injection, which is actually difficult for a metal/semiconductor ohmic contact. Tunneling through a barrier between the FM and the semiconductor provides a more efficient route for the spin injection [14–17]. 3) If the spacer is a thin insulator, the electrical transport is based on spin-conserved tunneling between the two electrodes. Therefore, the MR is related to the alignment of spin polarization of the initial and final states of the tunneling.

Organic spin valves are trilayer structures including organic semiconductors (OSC) or insulators as the spacer materials. The long spin life time of the organic materials [18,19] (due to the weak spin-orbit coupling in the light elements such as carbon and hydrogen), is appealing for spin transport. In addition, the flexibility, environment friendliness, and the vast chemical diversity of organic materials suggest great application potentials of organic spintronic devices. Organic spin valves generally belong to the latter two categories introduced above, where the two FM electrodes are decoupled in terms of exchange interactions [6]. The alignment of the magnetization of the two FM electrodes, can be tuned by an external magnetic field, based on their difference in magnetic coercivity. The MR has a butterfly-like shape, as illustrated in Fig. 1(b) and (c). If the resistance of the spin valve is high (low) when the magnetization of the two FM layers are antiparallel, it is called normal (inverse) or positive (negative) MR.

Encouraged by early promising results on organic spin valves [20,21], efforts on understanding the fundamental mechanism and on realizing organic spintronic devices, has been growing rapidly. However, several key issues, such as spin injection and spin polarization at the FM/organic interfaces, are still not fully understood in organic spin valves. To tackle these key issues, being able to tune the crystal structure and electronic structure at the FM/organic interfaces (spinterface [22]) appears to be critical, because the sign and magnitude of the MR is determined by the spin polarization at these interfaces, which are sensitive to the

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