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Multiferroic spintronics

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Multiferroics are singular materials that can exhibit simultaneously electric and magnetic orders, with in some cases a magnetoelectric between the two. As such, these compounds bring new functionalities to spintronics [1] and new device possibilities, such as multinary memory elements or magnetic random access memories with electrical write operation. For practical purposes, the main problem of multiferroics is their scarcity. Notable examples in the perovskite family include the low temperature ferromagnetic ferroelectric material (La,Bi)MnO3, and the room temperature antiferromagnetic ferroelectric compound BiFeO. We will present experiments on 2 to 4 nm thick ferromagnetic (La,Bi)MnO3 layers used as tunnel barriers in junctions with a La2/3Sr1/3MnO3 bottom electrode and a Au top electrode. In these junctions, the tunnel current is modulated by the ferromagnetic order parameter of the barrier material via the spin-filter effect, giving rise to a TMR of up to 100% [2,3]. Remarkably, 2 nm-thick (La,Bi)MnO3 films are also ferroelectric [4]. Accordingly, the concomitance of ferromagnetism and ferroelectricity in a unique tunnel barrier allows obtaining a four level resistance state from the combination of the spin-filter effect and the influence of ferroelectricity on tunneling [4]. The interest of the antiferromagnetic-ferroelectric BiFeO3 is for room-temperature control of magnetization by the application of an electric field. We will show that BiFeO3 films can be used to establish a robust exchange-bias effect [5]. Remarkably, the exchange field correlates with the multiferroic domain size, as expected from Malozemoff's model of exchange bias extended to multiferroics [6]. Perspectives for electric control of spintronics devices will be given. A way to overcome the scarcity of multiferroic materials at room temperature is to design a artificial multiferroics by combining ferroelectric and ferromagnetic materials. We will present experiments on heterostructures combining ferroelectric tunnel barriers of BaTiO3 and ferromagnetic electrodes (Fe or Co). This kind of heterostructures allows to generate, within a single device, not only a tunnel magnetoresistance (TMR) phenomena related to the relative orientation of the magnetization of the electrodes and a very large tunnel electroresistance (TER) – up to 750000% at 3nm- induced by the ferroelectric polarisation of the barrier [7]. They also give rise to a unusual modulation of the spin polarisation at the interface by the ferroelectricity [8] resulting in a large TEMR (Tunnel Electro MagnetoResistance) effect. [1] M. Bibes and A. Barthélémy, IEEE Trans. Electron Dev. 54, 1003 (2007) [2] M. Gajek et al, J. Appl. Phys 97, 103909 (2005) [3] M. Gajek et al, Phys. Rev. B 72, 020406(R) (2005) [4] M. Gajek et al, Nature Materials 6, 296 (2007) [5] H. Béa et al, Appl. Phys. Lett. 89, 242114 (2006) [6] H. Béa et al, Phys. Rev. Lett 100, 017204 (2008) [7] V. Garcia et al.; Nature 460, 81 (2009) [8] C. G. Duan et al. ; Phys. Rev. Lett. 97, 047201 (2006)