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# FERROELECTRIC TUNNEL JUNCTIONS FOR ELECTRONICS AND SPINTRONICS

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**Short biography**

Born in Sainte-Foy-la-Grande (Gironde, France) in 1976, Manuel Bibes is a research scientist at the joint CNRS/Thales laboratory in Palaiseau. He received his Ph.D. in 2001 from the Universitat Autònoma de Barcelona and the INSA Toulouse after a joint Franco-Spanish thesis on manganite interfaces at the Institut de Ciència de Materials de Barcelona. Following two years of postdoctoral work with Albert Fert's group in Orsay he became a CNRS researcher and joined the Institute of Fundamental Electronics at the University Paris-Sud in 2003. In 2007, he returned to the CNRS/Thales lab to develop research lines on multiferroics, oxide interfaces and ferroic tunnel junctions. He is the recipient of the 2013 Materials Prize for scientists under 40 of the European Materials Research Society. He is the coauthor of more than 110 articles in international journals including several reviews, totalizing over 4500 citations.

**Abstract**

Because it is spontaneous, stable and electrically switchable the polarization of ferroelectrics is an excellent state variable for non-volatile data storage. In addition, polarization reversal can be as fast as tens of ps [1] and only dissipates the modest power associated with polarization charge switching (with current densities typically lower than $10^4$ A/cm²). When ferroelectrics are made as thin as a few nm, they can be used as tunnel barriers and the tunneling current is influenced by the polarization direction [2] enabling a simple non-destructive readout of the polarization state. In this talk, I will show how the tunnel resistance can vary by more than two orders of magnitude upon polarization switching in highly-strained ultrathin $BaTiO_3$ tunnel barriers. This strong electroresistance effect can be probed using a conductive AFM tip as the top electrode [3], or using solid-state submicron pads. Such ferroelectric tunnel junctions show large, stable, reproducible and reliable tunnel electroresistance, with resistance switching related to ferroelectric polarisation reversal [4]. They emerge as an alternative to other resistive memories, with the additional advantage of not being based on voltage-induced migration of matter at the nanoscale, but on a purely electronic mechanism. Furthermore, a quasi-continuum of resistance states in accessible between the ON and OFF states, which corresponds to a memristive behavior. Coupled transport and domain imaging studies reveal that the memristive response is here determined by ferroelectric domain dynamics [5].

The low-power, electric-field-driven control of information in ferroelectric tunnel barriers can also be interesting for spintronics if ferromagnetic electrodes – here $La_{2/3}Sr_{1/3}MnO_3$ and Fe (or Co) – are used (thereby defining "artificial" multiferroic tunnel junctions). We have found that such devices not only show tunnel magnetoresistance (TMR) and tunnel electroresistance (as expected from their ferromagnetic electrodes, and their ferroelectric barrier, respectively) but also a tunnel *electromagnetoresistance* effect, *i.e.* a dependence of the TMR on the ferroelectric polarization direction [5]. This signals a magnetoelectric coupling at the interface between $BaTiO_3$ and Fe (Co), in line with first-principles calculations [6]. A predicted corollary of this coupling is the induction of a magnetic moment by Fe in $BaTiO_3$. I will present soft X-ray resonant magnetic scattering data revealing that, in addition to being ferroelectric, such ultrathin $BaTiO_3$ films possess a spontaneous and hysteretic magnetization at room temperature, qualifying them as novel interface-induced multiferroics [7].

[1] D.S. Rana et al. *Adv. Mater.* **21**, 2881 (2009); [2] E.Y. Tsymbal and H. Kohlstedt, *Science* **313** (2006)
[3] V. Garcia et al, *Nature* **460**, 81 (2009); [4] A. Chanthbouala et al, *Nature Nanotech.* **7**, 101 (2012)
[5] A. Chanthbouala et al, *Nature Mater.* **11**, 860 (2012; [6] V. Garcia et al, *Science* **327**, 1106 (2010)
[7] C.G. Duan et al, *Phys. Rev. Lett.* **97**, 047201 (2006) ; M. Fechner et al, *Phys. Rev. B* **78** 212406 (2008) ; L. Bocher et al, *Nano Lett.* **12**, 376 (2012); [8] S. Valencia et al, *Nature Mater.* **10**, 753 (2011)