Theoretical Studies of Magnetoelectric Interfaces and Ferroelectric Tunnel Junctions

E. Y. Tsymbal,[A] M. Ye. Zhuravlev [A,B] and S. Maekawa[C]

[A]*Department of Physics and Astronomy, University of Nebraska-Lincoln*
[B] *Kurnakov Institute for General and Inorganic Chemistry, Russian Academy of Sciences, Moscow, Russia*
[C]*Instiute for Materials Research, Tohoku University*

Period of visit 27/04/09 – 12/06/09

Background: Ferroelectric tunnel junctions (FTJ) have recently aroused considerable interest due to potential applications as nanoscale resistive switching devices. A FTJ consists of two metal electrodes separated by a nm-thick ferroelectric barrier which allows electron tunneling through it. The key property is tunneling electroresistance (TER) that is the change in resistance of a FTJ with reversal of ferroelectric polarization. Functionalities of a FTJ can be enhanced in a multifferoic tunnel junction (MFTJ) which represents a magnetic tunnel junction (MTJ) with a ferroelectric barrier. In a MTJ the tunneling current depends on the relative magnetization orientation of the two electrodes, a phenomenon known as tunneling magnetoresistance (TMR). In a MFTJ the TER and TMR effects coexist, and therefore, a MFTJ represents a four-state resistance device which is interesting for multifunctional applications.

In both FTJs and MFTJs the important contribution to TER originates from the incomplete screening of polarization charges at the interfaces. This creates finite size charge depletion (accumulation) regions and hence an asymmetric potential profile in FTJs with different electrodes or/and with a composite barrier. If the electrodes are ferromagnetic the screening of polarization charges is expected to be spin-dependent due the exchange splitting of the spin bands in ferromagnetic metal electrodes. The existing studies of the TER effect in MFTJs based on free-electron models have ignored the spin-dependent screening at the interfaces and its contribution to TMR.

Plan: (1) Explore efficient way to enhance the TER considerably by using a layered composite barrier combining a functional ferroelectric film and a thin film of a non-polar dielectric material. (2) Include the spin-dependent screening in a free-electron model for MFTJs and explore its effect on TMR and TER effects in these junctions.

Results: (1) We have found that a thin non-polar dielectric layer at the interface between a ferroelectric barrier and a metal electrode in a FTJ significantly enhances TER. [1] This dielectric layer serves as a switch that changes its barrier height from a low to high value when the polarization of the ferroelectric barrier is reversed, resulting in giant TER values. (2) We have developed a simple model for a MFTJ that explicitly includes the spin-dependent screening. [2] The effect of spin-dependent screening may be sizable and may provide significant contributions to TMR and TER in MFTJs.

Summary: A FTJ with a composite barrier that has a thin dielectric barrier at the interface allows resistance change by several orders in magnitude with ferroelectric polarization switching. This method of enhancing TER may be practical for device applications and may explain recent experimental findings of giant TER values. Four resistance states in MFTJs with a significant difference in resistance and a possibility to control these resistances by an electric field (through ferroelectric polarization of the barrier) and by a magnetic field (through magnetization configuration of the electrodes) has been demonstrated within a model that takes into account spin-dependent screening. These functionalities may be interesting to device applications of MFTJs.

Publications:

[1] M. Ye. Zhuravlev, Y. Wang, S. Maekawa, and E. Y. Tsymbal, “Tunneling Electroresistance in Ferroelectric Tunnel Junctions with a Composite Barrier”, *Applied Physics Letters* 95 (2009) 052902.

[2] M. Y. Zhuravlev, S. Maekawa, and E. Y. Tsymbal, “Effect of spin-dependent screening on tunneling electroresistance and tunneling magnetoresistance in multiferroic tunnel junctions”, *Physical Review B* (2010), in press.

[3] E. Y. Tsymbal, D. G. Pettifor, and S. Maekawa, “Giant Magnetoresistance: Theory”, in “Spin Transport and Magnetism in Electronic Systems”, eds. E. Y. Tsymbal and I. Zutic (Taylor&Francis, 2010), to be published.