Magneto-Ionic Control of Magnetism

G. S. D. Beach[1]

[1]Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, MA, 02139, USA

[*]Corresponding Author: gbeach@mit.edu

Voltage control of magnetism has the potential to substantially reduce power consumption in spintronic devices, while offering new functionalities through field-effect operation. Magneto-electric coupling has usually been achieved using complex oxides such as ferroelectrics, piezoelectrics, or multiferroics. Here, I describe an alternative approach known as magneto-ionic switching [1,2], which relies on solid-state electrical gating of a mobile ionic species to modulate the properties of a thin ferromagnetic film.

First, I will review our initial discoveries of voltage control of magnetism through solid-state electrochemical switching of the interfacial oxidation state [1-3] in thin metallic ferromagnets. In ultrathin ferromagnet/oxide bilayers, perpendicular magnetic anisotropy (PMA) arises from interfacial hybridization between the ferromagnetic 3d and oxygen 2p orbitals. By using GdOx as a gate oxide with high oxygen ion mobility, I show that O^{2-} can be reversibly displaced at a Co/GdOx interface with a small gate voltage, leading to unprecedented large, non-volatile changes to interfacial PMA by > 0.75 erg/cm^2 [3]. High-resolution cross-sectional transmission electron microscopy (TEM) and in-situ electron energy-loss spectroscopy (EELS) during bias application [2] directly reveals the reversible redox reaction taking place at the Co/GdO_x interface. By optimizing the device structure and geometry, I show that these effects can be achieved with switching times down to <100 microseconds [2], and can be integrated into devices [1,3] that can be gated locally to realize memory and logic functionalities.

In the second part of the talk, I focus on our recent discovery [4] that magnetic anisotropy can be reversibly and nondestructively toggled at room temperature with a small gate voltage through H^+ pumping in all-solid-state heterostructures, eliminating the irreversibility and structural degradation that occurs in oxygen redox-based structures. I show that H_2O hydrolysis in ambient atmosphere catalyzed by a rare-earth oxide/noble metal interface can serve as a solid-state proton pump that enables nondestructive magnetic property gating with a modest voltage. We demonstrate reversible 90^o magnetization switching in a thin Co film at room temperature by either inserting H^+ at its interface with an oxide or loading hydrogen into an adjacent heavy metal layer. The mechanism permits both unipolar toggle switching and nonvolatile state retention, with no discernible irreversibility in magnetic properties of the ferromagnet after >2000 cycles. Moreover, since heavy metals like Pt and Pd that exhibit strong spin-orbit coupling are also well-known hydrogen storage materials that can be driven between a metal and metal-hydride phase, a host of spin-orbit induced phenomena at heavy-metal/ferromagnetic interfaces becomes accessible to voltage gating despite the fact that electric fields cannot be applied directly.

References

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