

# Wednesday Morning, November 1, 2017

## Magnetic Interfaces and Nanostructures Division

Room: 11 - Session MI+SA-WeM

### Controlling Magnetism in Oxides and Multiferroics and Chirality in Spin Transport and Magnetism (cont.)

Moderator: Valeria Lauter, Oak Ridge National Laboratory

#### 8:20am MI+SA-WeM2 Integrated Magnetism and Multiferroics for Compact and Power Efficient Sensing, Power, RF, Microwave and mm-Wave Tunable Electronics, *Nian Sun*, Northeastern University INVITED

The coexistence of electric polarization and magnetization in multiferroic materials provides great opportunities for realizing magnetoelectric coupling, including electric field control of magnetism, or vice versa, through a strain mediated magnetoelectric coupling in layered magnetic/ferroelectric multiferroic heterostructures [1-9]. Strong magnetoelectric coupling has been the enabling factor for different multiferroic devices, which however has been elusive, particularly at RF/microwave frequencies. In this presentation, I will cover the most recent progress on new integrated multiferroic materials and devices for sensing, and from power to mm-wave electronics. Specifically, we will introduce magnetoelectric multiferroic materials, and their applications in different devices, including: (1) ultra-sensitive magnetometers based on RF NEMS magnetoelectric sensors with picoTesla sensitivity for DC and AC magnetic fields, which are the best room temperature nano-scale magnetometers; (2) novel ultra-compact multiferroic antennas immune from ground plane effect with  $f200\mu\text{m} \times 1\mu\text{m}$  or  $l_0/600$  in size, -18dBi gain, self-biased operation and 1~2% voltage tunable operation frequency; and (3) novel GHz magnetic and multiferroic inductors with a wide operation frequency range of 0.3~3GHz, and a high quality factor of close to 20, and a voltage tunable inductance of 50%~150%. At the same time, I will also demonstrate other voltage tunable multiferroic devices, including tunable isolating bandpass filters, tunable bandstop filters, tunable phase shifters, etc. These novel integrated multiferroic devices show great promise for applications in compact, lightweight and power efficient sensing, power, RF, microwave and mm-wave integrated electronics.

**Reference:** 1. N.X. Sun and G. Srinivasan, *SPIN*, 02, 1240004 (2012); 2. J. Lou, et al., *Advanced Materials*, 21, 4711 (2009); 3. J. Lou, et al. *Appl. Phys. Lett.* 94, 112508 (2009); 4. M. Liu, et al. *Advanced Functional Materials*, 21, 2593 (2011); 5. T. Nan, et al. *Scientific Reports*, 3, 1985 (2013); 6. M. Liu, et al. *Advanced Materials*, 25, 1435 (2013); 7. M. Liu, et al. *Advanced Functional Materials*, 19, 1826 (2009); 8. Ziyao Zhou, et al. *Nature Communications*, 6, 6082 (2015). 9. T. Nan, et al. *Nature Comm.* under review.

#### 9:20am MI+SA-WeM5 Controlling Spin Selectivity in Photoinduced Charge Transfer through Patterned DNA Microarrays, *John Abendroth\**, *N. Nakatsuka*, *M. Ye*, *D. Stemer*, University of California at Los Angeles, *D. Kim*, *E. Fullerton*, University of California at San Diego, *A. Andrews*, *P. Weiss*, University of California at Los Angeles

Understanding spin-selective interactions between electrons and chiral molecules is critical to elucidating the prospective significance of electron spin in biological processes. We report the visualization of spin-dependent charge transport in microscale-patterned, self-assembled monolayers of double-stranded DNA on ferromagnetic substrates using fluorescence microscopy. Patterned DNA arrays provide background regions in every measurement to quantify the substrate magnetization-dependent fluorescence due to the chiral-induced spin selectivity effect. Fluorescence quenching of photoexcited dye molecules bound within DNA duplexes is dependent upon the rate of charge separation/recombination upon photoexcitation and efficiency of DNA-mediated charge transfer to the surface. Here, the latter process is modulated with an external magnetic field to switch the magnetization orientation of the underlying ferromagnetic substrates. Using this experimental technique, we are investigating molecular parameters that can be manipulated to influence the substrate magnetization-dependent fluorescence in DNA arrays to assess candidly the potential of chiral assemblies for organic spintronics. In particular, we are monitoring the influence of heavy metal species that are incorporated predictably within DNA duplexes to change the strength of molecular spin-orbit coupling as a result of the heavy atom effect.

#### 9:40am MI+SA-WeM6 Anomaly in Electric Transport Behaviour of $\text{Fe}_3\text{O}_4$ Thin Films, *Murtaza Bohra*, Mahindra Ecole Centrale, India

Nanocrystalline  $\text{Fe}_3\text{O}_4$  thin films were grown by adopting two different reduction approaches (1) vacuum annealing (2) wet  $\text{H}_2$  annealing. While vacuum annealed films shows Verwey transition with lower resistivity compared to the bulk  $\text{Fe}_3\text{O}_4$ , the same are not observed in electric transport properties of wet  $\text{H}_2$  annealed films. However, this transition was clearly seen in the temperature dependence of magnetization of both sets of  $\text{Fe}_3\text{O}_4$  thin films. This seems to indicate that the both electric transport and magnetization are independent processes; it's just coincidence to happen at same place of Verwey transition at 120 K in  $\text{Fe}_3\text{O}_4$ . Different electric transport properties in both reductions treated  $\text{Fe}_3\text{O}_4$  films could be ascribed to different grain sizes/grain boundary volumes, inhomogeneities and presence of residual atomic-H at grain boundaries emanating from complex reductions treatments.

#### 11:00am MI+SA-WeM10 Intrinsic Interfacial Phenomena and Spin Structure in Nano and Heterostructures, *Carlos Vaz*, Paul Scherrer Institut, Switzerland INVITED

One fundamental route towards the control of the electronic properties of materials is via modulation of the charge carrier density, either through chemical, ionic, or electrostatic doping. The latter process relies on charge screening effects at the interface between a gate dielectric and a channel layer, and forms the basis of important technological applications, such as field effect devices. A more recent extension of this concept employs a ferroelectric gate dielectric in combination with correlated materials to form switchable, non-volatile ferroelectric field effect devices, or artificial multiferroic heterostructures relying on interfacial modulations of the magnetic properties of the channel layer [1]. A particularly striking manifestation of the latter has been found in ferroelectric/ferromagnetic mixed valency manganite heterostructures, where control of the ground state of a 10 unit cells  $\text{La}_{0.8}\text{Sr}_{0.2}\text{MnO}_3$  film (LSMO) in contact with a ferroelectric PZT layer leads to a spin reconstruction in the LSMO that is intrinsic to the PZT/LSMO interface, as a consequence of the modulation in the charge density [2]. In this contribution I discuss recent results aiming at resolving the magnetic configuration of the interfacial spin reconstruction in the LSMO using soft x-rays as a localised probe of the electronic and magnetic structure at the interface. In particular, I show that resonant x-ray magnetic reflectivity can probe deeply buried interfaces with high sensitivity. Changes in the reflectivity spectra are observed upon switching of the ferroelectric polarisation and reflect directly the changes in the spin structure at the interface. The results of these studies underline the unique strengths of synchrotron x-ray light to address fundamental and practical issues in a wide range of physical systems [3].

[1] C. A. F. Vaz, F. J. Walker, C. H. Ahn, and S. Ismail-B, *J. Phys.: Condens. Matter* 27 (2015) 123001.

[2] C. A. F. Vaz, J. Hoffman, Y. Segal, J. W. Reiner, R. D. Grober, Z. Zhang, C. H. Ahn, and F. J. Walker, *PRL* 104, 127202 (2010).

[3] M.-A. Husanu and C.A.F. Vaz, Spectroscopic characterisation of multiferroic interfaces. In C. Cancellieri and V. N. Strocov (editors), *Spectroscopy of TMO interfaces*. Springer-Verlag, 2017 (forthcoming).

#### 11:40am MI+SA-WeM12 Enantiomer-dependent Spin Orientation in Photoelectron Transmission through Heptahelicene Molecules, *Matthias Kettner*, *D. Nürenberg*, University of Münster, Germany, *J. Seibel*, Empa, Swiss Federal Laboratories for Materials Science and Technology, Switzerland, *H. Zacharias*, University of Münster, Germany, *K.-H. Ernst*, Empa, Swiss Federal Laboratories for Materials Science and Technology, Switzerland

The interaction of electrons with helical molecules attains growing interest due to a spin selectivity in electron transmission. Experiments on self-assembled monolayers of double stranded DNA [1] and oligopeptides [2,3] indicated a very efficient spin filtering behavior of the molecules at room temperature.

In present experiments enantiopure M- and P-heptahelicene molecules are evaporated onto different metal single crystal surfaces. The molecules arrange themselves to a highly ordered monolayer [4,5]. Samples are then irradiated with  $\lambda = 213\text{nm}$  laser radiation to generate photoelectrons from the substrate. These electrons are transmitted through the heptahelicene layer and analyzed with regard to their average longitudinal spin orientation by Mott scattering. The sign of the spin polarization depends on the helicity of the

\* Falicov Student Award Finalist

enantiomer. The effect of the heptahelicene on the spin orientation seems to be independent on the substrate.

#### References

- [1] Göhler, B.; Hamelbeck, V.; Markus, T. Z.; Kettner, M.; Hanne, G. F.; Vager, Z.; Naaman, R.; Zacharias, H., *Science* **2011**, *331*, 894.
- [2] Ray, K.; Ananthavel, S. P.; Waldeck, D. H.; Naaman, R. *Science* **1999**, *283*, 814.
- [3] Kettner, M.; Göhler, B.; Zacharias, H.; Mishra, D.; Kiran, V.; Naaman, R.; Fontanesi, C.; Waldeck, D. H.; Şek, S.; Pawłowski, J.; Juhaniewicz, J. *J.Phys.Chem. C* **2014**, *119*, 26.
- [4] Fasel, R.; Cossy, A.; Ernst, K.-H.; Baumberger, F.; Greber, T.; Osterwalder, J. *J. Chem. Phys.* **2001**, *115*, 2.
- [5] Seibel, J.; Parschau, M.; Ernst, K.-H., *J.Phys.Chem. C* **2014**, *118*, 29135

12:00pm **MI+SA-WeM13 Spin-selective Electron Transmission through Self-Assembled Layers of PNA**, *Paul Möllers, M. Kettner, D. Nürnberg, Westfälische Wilhelms-Universität Münster, Germany, F. Tassinari, T. Markus, Weizmann Institute of Science, Israel, C. Achim, Carnegie Mellon University, R. Naaman, Weizmann Institute of Science, Israel, H. Zacharias, Westfälische Wilhelms-Universität Münster, Germany*

The yield of electrons transmitted through chiral molecules can depend on the electron's spin; chiral molecules can therefore act as spin filters. This effect is referred to as chirality-induced spin selectivity (CISS). Previous experiments have e.g. been performed with monolayers of double-stranded DNA adsorbed on gold [1] and silicon [2] substrates. In this contribution, we present results of our spin-resolved photoemission experiments performed at room temperature. The samples consist of self-assembled monolayers of helical molecules – various types of double-stranded peptide nucleic acid (PNA) – on polycrystalline gold surfaces. The samples are irradiated by a laser at  $\lambda = 213\text{nm}$  to generate photoelectrons from the gold substrate which are then transmitted through the adsorbed monolayer. Subsequently, the electrons are analyzed by a Mott polarimeter. We found longitudinal spin polarizations of  $-6\%$  for PNA and  $+25\%$  for  $\gamma$ -PNA. The results indicate that the adsorbed molecules act as a spin filter.

[1] B. Göhler et al., *Science* 331, 894 (2011)

[2] M. Kettner et al., *Adv. Mater. Interfaces* 3, 1600595 (2016)

# Authors Index

**Bold page numbers indicate the presenter**

## — A —

Abendroth, J.: MI+SA-WeM5, **1**  
Achim, C.: MI+SA-WeM13, **2**  
Andrews, A.: MI+SA-WeM5, **1**

## — B —

Bohra, M.: MI+SA-WeM6, **1**

## — E —

Ernst, K.-H.: MI+SA-WeM12, **1**

## — F —

Fullerton, E.: MI+SA-WeM5, **1**

## — K —

Kettner, M.: MI+SA-WeM12, **1**; MI+SA-WeM13,  
**2**

Kim, D.: MI+SA-WeM5, **1**

## — M —

Markus, T.: MI+SA-WeM13, **2**  
Möllers, P.: MI+SA-WeM13, **2**

## — N —

Naaman, R.: MI+SA-WeM13, **2**  
Nakatsuka, N.: MI+SA-WeM5, **1**  
Nürnberg, D.: MI+SA-WeM12, **1**; MI+SA-  
WeM13, **2**

## — S —

Seibel, J.: MI+SA-WeM12, **1**  
Stemer, D.: MI+SA-WeM5, **1**  
Sun, N.: MI+SA-WeM2, **1**

## — T —

Tassinari, F.: MI+SA-WeM13, **2**

## — V —

Vaz, C.: MI+SA-WeM10, **1**

## — W —

Weiss, P.: MI+SA-WeM5, **1**

## — Y —

Ye, M.: MI+SA-WeM5, **1**

## — Z —

Zacharias, H.: MI+SA-WeM12, **1**; MI+SA-  
WeM13, **2**