**UC Berkeley NRI/NSF center on-site review (Jul. 14, 2010)**

**Location: 554 Sutardja Dai Hall, UC Berkeley, CA**

**Attendees**:

| NRI liaison team | UC Berkeley |
|---|---|
| C.Y. Sung (IBM)<br>Ajey Jacob (Intel)<br>Steve Kramer (Micron)<br>An Chen (GLOBALFOUNDRIES)<br>Andrew Marshall (TI) – dial-in | Sayeef Salahuddin (PI)<br>William Michelson (COINS Executive Director)<br>Khalid Ashraf (student) |

**Meeting schedule**:

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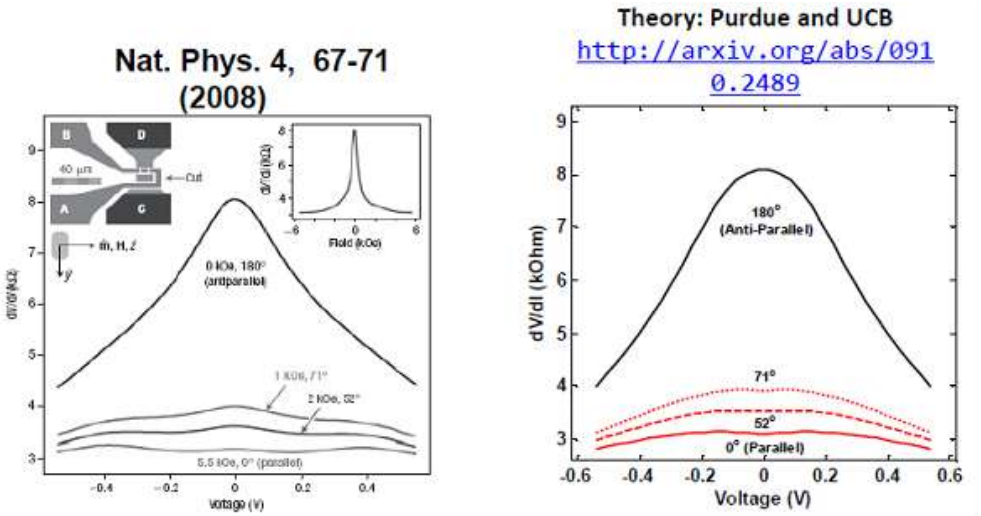
|---|---|
| 1:00 PM | Welcome, Sayeef Salahuddin |
| 1:10-2:10 PM | **COINS Overview**, William Michelson |
| 2:10-2:30 PM | Break |
| 2:30-3:30 PM | **NRI/NSF task review**, Sayeef Salahuddin |
| 3:30-5:00 PM | Discussion and feedback |

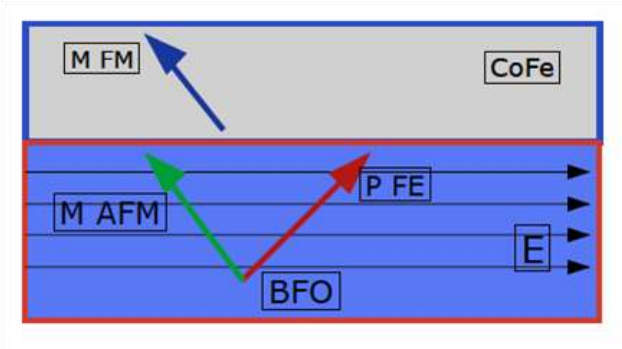
**Meeting summary:**

The UC Berkeley NRI/NSF program focuses on the modeling of spin-transfer-torque dynamics and device characteristics. By combining NEGF and spin dynamics described by LLG equations, the team has developed self-consistent solutions of the transport and magnetization dynamics. Their model is able to explain the experimental (published in literature) results very well, as shown in the figure below. The modeling capability may enable device benchmark and experimental design. The group also integrated the device model with circuit design to evaluate the STT device performance in circuits.




The team has now focused more on electrical field induced magnetic switching, which is expected to be more energy efficient. The initial model is established on multiferroic systems, in

specific, a CoFe/BFO structure as shown below. The objective is to model key aspects including energy dissipation, frequency response, footprint, retention, and optimized device architecture. The modeling of the ferroelectric properties uses the time-dependent Ginzberg-Landau equation. The team has developed the numerical capability of simulating a system with size of 32nm × 32nm × 16nm (131k grid points) and is moving toward solving systems with 500k grid points. This modeling work is in collaboration with the experimental work led by Prof. Ramesh at Berkeley.




The work-in-progress includes the study of the FM-AFM interface between CoFe and BFO, the comparison of ferroelectric switching with experimental results, and the determination of magneto-electric coefficient in thin films.

In the kick-off meeting last year, the liaison team suggested the team to investigate the effects involved in manufacturing and material design, and encouraged them to collaborate with other related NRI groups, especially experimentalists. S. Salahuddin has made effort to reach out to several STT research groups sponsored by NRI and purposed collaboration opportunities. He has also tried to obtain more direct access to experimental data to compare with their models. The liaison team may be able to help more on the access to experimental results.

## Feedback from liaison team:

- In this relatively small program, the group has made very good progress. The group is developing valuable models and simulation methods to evaluate STT devices and multiferroic systems. The PI is very responsive to the feedback from the liaison team, and also made effort to develop collaborations with other related NRI groups.
- The current direction of modeling multiferroic system fits well with NRI mission and the expertise available at UC Berkeley. The PI is developing simulation models that can be tested with experimental results, through the collaboration with experimentalists at UC Berkeley.
- STT-RAM based on perpendicular MTJ structure is a very interesting direction. It would be very helpful for NRI if the PI and the group can help to understand the perpendicular STT-RAM working mechanism and simulation of the characteristics.
- We appreciate the group's effort to reach out to experimentalists and would encourage the group to continue to do so. We will also try to help on the collaborations.