



EQ03.13.36: ID # 3711109

Dramatic Effects of Electrode Metal on Tunnel Junction Based Molecular Spintronic Devices

Pawan Tyagi,

Prof. Mechanical Engineering,

NSF-CREST: Center for Nanoscale Research and Education,
University of The District of Columbia, Washington DC-20008

*Students: Eva Mutunga, Hayden Brown, Andrew Grizzle, Christopher D'Angelo, Marzieh Savadkoohi, Pius Suh
Postdoc Bishnu R. Dahal, Eva Mutunga*

Acknowledgement:

National Science Foundation-CREST Award (Contract # HRD- 1914751),

Department of Energy/ National Nuclear Security Agency (DE-FOA-0003945).

2012-National Science Foundation-Research Initiation Award (Contract # HRD-1238802),

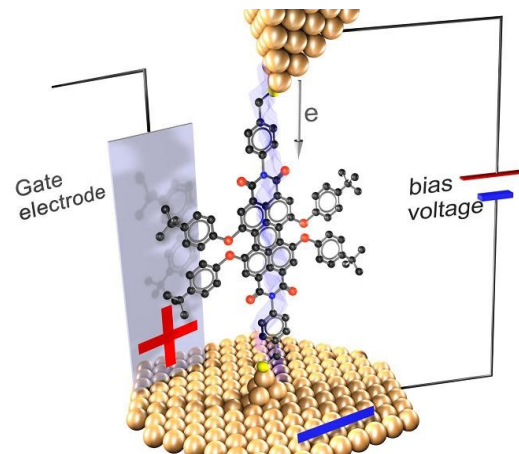
2013-Air force office of sponsored research (Award #FA9550-13-1-0152)

We also acknowledge National Institute of Standards and Technology (NIST)'s Center of Nanoscale Science and Technology.

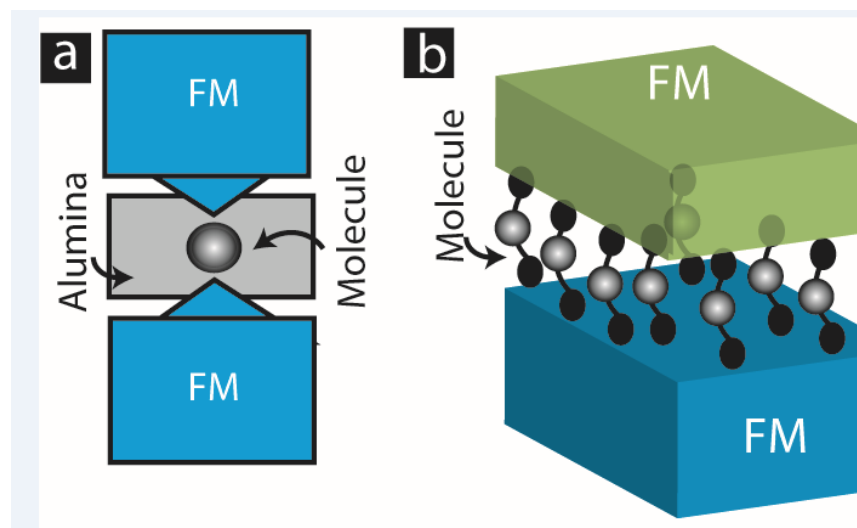


70-Year-Old Dream: Molecule based logic

- ~1950 AFOSR meeting discussed using molecule as device.
 - ~1990 Experimental work
 - Molecular spintronics
- Break junction approach



https://mom.dcb.unibe.ch/mom_pages/mom_2008-07.html



► Nat Nanotechnol. 2013 Jun;8(6):378-81. doi: 10.1038/nnano.2013.110.

A brief history of molecular electronics

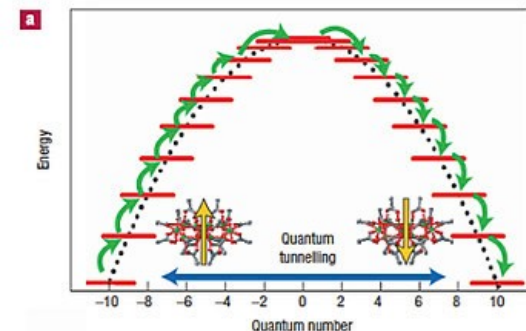
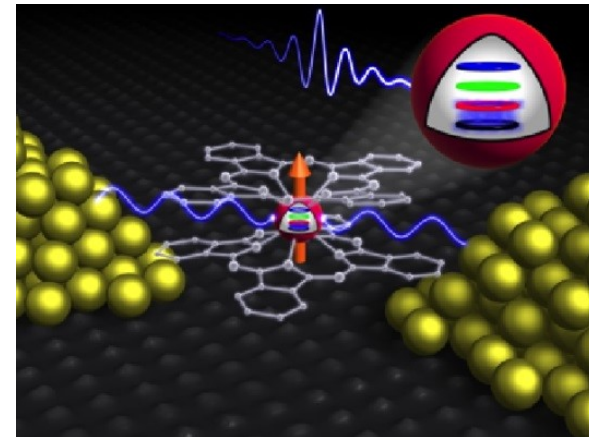
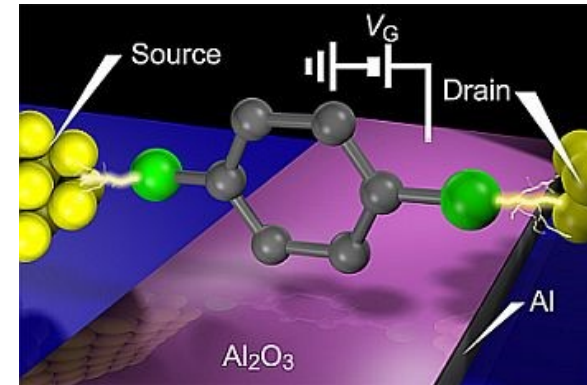
Mark Ratner¹

Affiliations + expand

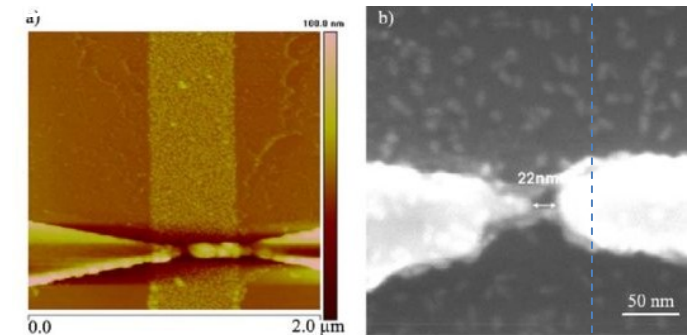
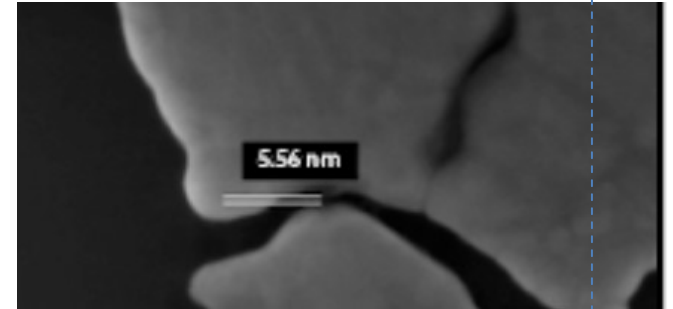
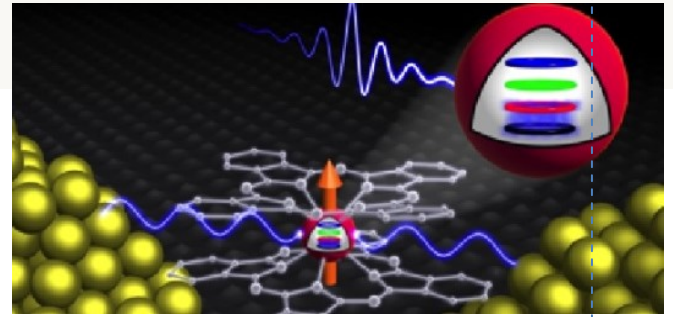
PMID: 23736207 DOI: 10.1038/nnano.2013.110

Why molecular spintronics?

- Limit of Miniaturization: Atoms or molecule?
- Billion types
- Memory: Beyond binary
- Logic: Quantum computers
- Body compatible computers (DNA, porphyrin make computers)
- Numerous spin state-each spin state= one “--nary” 7 spin= Heptanary
- Low energy consumption



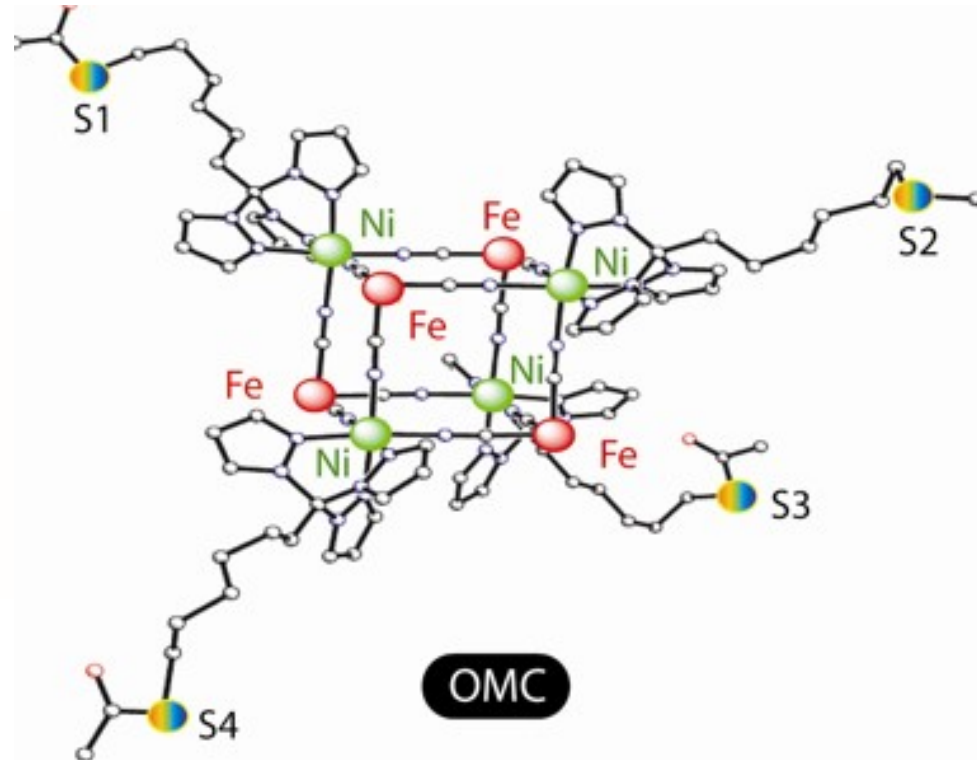
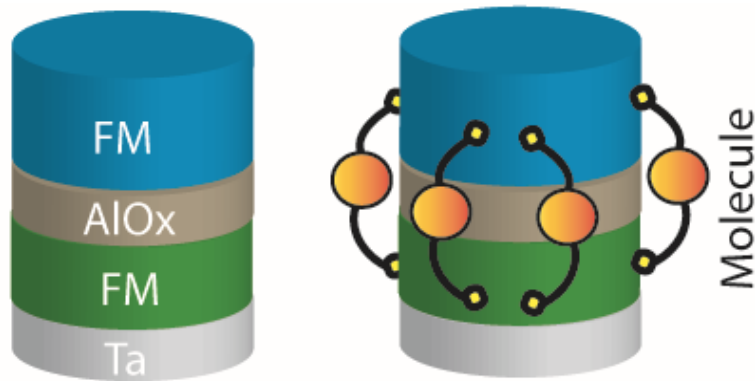
20 Years Research Leading to Deadened



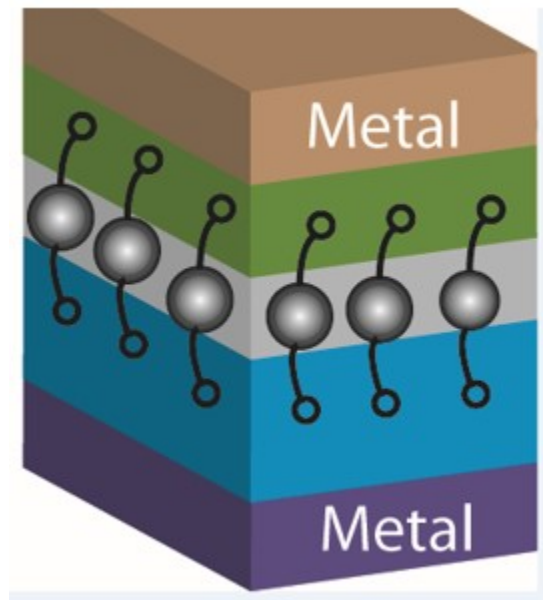
- Fabrication may change/damage molecule?
- 5-10% yield
- Short life (hours?)
- No two junctions are same.
- Defects compete with molecules.
- Gold is gold (Ni, Co, Fe extremely difficult)
- Magnetic measurement Control experiments
- Integration with trillion-dollar semiconductor fabs?

Magnetic Tunnel Junction based Molecular Spintronics Devices(MTJMSD)

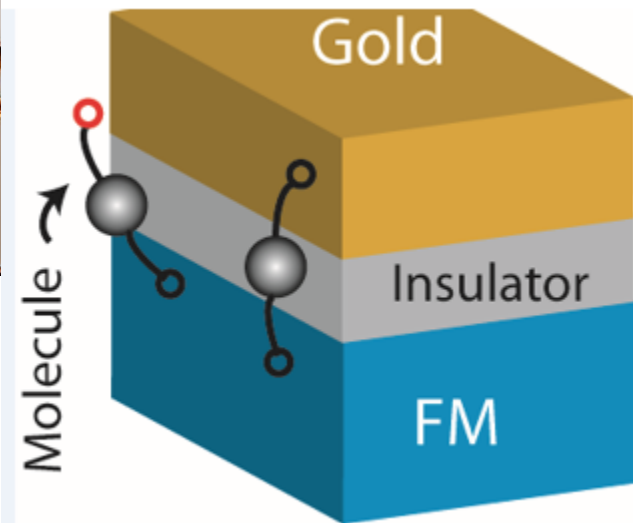
Is it a Gateway to Infinite Innovation Possibilities?



Removing Roadblocks with MTJMSD



Commercially Mature
foundation:
MTJ in read heads

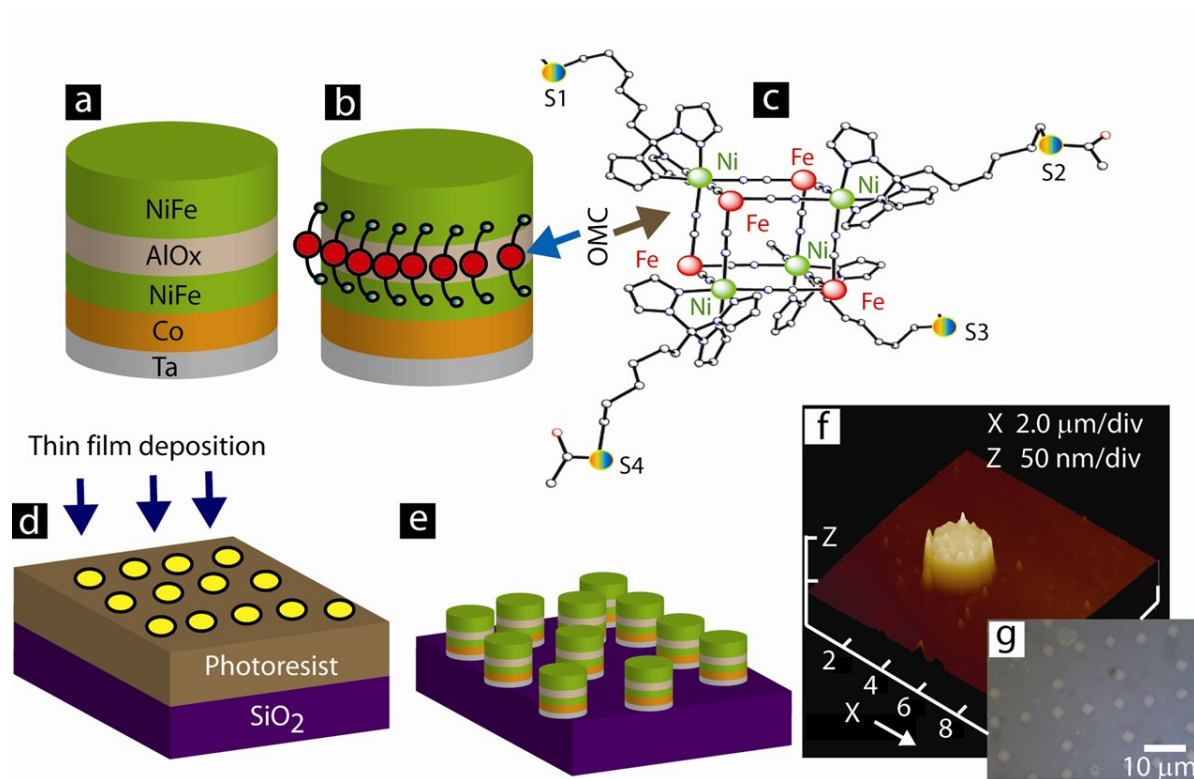


Tyagi, P.; Friebe, E.; Baker, C., Advantages of Prefabricated Tunnel Junction Based Molecular Spintronics Devices. *NANO* **2015**, *10* (3), 1530002.

Tyagi, P., Multilayer edge molecular electronics devices: a review. *J. Mater. Chem.* **2011**, *21* (13), 4733-4742.

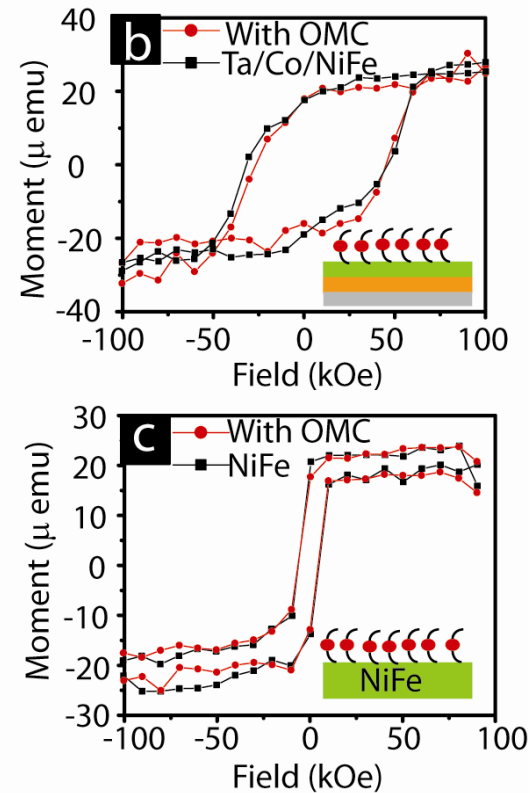
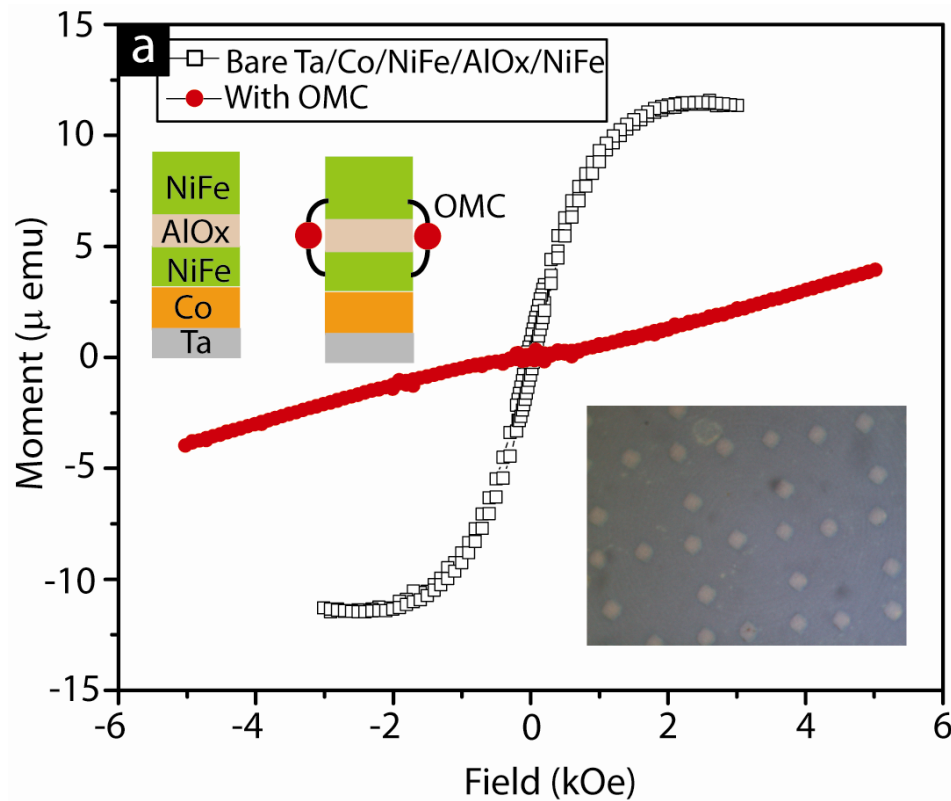
Tyagi, P., Molecular Spin Devices: Current Understanding and New Territories. *Nano* **2009**, *4* (6), 325-338

Testing magnetic properties

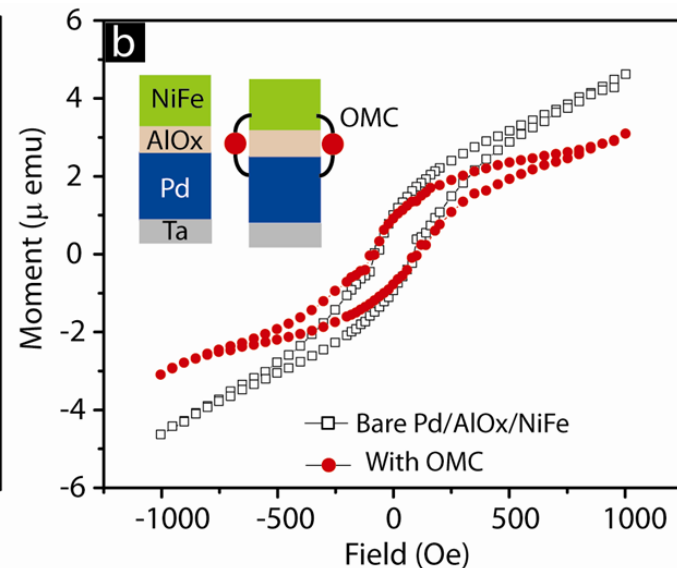
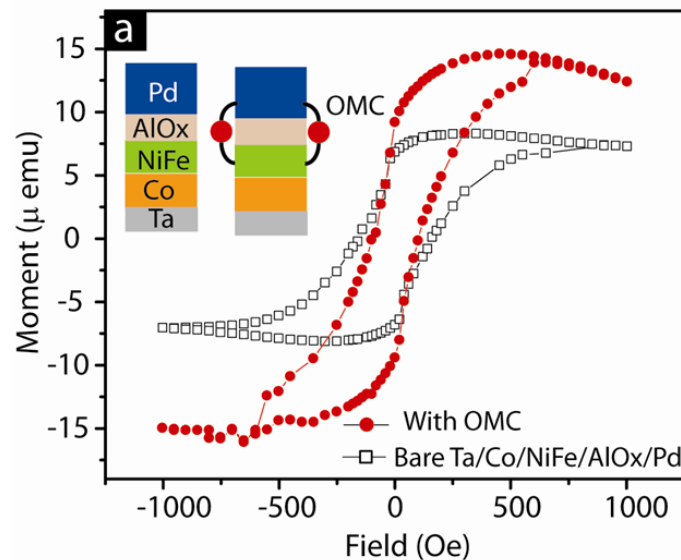
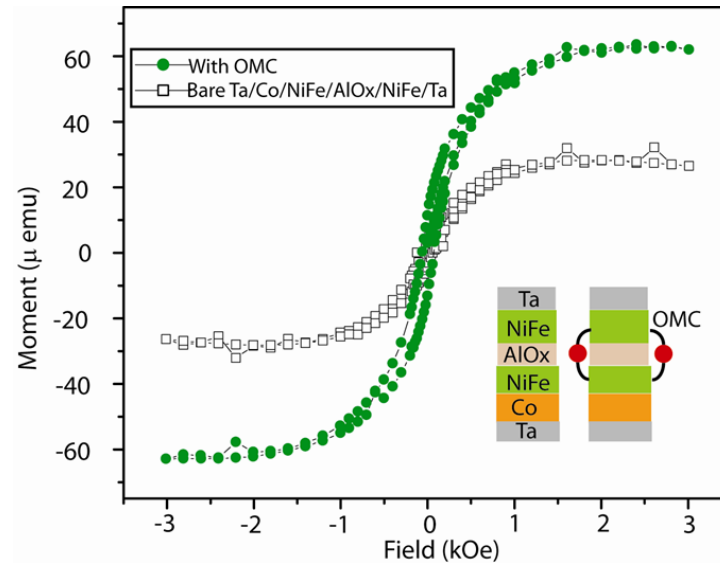


Tyagi, P.; Baker, C.; D'Angelo, C., Paramagnetic Molecule Induced Strong Antiferromagnetic Exchange Coupling on a Magnetic Tunnel Junction Based Molecular Spintronics Device. *Nanotechnology* **2015**, *26*, 305602.

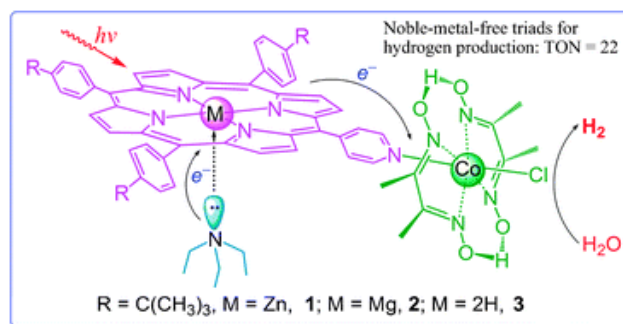
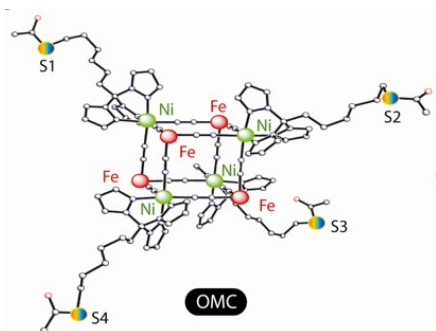
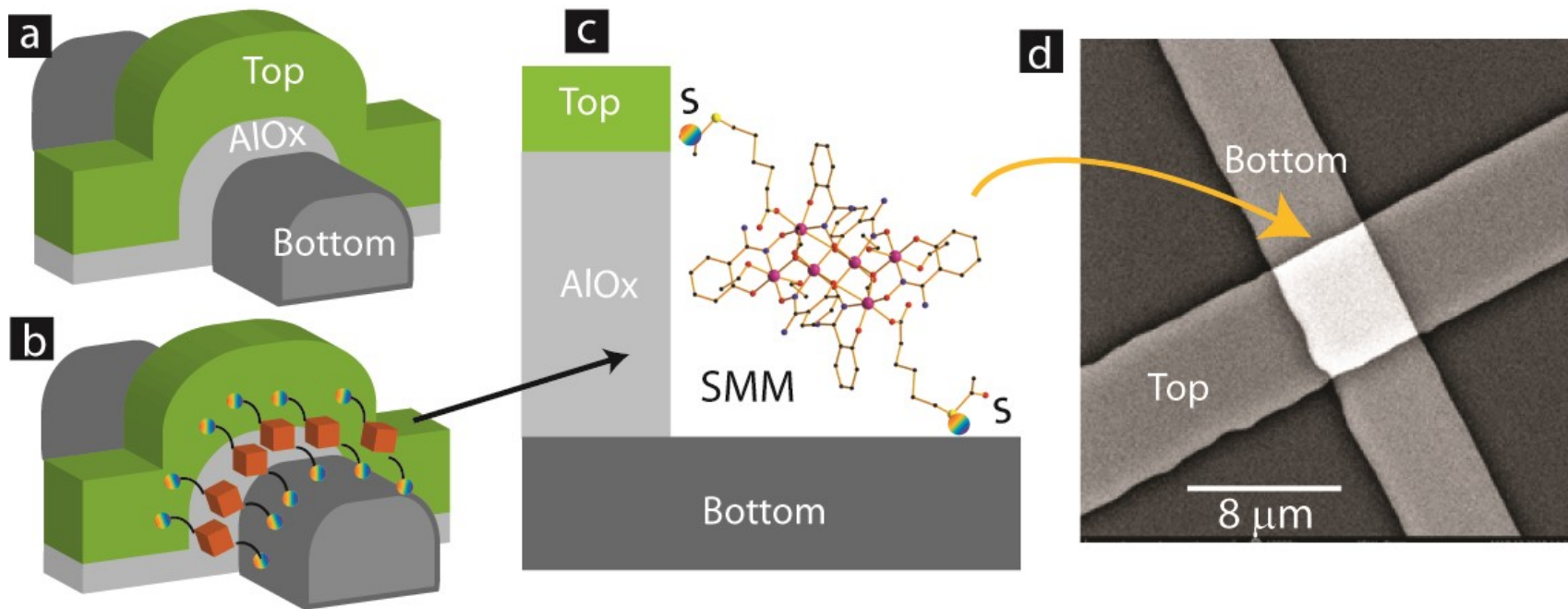
SQUID Magnetometry



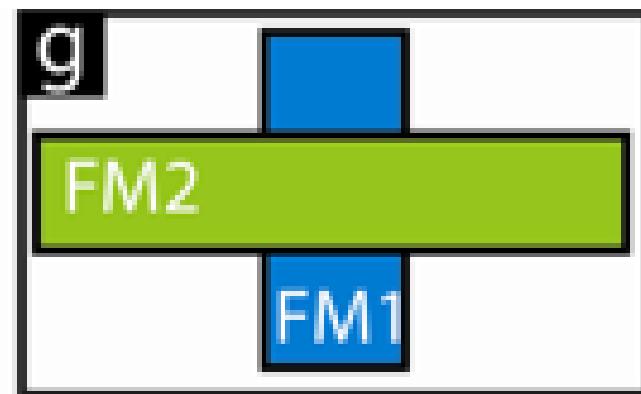
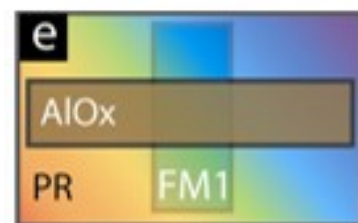
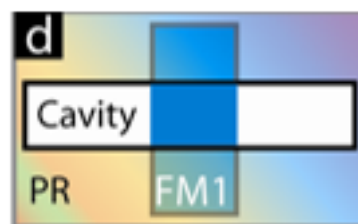
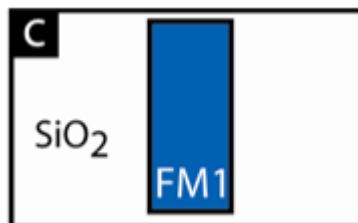
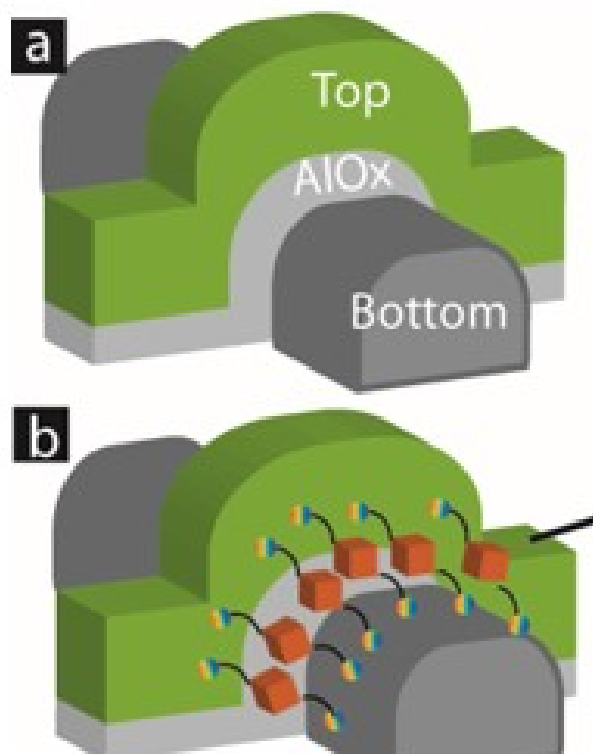
Squid Magnetometry of other MTJMSDs



Cross-junction shaped MTJMSD

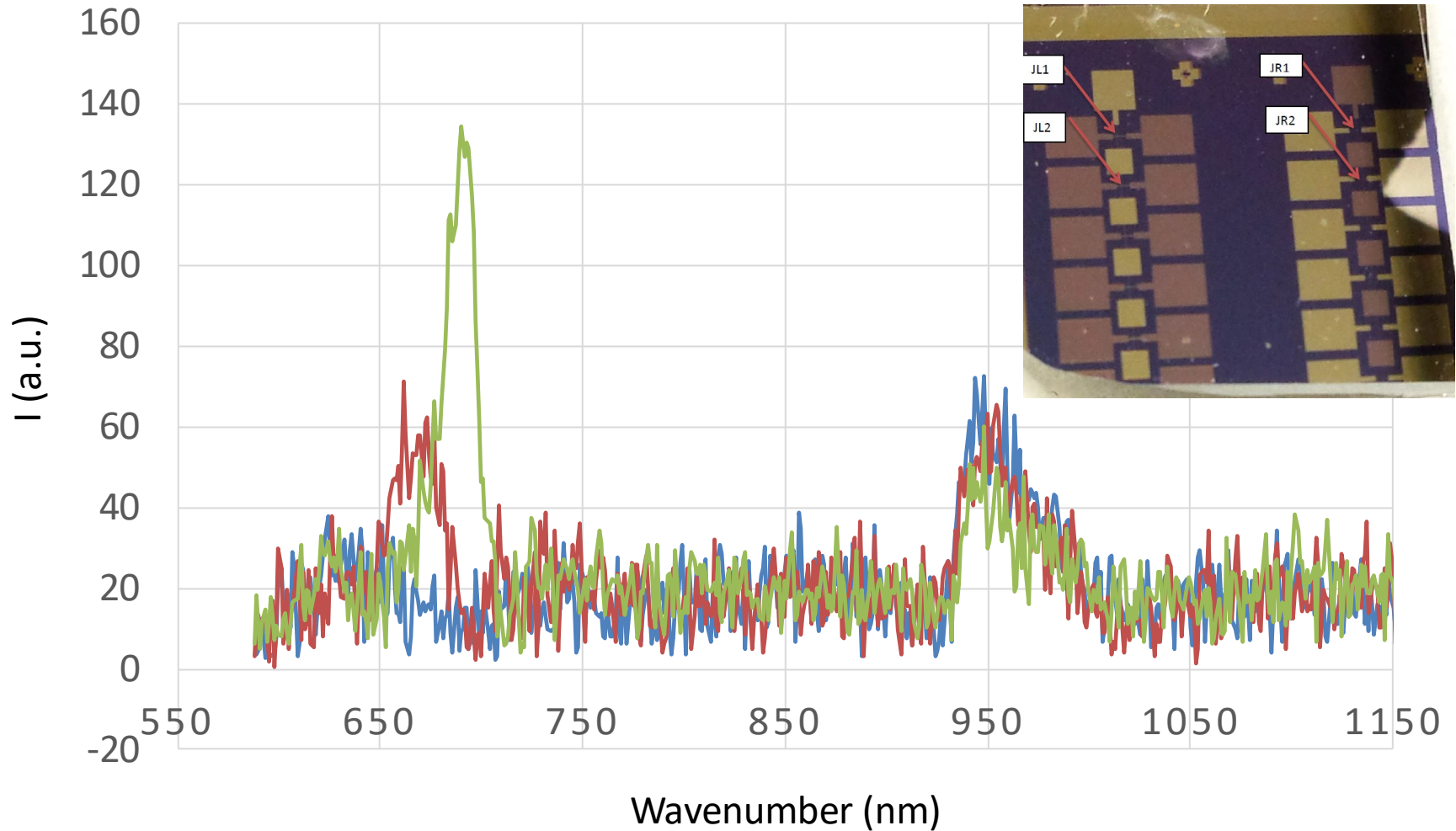


MTJMSD –Liftoff based Fabrication

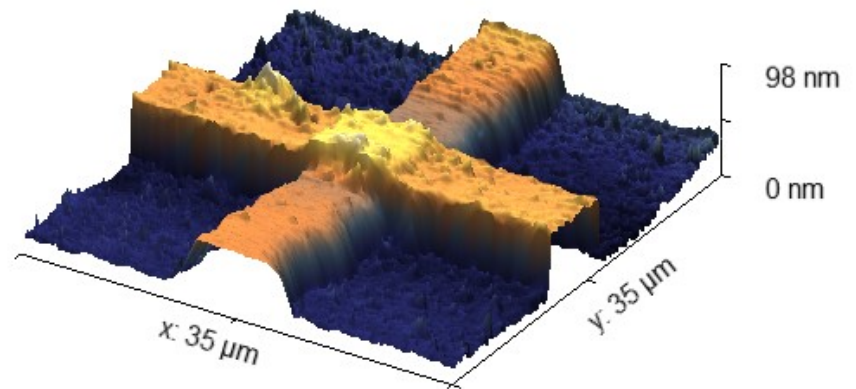
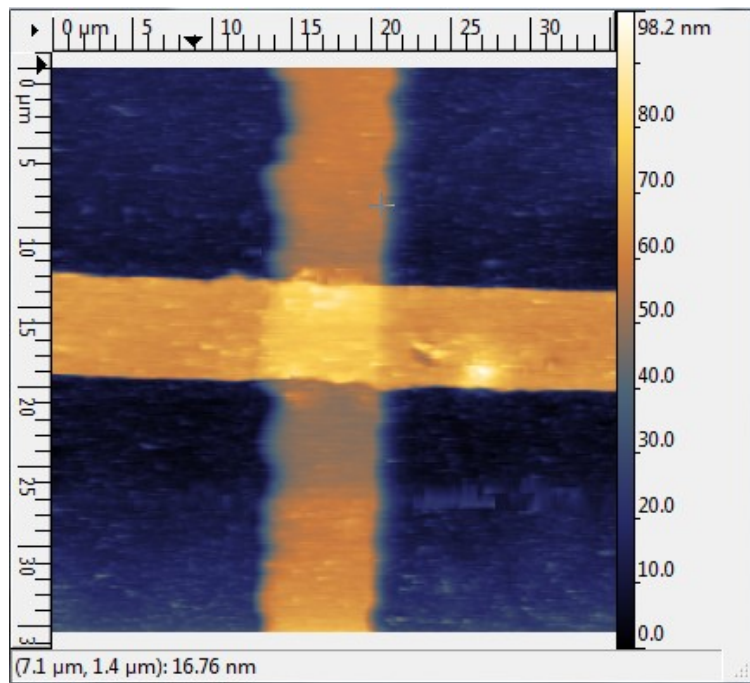


RAMAN 765 nm

— NiFe — TaCoNiFe — MTJMSD

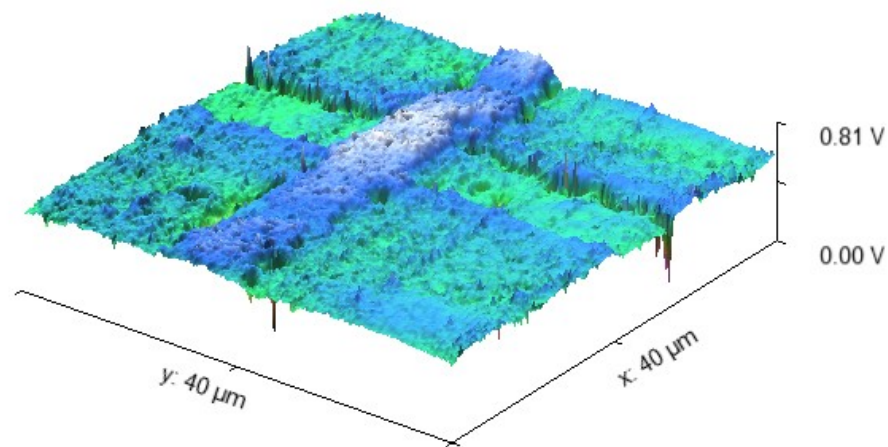
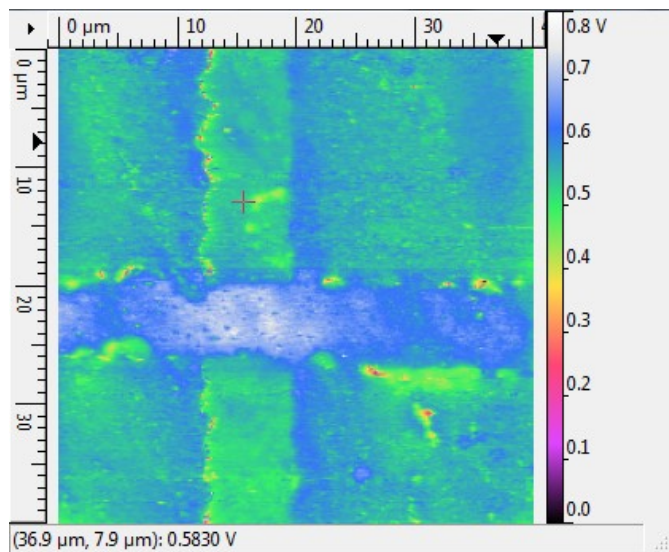


Kelvin Probe Atomic Force Microscopy

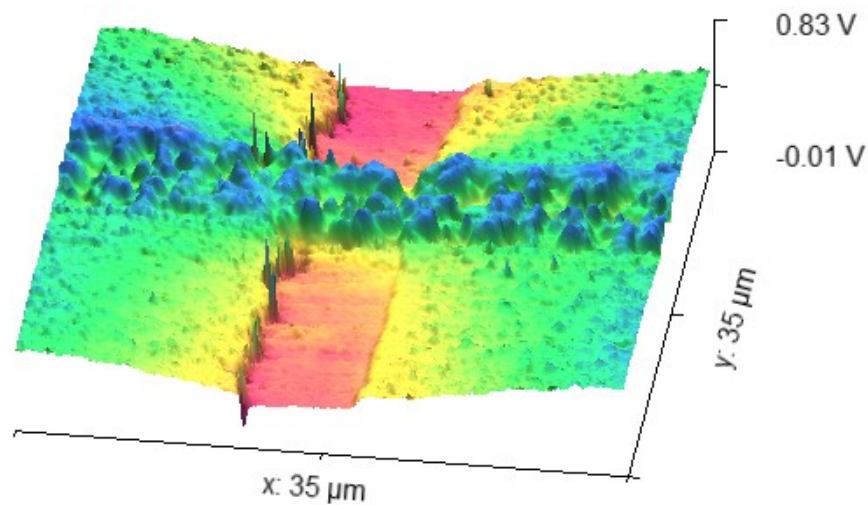
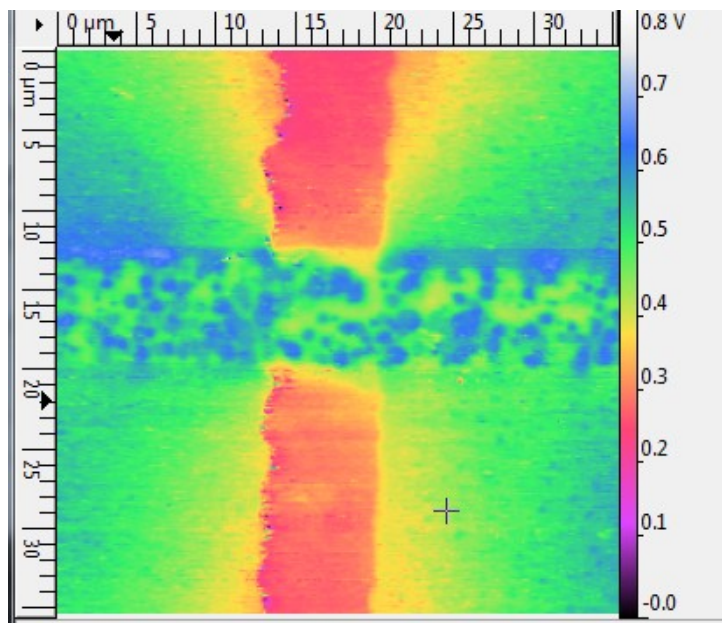


KPAFM

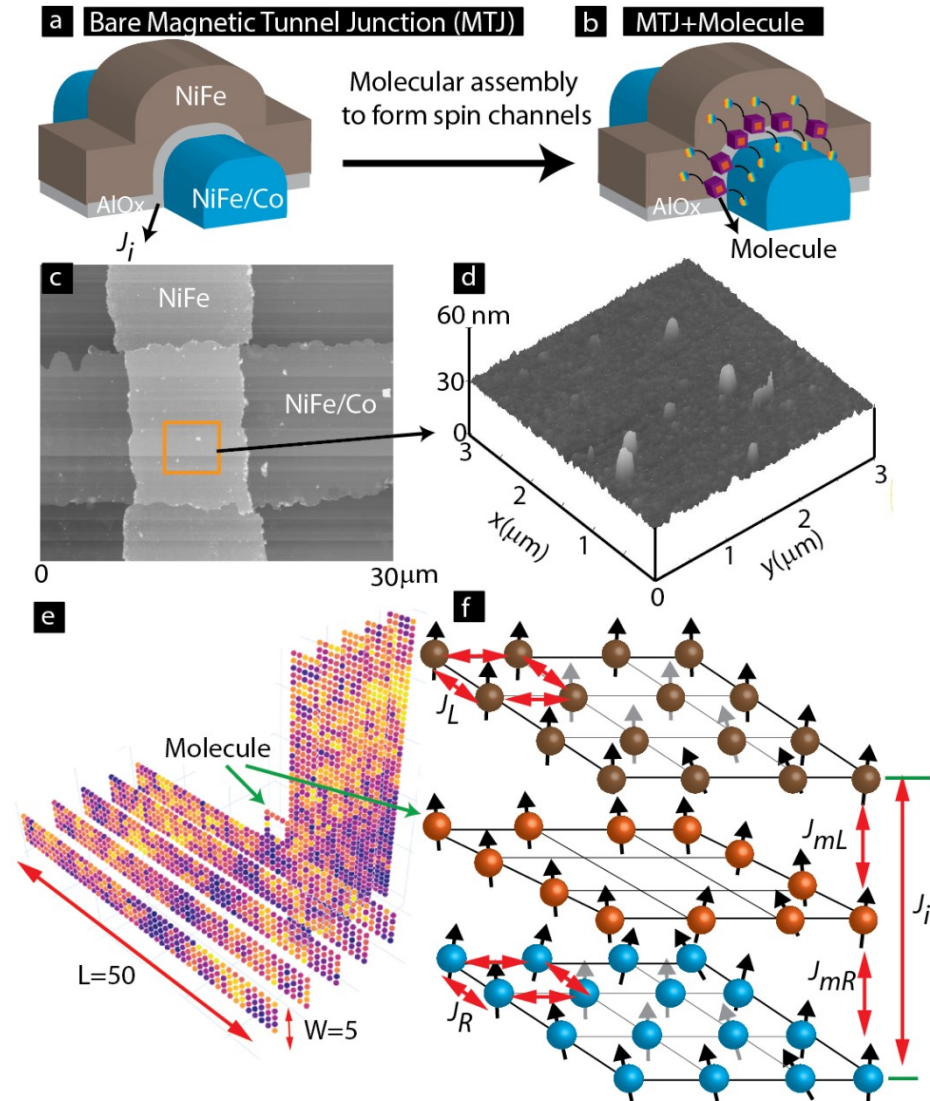
Bare



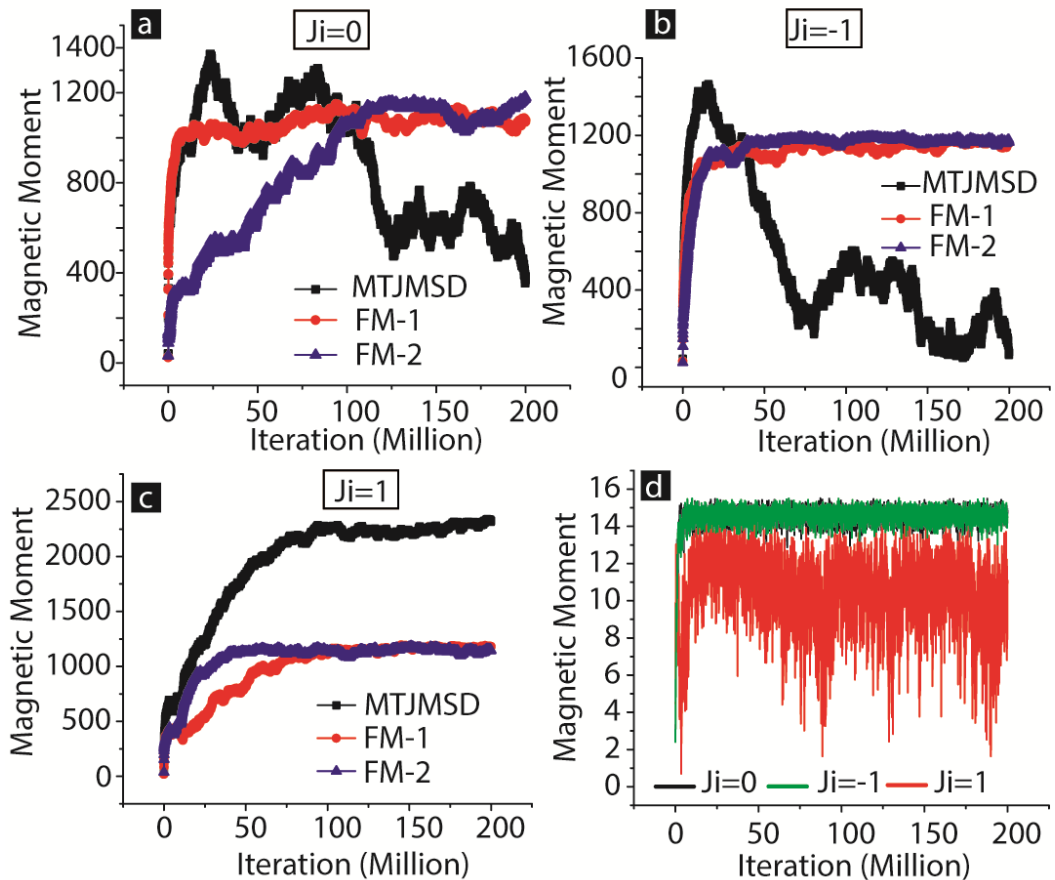
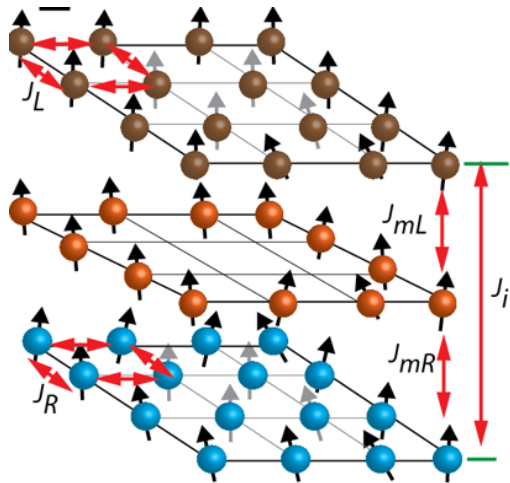
With Molecules



Molecular competing with defects within insulator

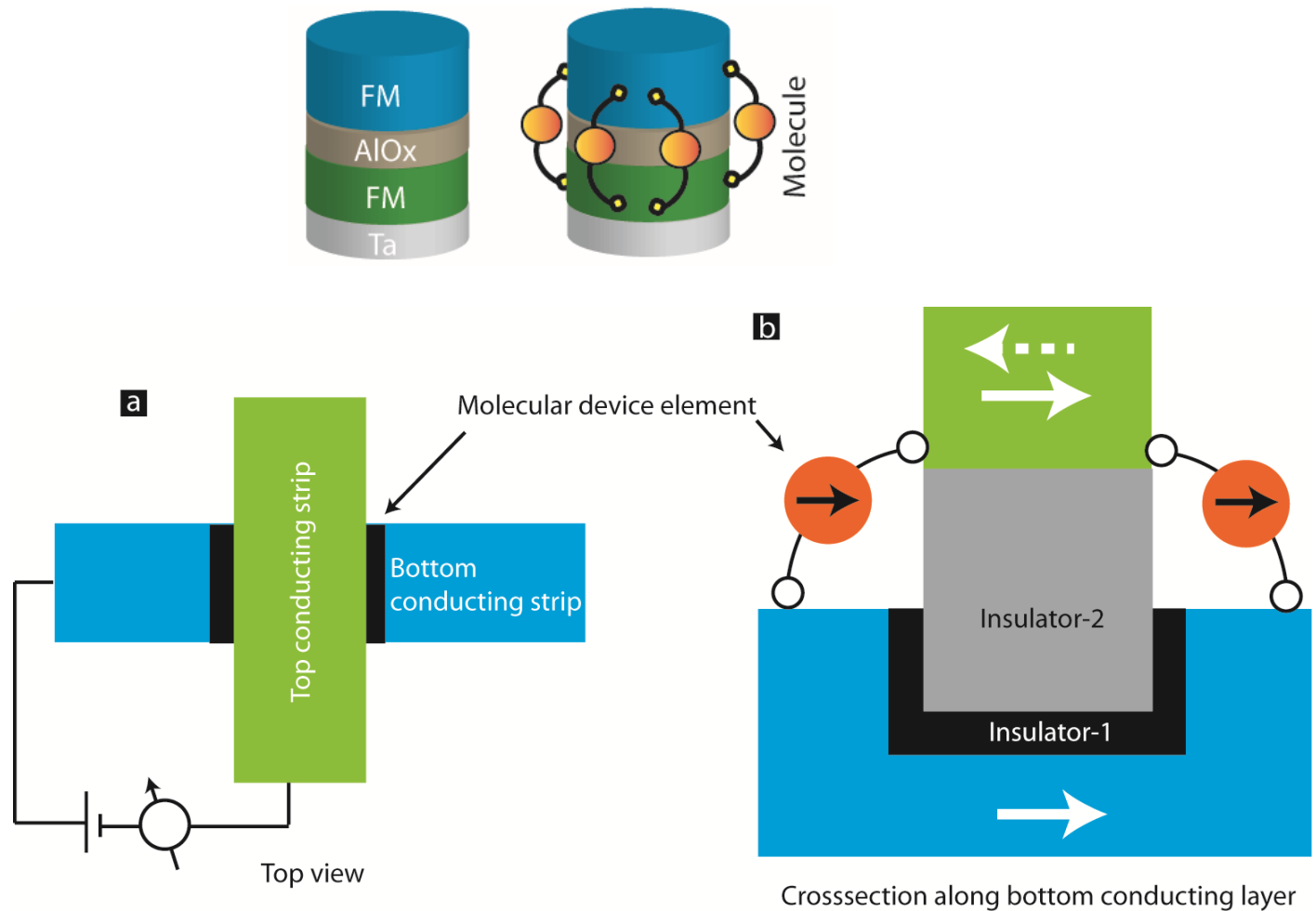


Monte Carlo Simulation of MTJMSD



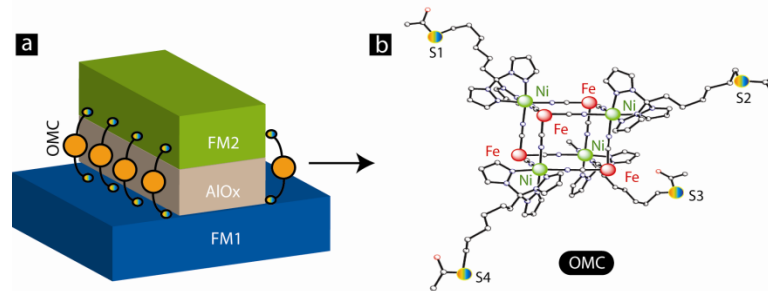
Tyagi, P.; Brown, H.; Grizzle, A.; D'Angelo, C.; Dahal, B. R., Molecular coupling competing with defects within insulator of the magnetic tunnel junction-based molecular spintronics devices. *Scientific Reports* **2021**, *11* (1), 1-13.

New generation: Trenched Bottom Electrode and Liftoff based Molecular Devices(TBEMD)



Pawan Tyagi, 2020, US Patent: 16/102732

Improving MTJMSD for “18” Years?



- **Stability of tunnel barrier-smaller the molecule thinner the tunnel barrier**

Tyagi, P.; Hinds, B. J., Mechanism of Ultrathin Tunnel Barrier Failure Due to Mechanical Stress Induced Nano-Sized Hillocks and Voids. *J. Vac. Sci. Technol. B* **2010**, *28* (5), 517-521.

- **Creating exposed side edges of a tunnel junction for molecular devices**

Tyagi, P.; Li, D. F.; Holmes, S. M.; Hinds, B. J., Molecular electrodes at the exposed edge of metal/insulator/metal trilayer structures. *J. Am. Chem. Soc.* **2007**, *129* (16), 4929-4938.

Tyagi, P., Fabrication of Tunnel Junction based Molecular Electronics and Spintronics Devices *J. Nanoparticle Res.* **2012**, *14* (10), 1195.

Tyagi, P.; Friebe, E.; Baker, C., Advantages of Prefabricated Tunnel Junction Based Molecular Spintronics Devices. *NANO* **2015**, *10* (3), 1530002.

- **Ferromagnetic metal form oxide in air**

Tyagi, P.; Friebe, E.; Baker, C., Addressing the challenges of using ferromagnetic electrodes in the magnetic tunnel junction-based molecular spintronics devices. *J. Nanoparticle Res.* **2015**, *17* (11), 452.

- **Ease of fabrication: Photolithography, thin film deposition**

Tyagi, P.; Friebe, E.; Jacquis, B.; Goulet, T.; Travers, S.; Garcia Moreno, F., Taguchi Design of Experiment Enabling the Reduction of Spikes on the Sides of Patterned Thin Films for Tunnel Junction Fabrication. *MRS Advances* **2017**, *First view*, 6

Tyagi, P., Molecular electronics and spintronics devices produced by the plasma oxidation of photolithographically defined metal electrode *App. Phys. A: Mat. Sci. & Proc.* **2012**, *108* (3), 529-536.

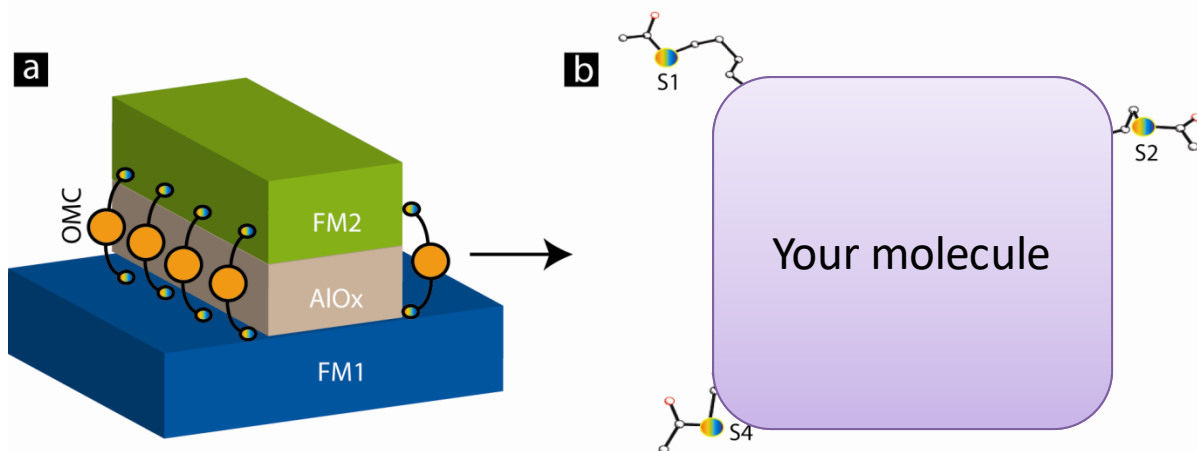
Seeking collaborators & postdoc

We invite chemistry researchers for the development of various forms of inorganic molecules for molecular spintronics devices.

Please contact: Dr. Pawan Tyagi,

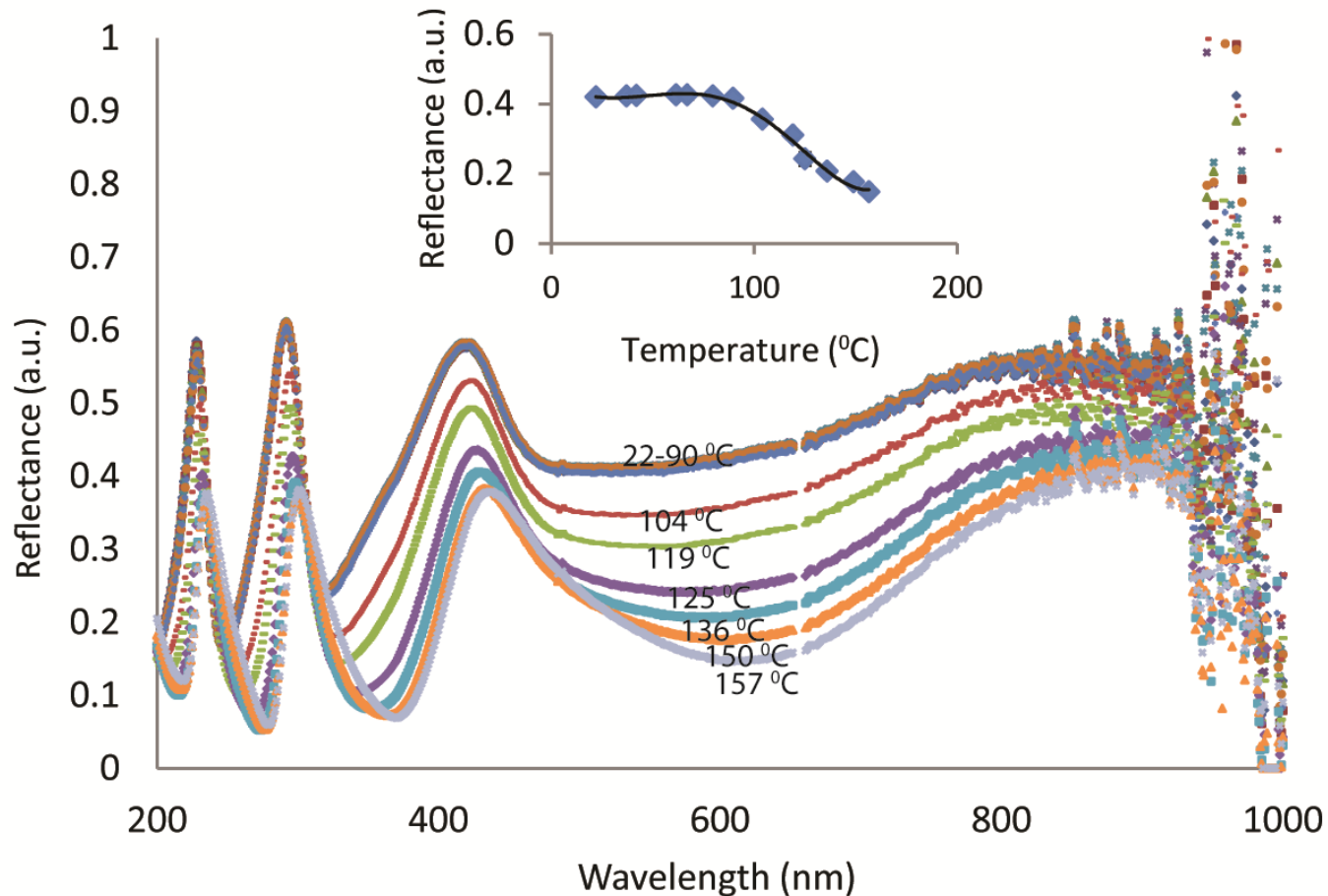
Email: ptyagi@udc.edu

Ph: 202-274-6601



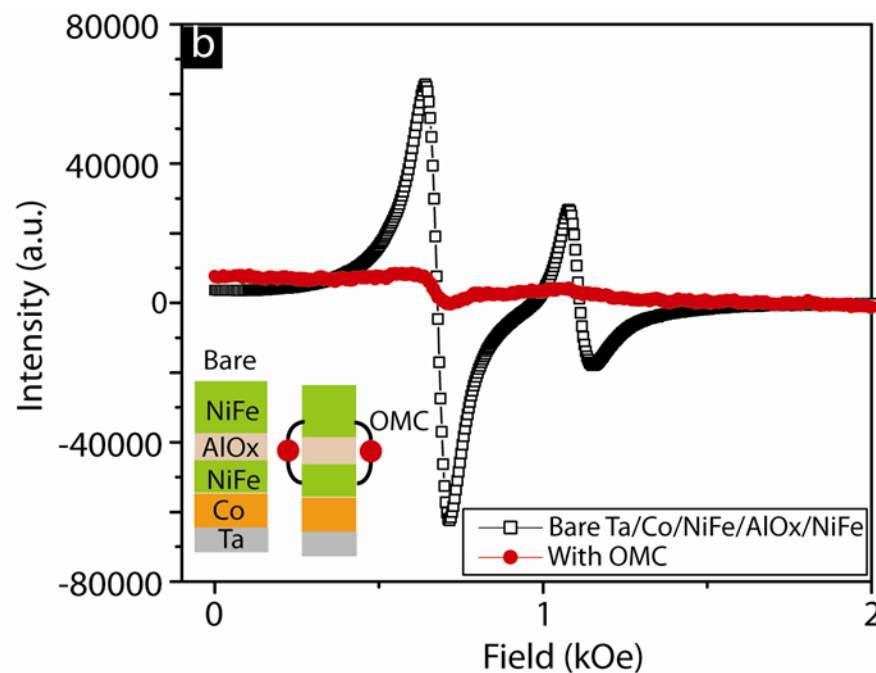
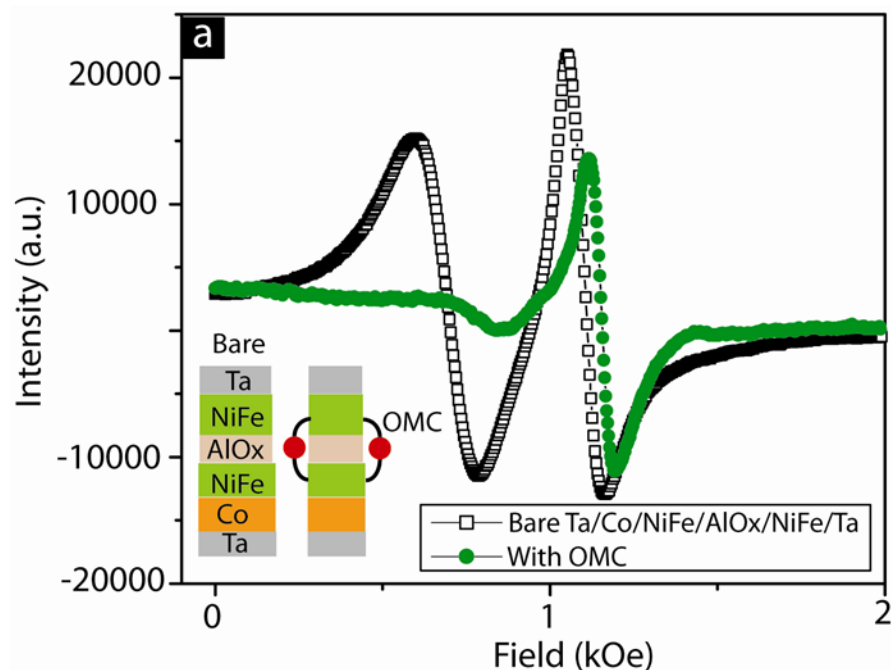
Thank you

Is air oxidation problem for MTJMSD?



Tyagi, P.; Friebe, E.; Baker, C., Addressing the challenges of using ferromagnetic electrodes in the magnetic tunnel junction-based molecular spintronics devices. *J.Nanoparticle Res.* **2015**, *17* (11), 452.

Electron Paramagnetic Resonance



Magnetic Force Microscopy

