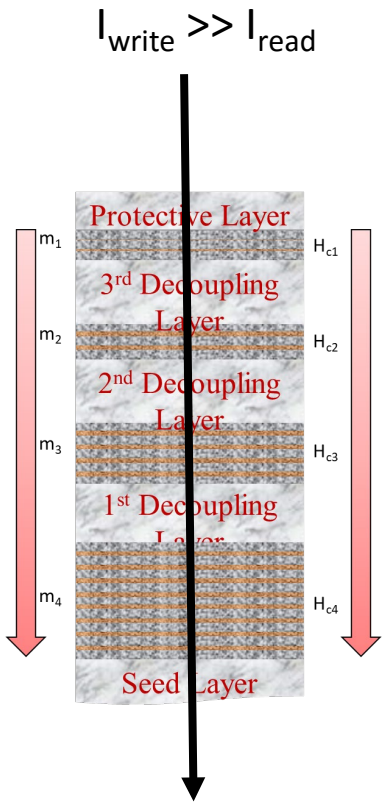
Considerations in the Design of Multilevel Magnetic Device

(Overview of the collaborative research at FIU and UC-Berkeley)

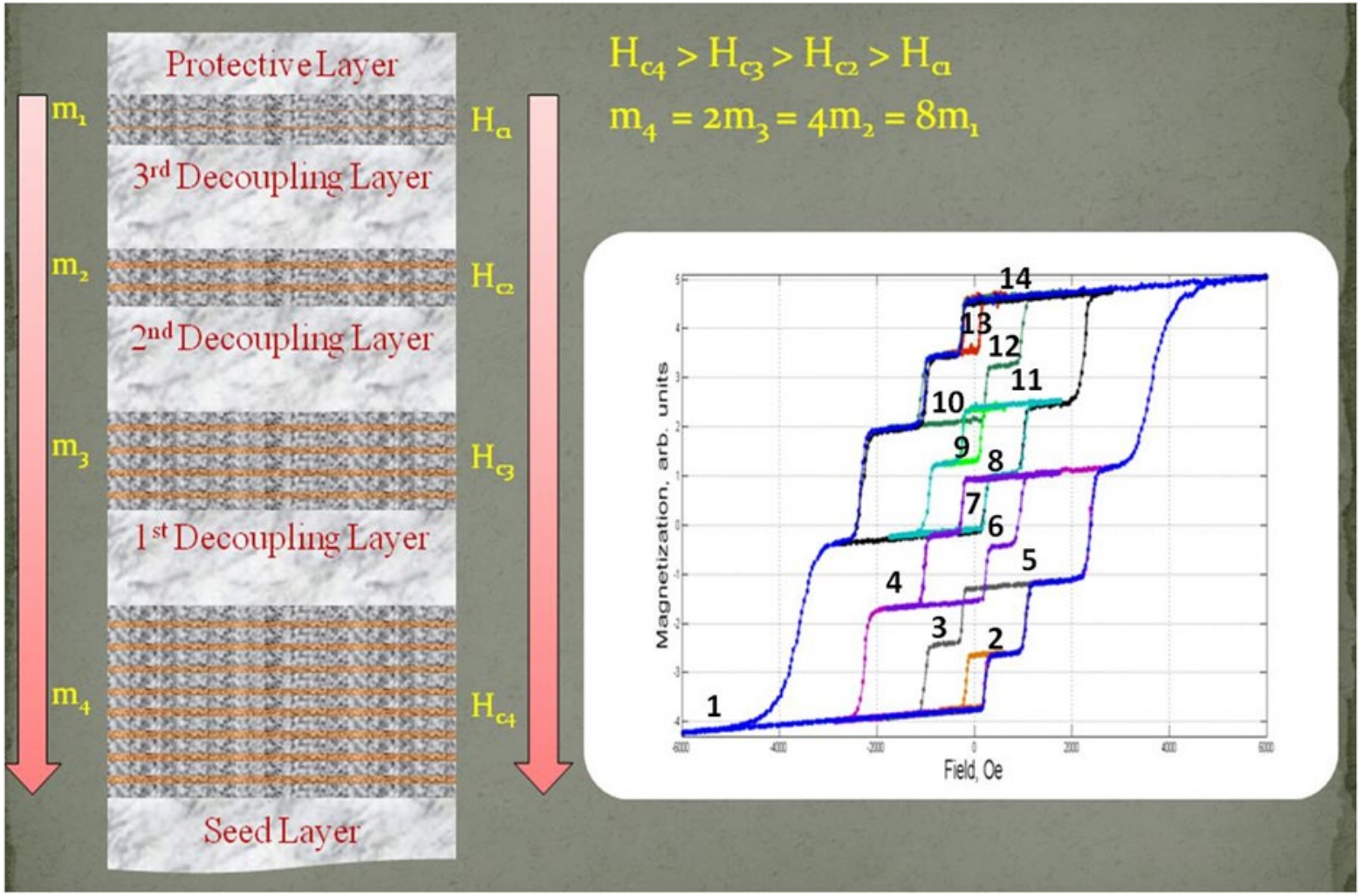
To create a multilevel device, information is recorded into a stack of weakly coupled magnetic layers. Each layer is made of a high anisotropy magnetic material, e.g., CoFeB or Co/Pt and/or Co/Pd pairs. Each layer is approximately 1 nm thick. The thickness of the separating layer, e.g., MgO or Pt or Pd, controls the exchange coupling between adjacent layers. Adjacent layers are weakly exchange coupled so that different layers can be independently recorded. By controlling the coercivity of the magnetic layers across the multilayer stack, it is possible to write and read multilevel signal from the media.



- Writing can be achieved either by a magnetic field or a spin polarized current through the STT effect (we have demonstrated this effect in a 3-layer media)
- Reading can be performed magnetically via the TMR/GMR signal from the stack itself or with a magnetic sensor placed on top of the stack
- Optionally, reading can be performed optically through the MOKE effect in the near field regime (demonstrated in a 4-layer 16-level media)

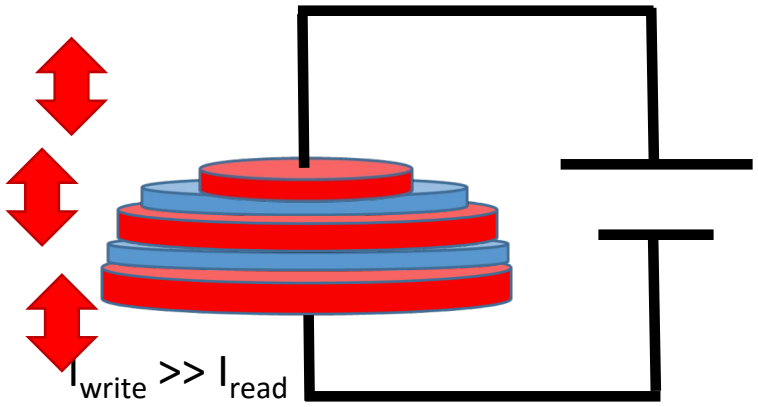
Writing Information Into Multilevel Media by Magnetic Fields*

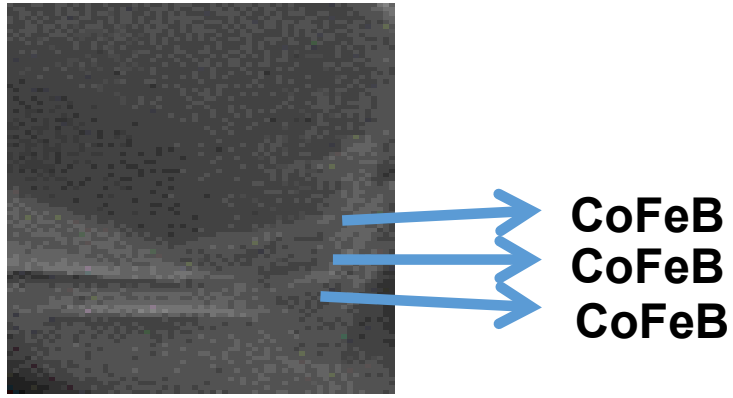
Magnetic transducer

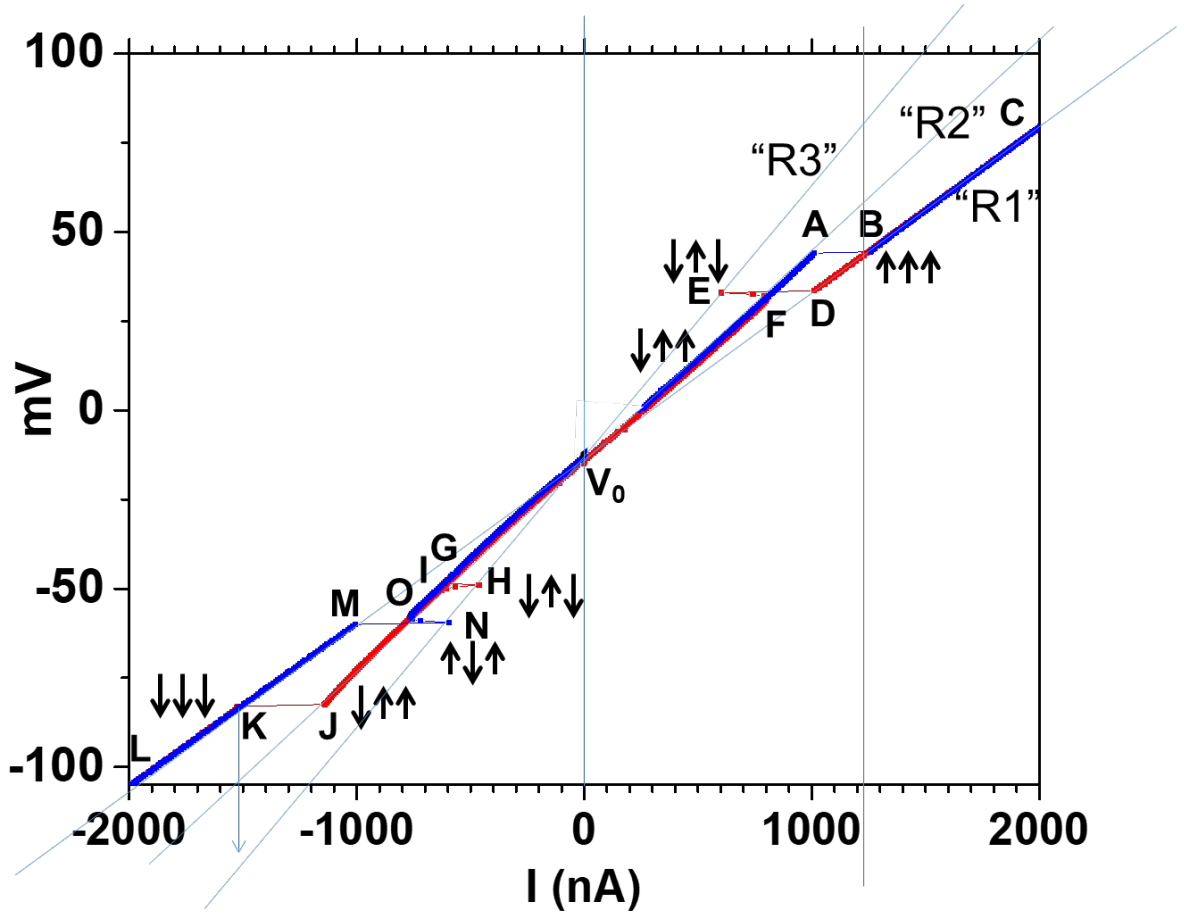


*N. Amos, J. Butler, B. Lee, M. Scachar, B. Hu, Y. Tian, J. Hong, D. Garcia, R. Ikkawi, R. Haddon, D. Litvinov, and S. Khizroev, "Multilevel-3D bit patterned magnetic media with 8 signal levels per nanocolumn," *PLoS ONE* **7** (7), e401234 (2012)

Writing Information Into Multilevel Media Through STT Effect*



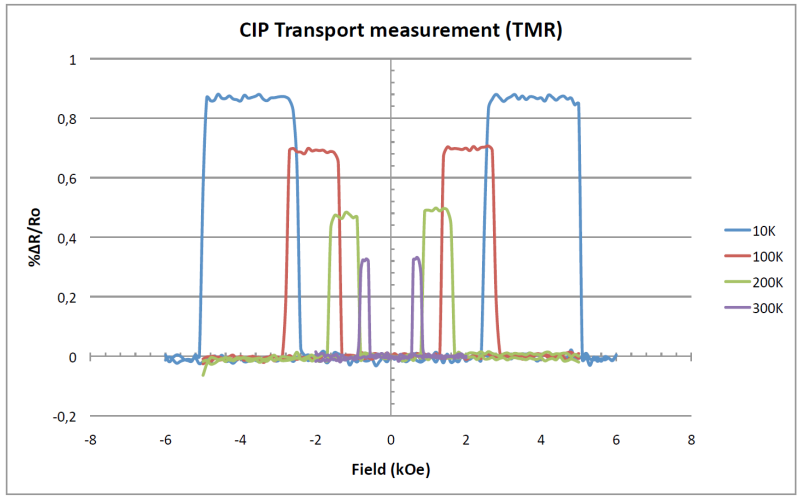




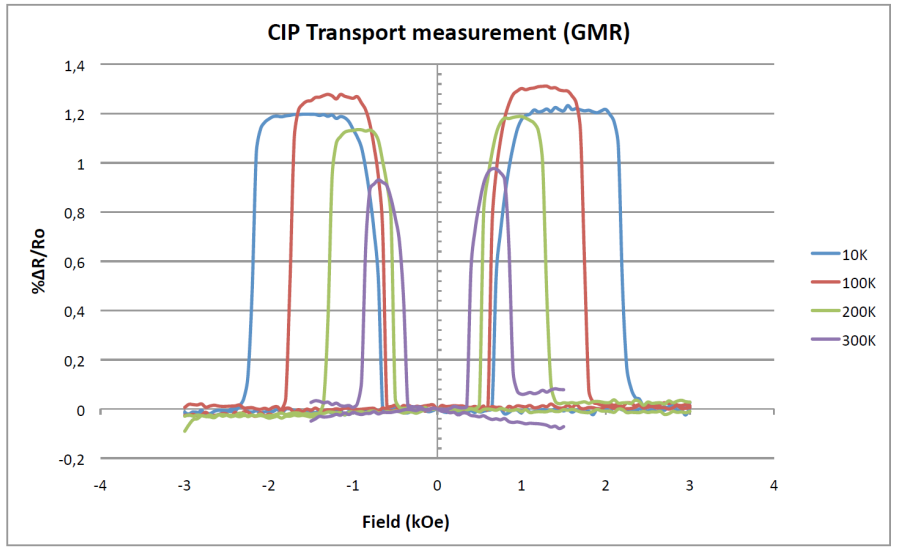
J. Hong, M. Stone, B. Navarette, K. Luongo, J. Bokor, S. Khizroev, "Multilevel three-dimensional spin computer," *Applied Physics Letters* **112**, 112402-4 (2018)

Reading Information From Multilevel Media Through GMR or TMR Effects*

Transport measurement of thin film TMR MTJ. Composition: Ti(5) / Pt(25) / (Co(0.55) / Pt(0.20)) x4 / Co(1) / MgO(2) / Co(0.3) / (Pd(0.50) / Co(0.30)) x4 / Pd(5)

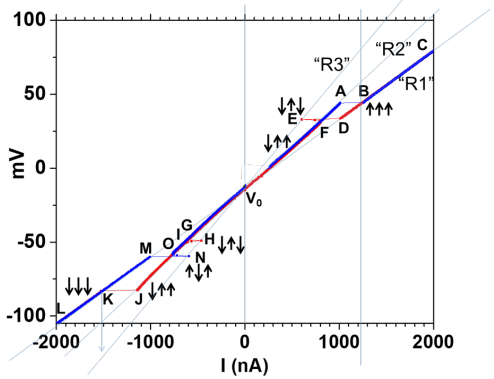


Transport measurement of thin film GMR MTJ. Composition: Ti(5) / Pt(25) / (Co(0.55) / Pt(0.20)) x4 / Co(2) / Au(2) / Co(0.3) / (Pd(0.50) / Co(0.30)) x4 / Pd(5)



Note: CPP measurements with Co/Pt and Co/Pd multilyaers are expected to provide stronger TMR values, however the samples are not ready for measurements.

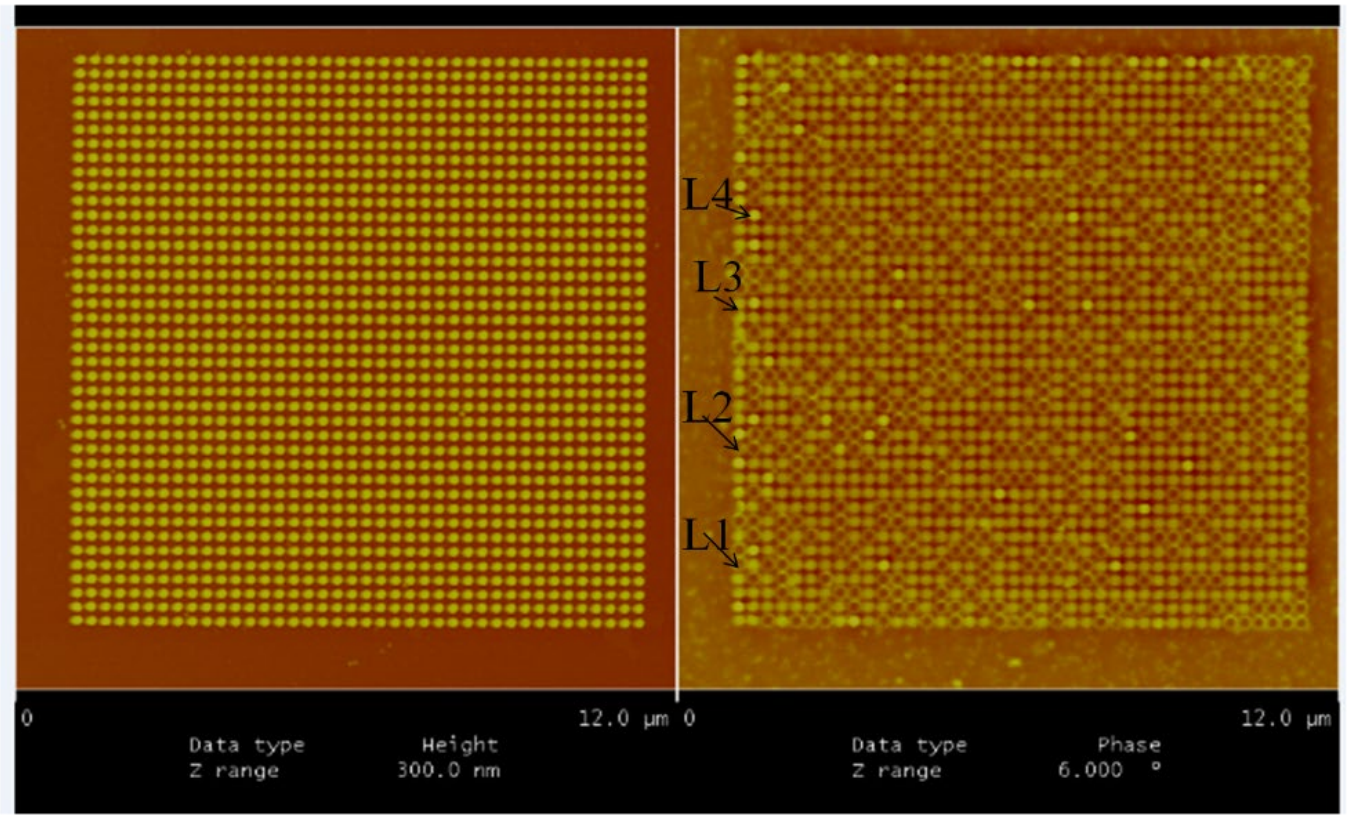
In a 3-layer made of 3 CoFeB layers separated by MgO layers, we can read 3 signal levels



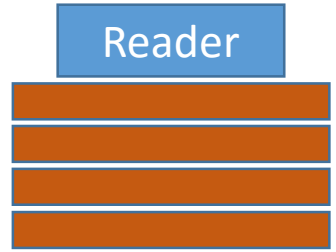
*The study conducted by exchange student from the University of Twente, Netherlands, Tjitte-Jelte Peters

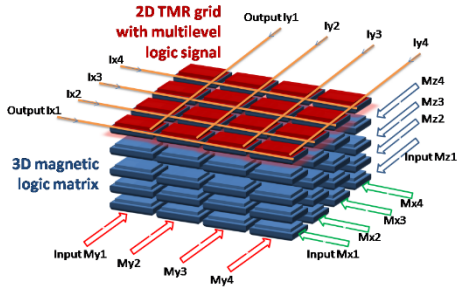
Reading Information From Multilevel Media With a Magnetic Reader on Top of the Stack

AFM MFM



Multilevel media

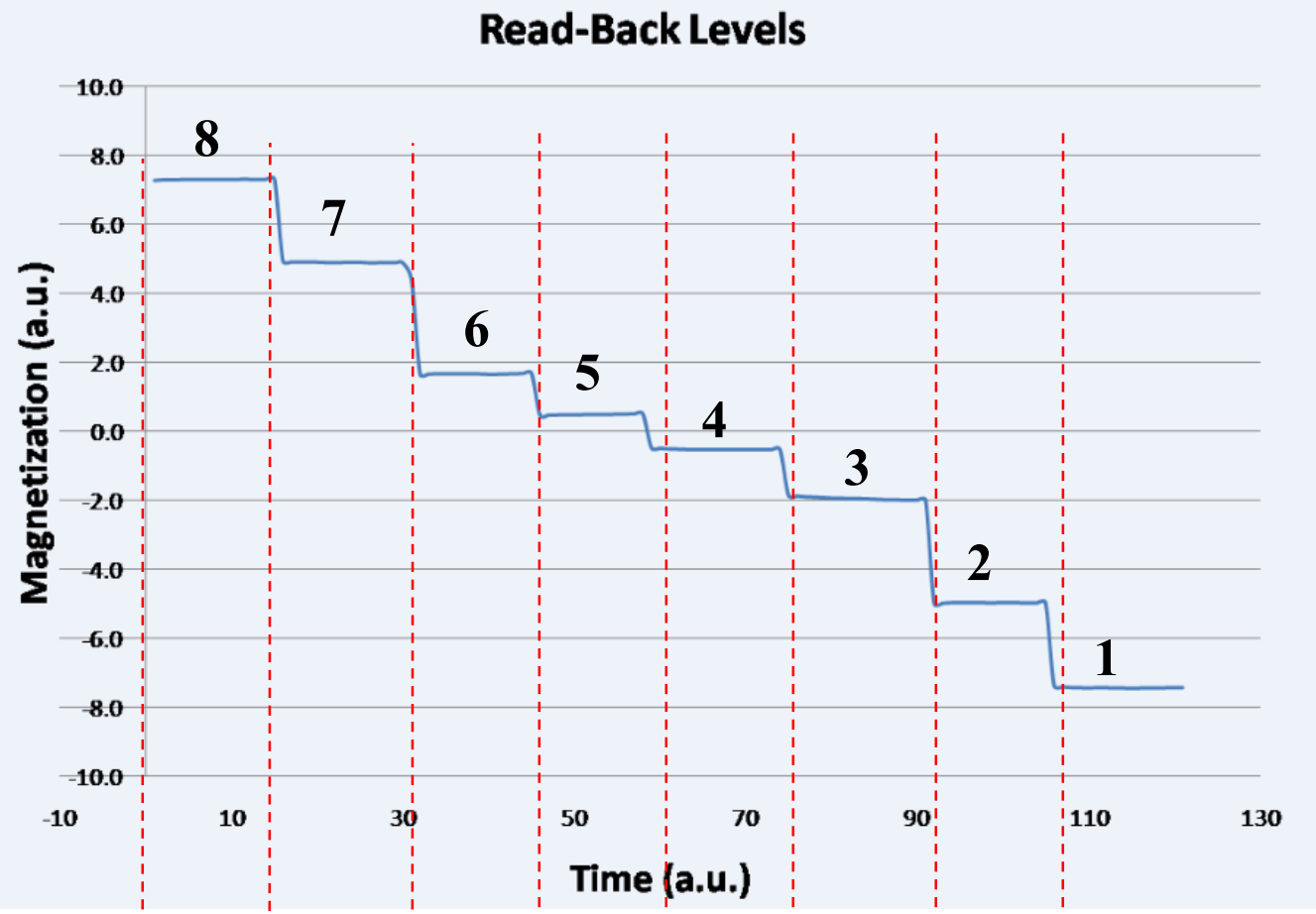


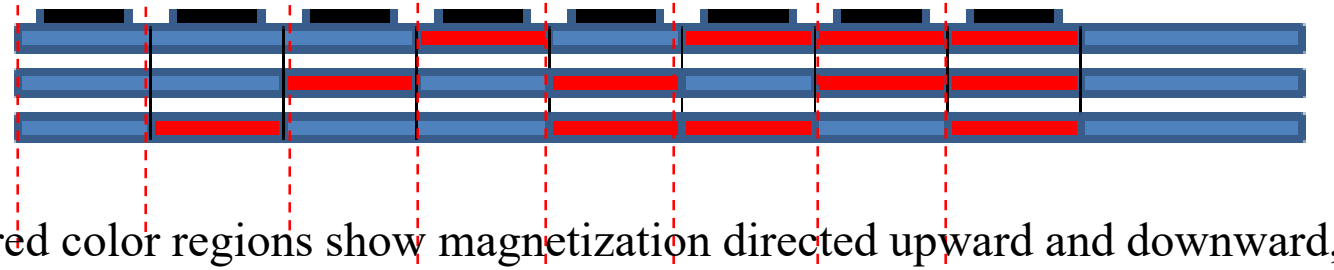


In a 3-layer media made of Co/Pt-Co/Pd multilayer stack, 4 signal levels can be distinguished with a magnetic probe (or a GMR sensor) placed on top of the stack.

*J. Butler, M. Shachar, B. Lee, D. Garcia, B. Hu, J. Hong, N. Amos, and S. Khizroev, "Reconfigurable and non-volatile vertical magnetic logic gates," *Journal of Applied Physics* **115**, 163903 (2014)

Reading Information From Multilevel Media Through MOKE*

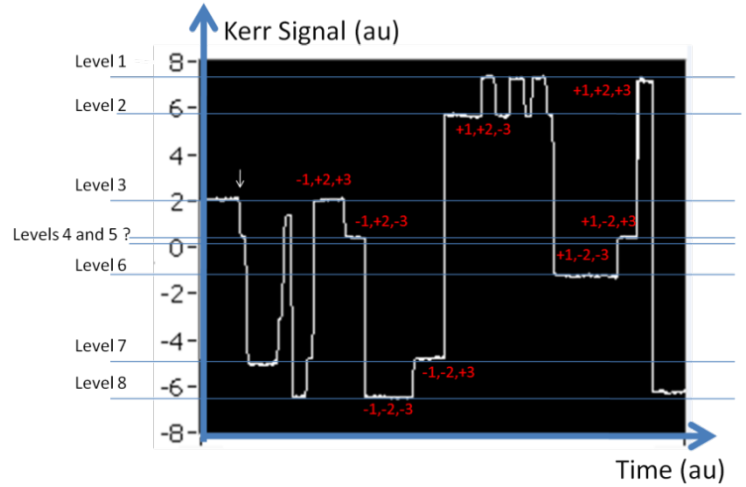




ML3D Media
(with 3 layers)

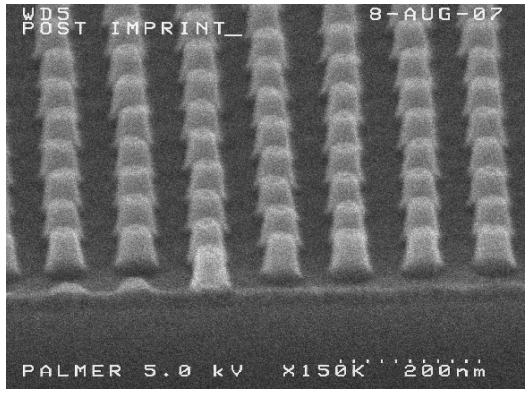
Note: Blue and red color regions show magnetization directed upward and downward, respectively

Spinstand Experiment

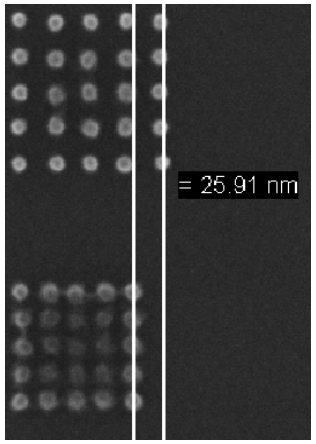


Patterning of Multilevel Devices

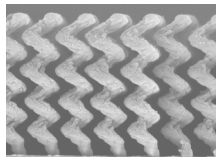
Imprint Lithography (cost-effective solution, 3-nm is possible)
(N. Joshi)

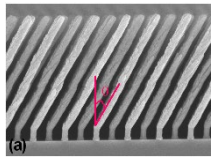


EBL
(B. Lee)



Oblique vapor deposition
(with Toh-Ming Lu, RPI)





Conclusions

- Writing can be done either by a magnetic field or a spin polarized current through the STT effect (we have demonstrated this effect is in a 3-layer media) or a combination of magnetic field and thermal energy from …
- Reading can be performed magnetically through the TMR/GMR effect (demonstrated in a 3-layer media)
- Optionally, reading can be performed optically through MOKE effect (demonstrated in a 4-layer 16-level media)
- Using this approach, we can build at least a 5-layer magnetic device capable of 32 signal levels

Acknowledgements

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Brayan Navarrete	Nissim Amos	Jeffrey Bokor
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Dennis Toledo		
Ping Wang		
Tjitte-Jelte Peters (Exchange Student at U of Twente)		