Address line-assisted switching of vertical magnetoresistive random access memory (VMRAM) cells

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Presentation Outline

- VMRAM Overview
- VMRAM Technology
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  - MR Response
  - Reading and Writing
  - Arrays w/ Address Lines
- Test and Analysis
- IC Prototype
- VMRAM vs. Hard Disk Drive
- Conclusion

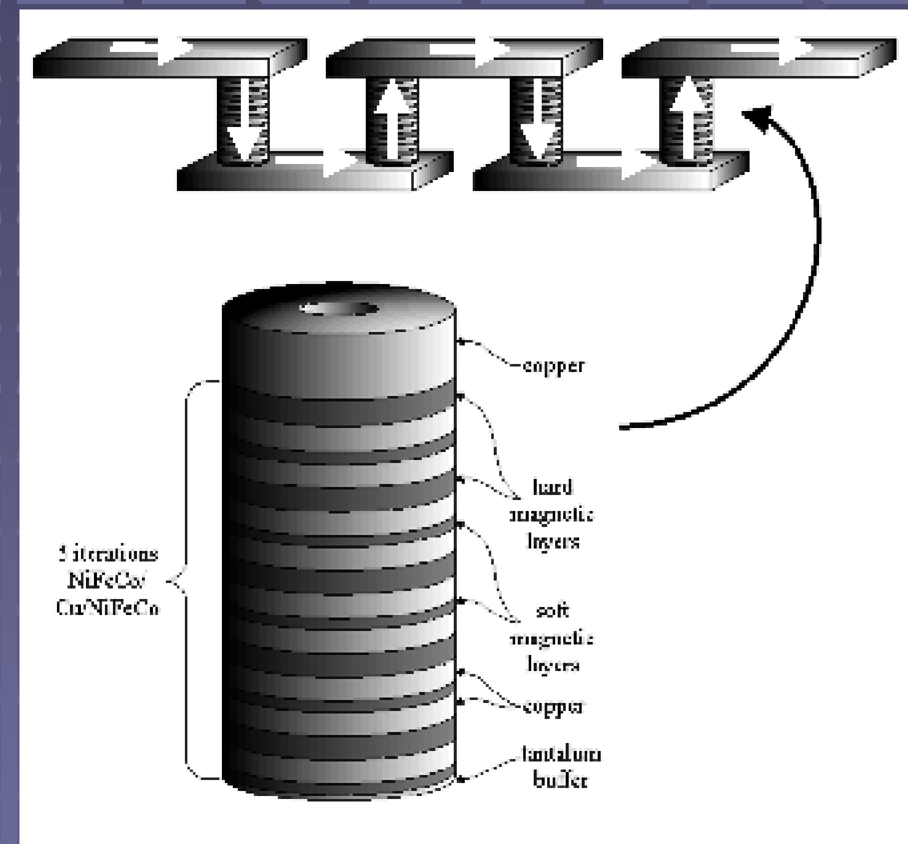
VMRAM Overview

- VMRAM = Vertical Magnetoresistive Random Access Memory
- Devised and developed by researchers at NRL and CMU
  - NRL: Dr. Gary Prinz[1,2,3], Dr. Konrad Bussmann[2]
  - CMU: Dr. Jian-Gang Zhu[1]
- VMRAM cells consist of toroid-shaped elements that have a stable closed-flux magnetic configuration
- Employs current perpendicular to the plane (CPP) to switch soft (read) and hard (write) magnetic layers of a GMR multilayer
- Address (word) lines generate radial torque fields that assist switching
- Teams from NVE Corp. and NRL have developed processes to fabricate 64-bit strings of 0.6μm O.D./0.2μm I.D. cells with address lines
- VMRAM is a high-density, non-volatile memory theoretically scaleable to 400Gbits/in^2 at $\lambda = 10$nm[1] and has the potential to compete with both semiconductor memories and mechanical hard disks.

[1]J-G. Zhu, Y. Zheng, and G.A. Prinz, J. Appl. Phys. **87**, 6668 (2000).
[2]K. Bussman, G.A. Prinz, R. Bass, J.-G Zhu, Appl. Phys. Ltrs. **78**, 2029 (2001).
[3]G. Prinz, U.S. Patent No. 5477482

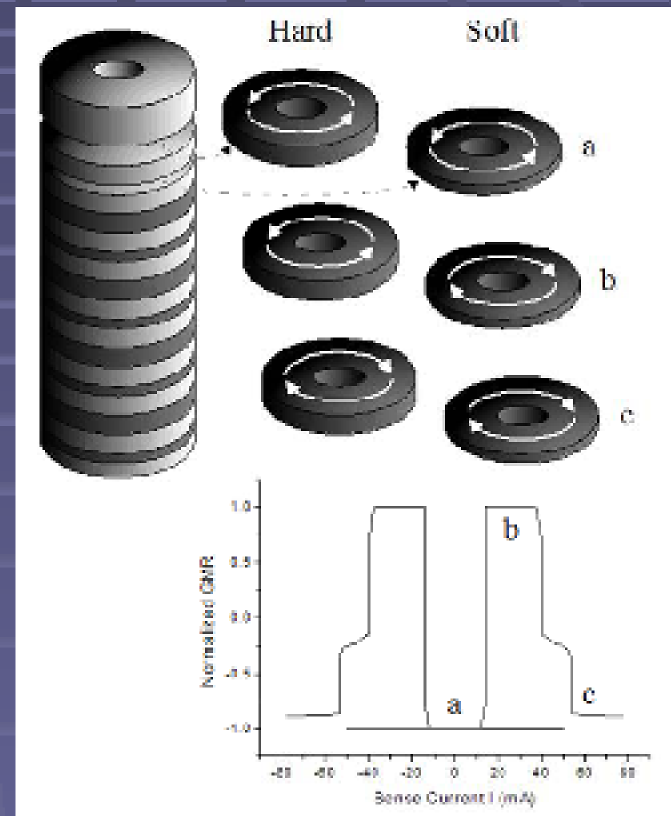
VMRAM Technology – Bits and Sense Lines

- 2000Å CMP'd Cu
- 40Å Ta phase breaking layer
- Multilayer stacks: [NiFeCo (20Å)/Cu (40Å)/ NiFeCo (40Å)/Cu (40Å)]x5
- 2000Å Cu connects cells such that current flows vertically
- Test arrays consist of 256 bits in 4x64-bit strings



VMRAM Technology – MR Response

- Response shape is similar to pseudo-spin valve
- Thicker (hard) layers act as storage mechanisms
- Thinner (soft) layers act as read mechanisms
- Simulated Response
  - Soft layers switch ~15mA
  - Hard layers switch 40 – 55mA
- Address line current effectively reduces switch thresholds



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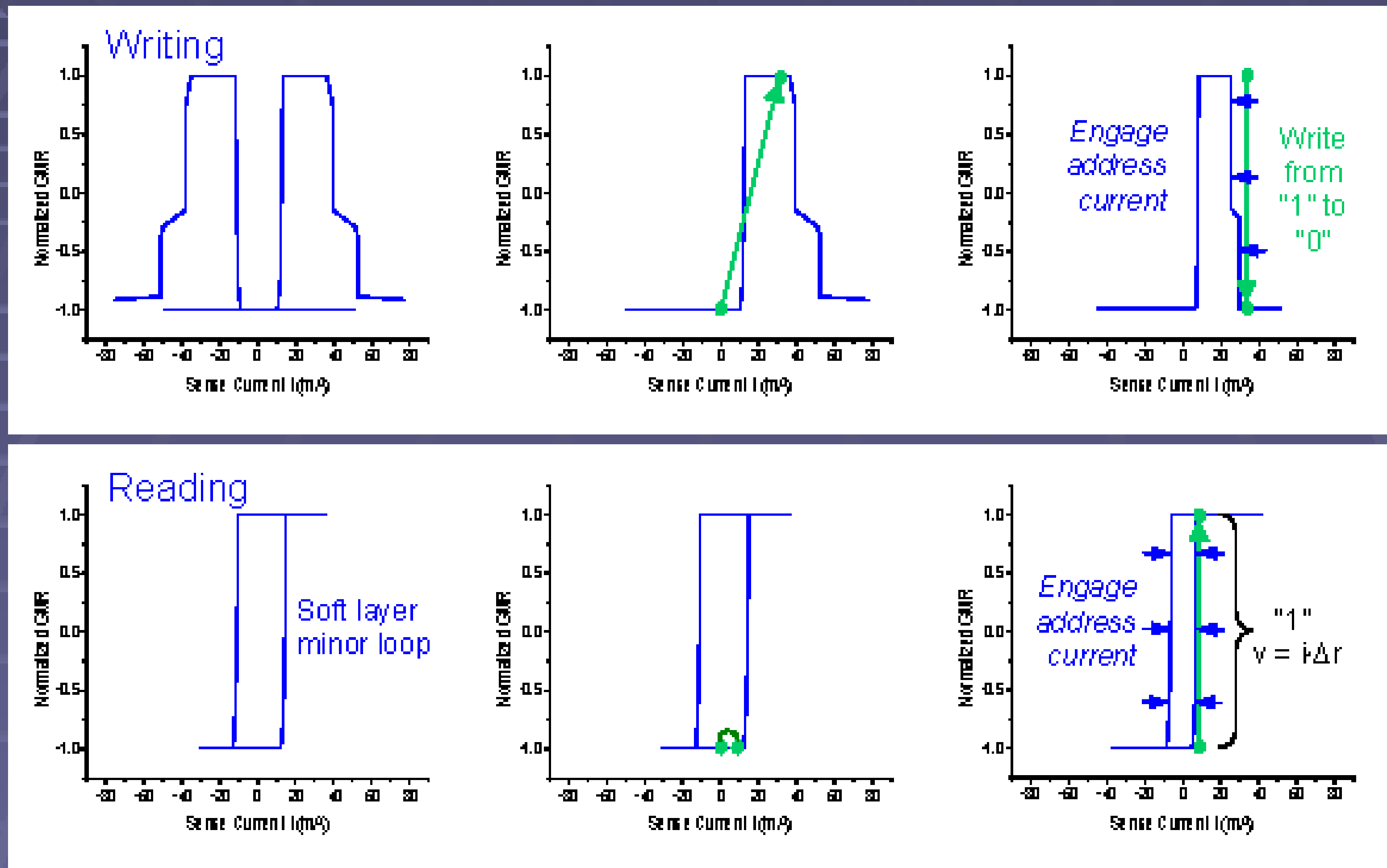
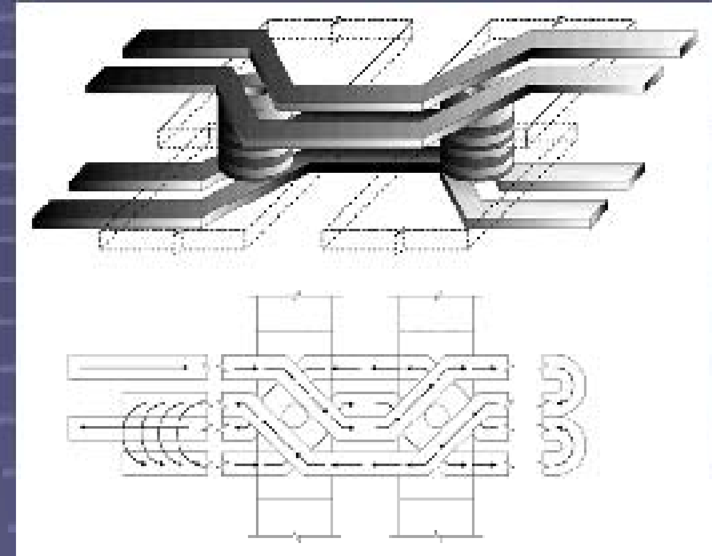
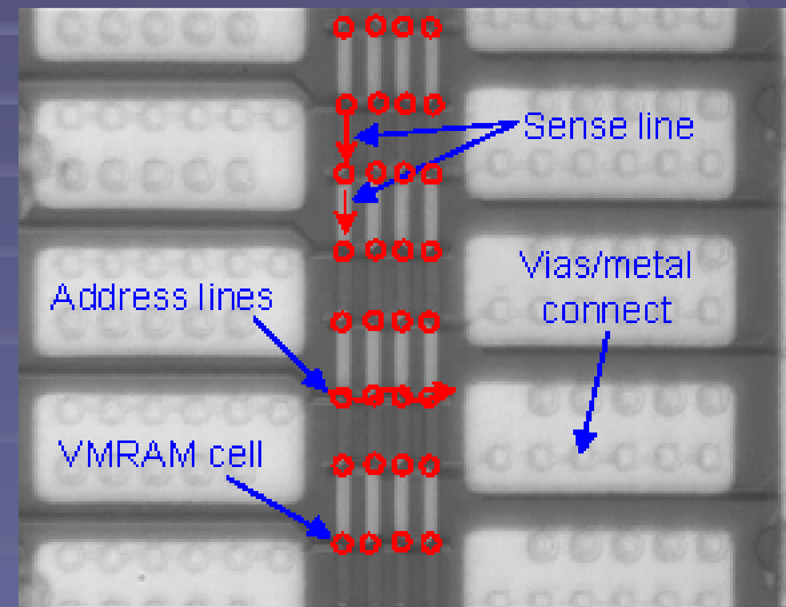
VMRAM Technology – Writing/Reading



VMRAM Technology – Array w/ Address Lines

- Serpentine arrangement yields orthogonal upper/lower address lines
- Address current generates an outward radial word field for the current direction shown
- 4x64 arrays (4x8 section shown)
  - 4 sense lines run vertically
  - Address lines run horizontally
- 2-D selection
- Top and bottom address line segments connect through vias
- VMRAM cells reside at the junctions – 32 cells shown



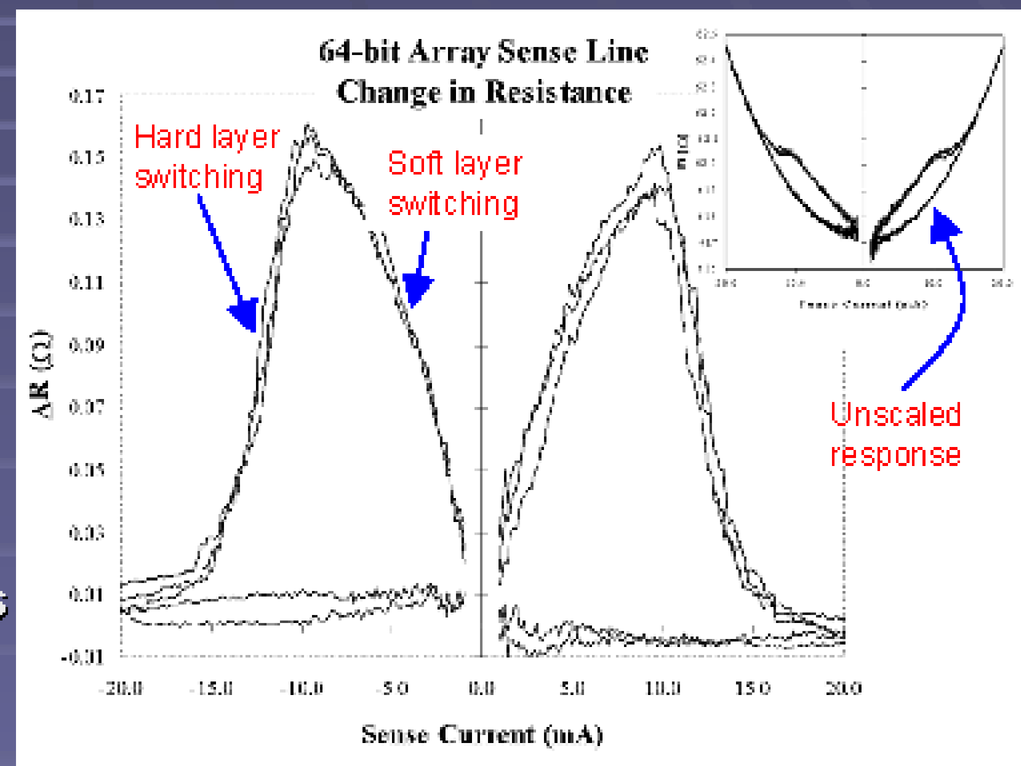


Test and Analysis – General Test Procedure

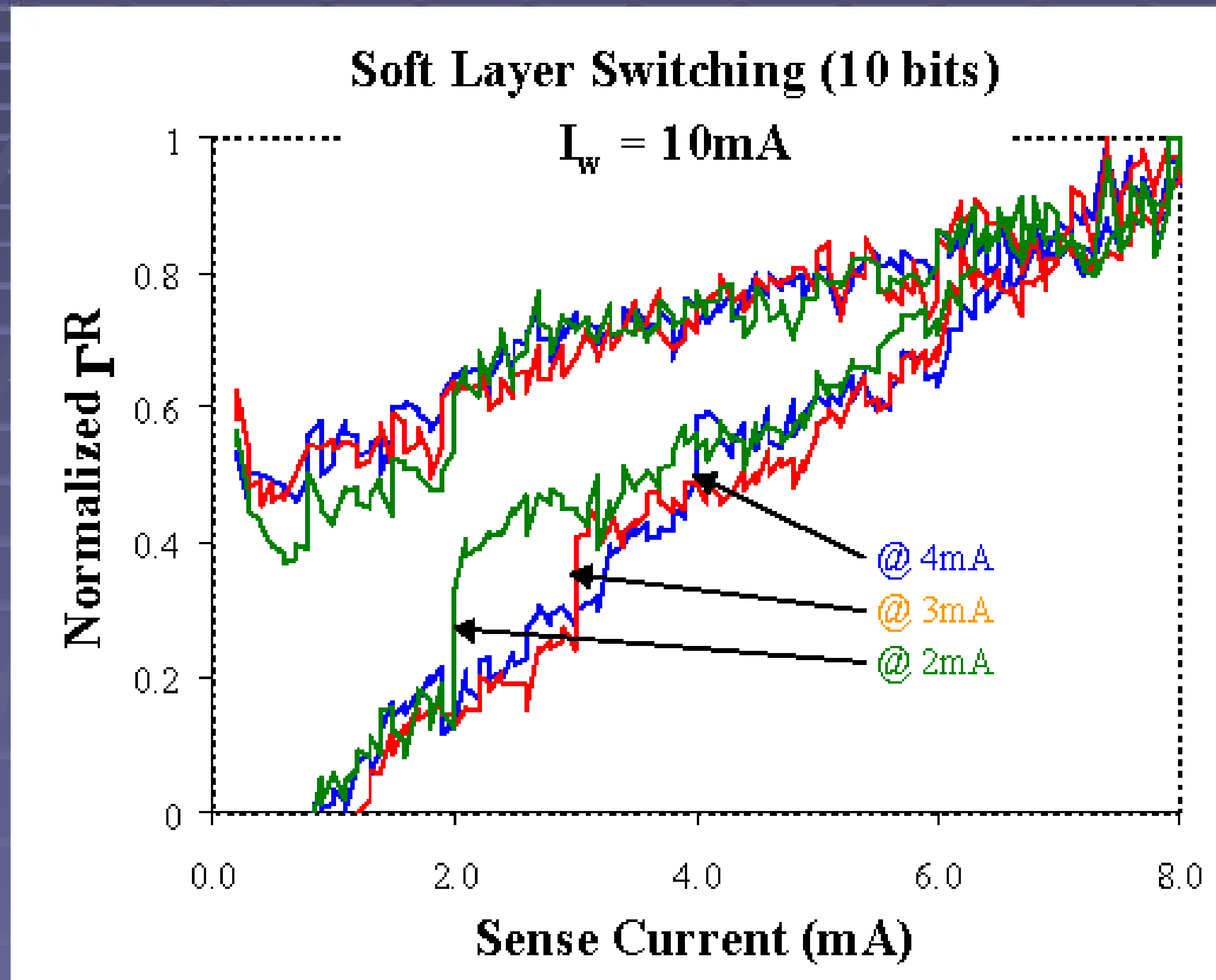
- Run bipolar sense current sweep to determine switch thresholds (+/- I_{th})
- Establish reference by saturating bits with $+I_{th}$mA and sweeping the sense line with the same polarity current
- Saturate sense line with < $|-I_{th}$mA$|$ and $I_{addr.}$mA
- Sweep sense current from $+I_{small}$mA to $+I_{th}$mA
- Read voltage at each sense current step:
  - Sample voltage
  - Assert address current
  - Sample voltage
- Generate MR transfer curve
- Scale data by subtracting out reference curve

Test and Analysis – MR Response

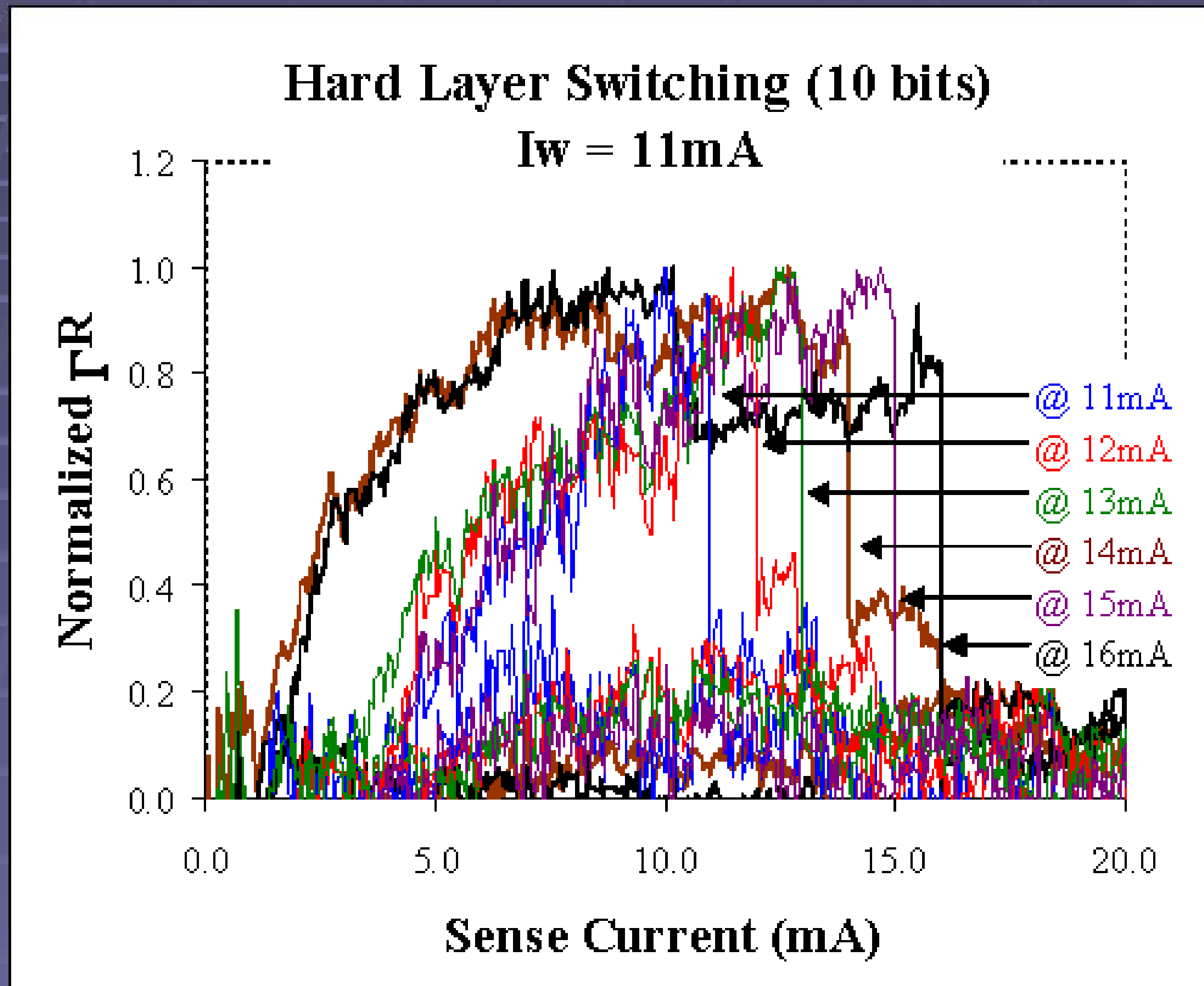
- Observations:
  - GMR <1% vs. 10%-20%
  - Smooth transitions for hard and soft layers vs. abrupt switching
- Suspected cause: magnetic material redeposition
  - couples the stack layers
  - limits antiparallel alignment between hard/soft layers
  - and/or, significantly reduces the number of "active" layers



Test and Analysis – Read Layer

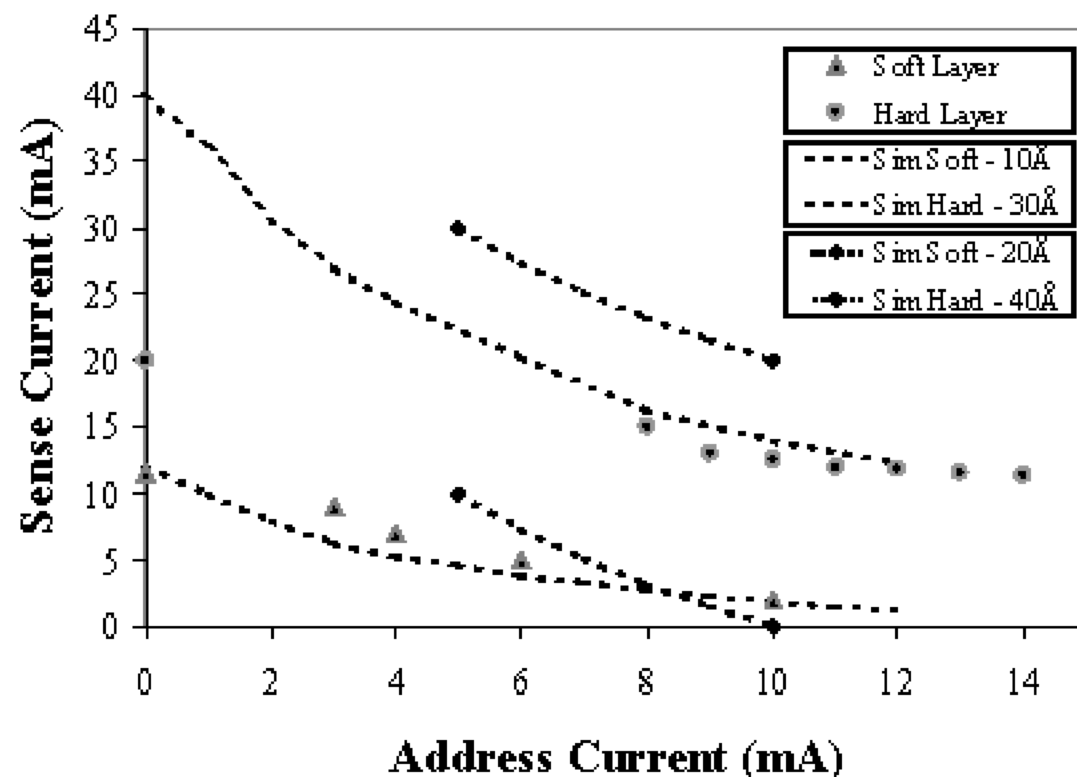


Test and Analysis – Write Layer

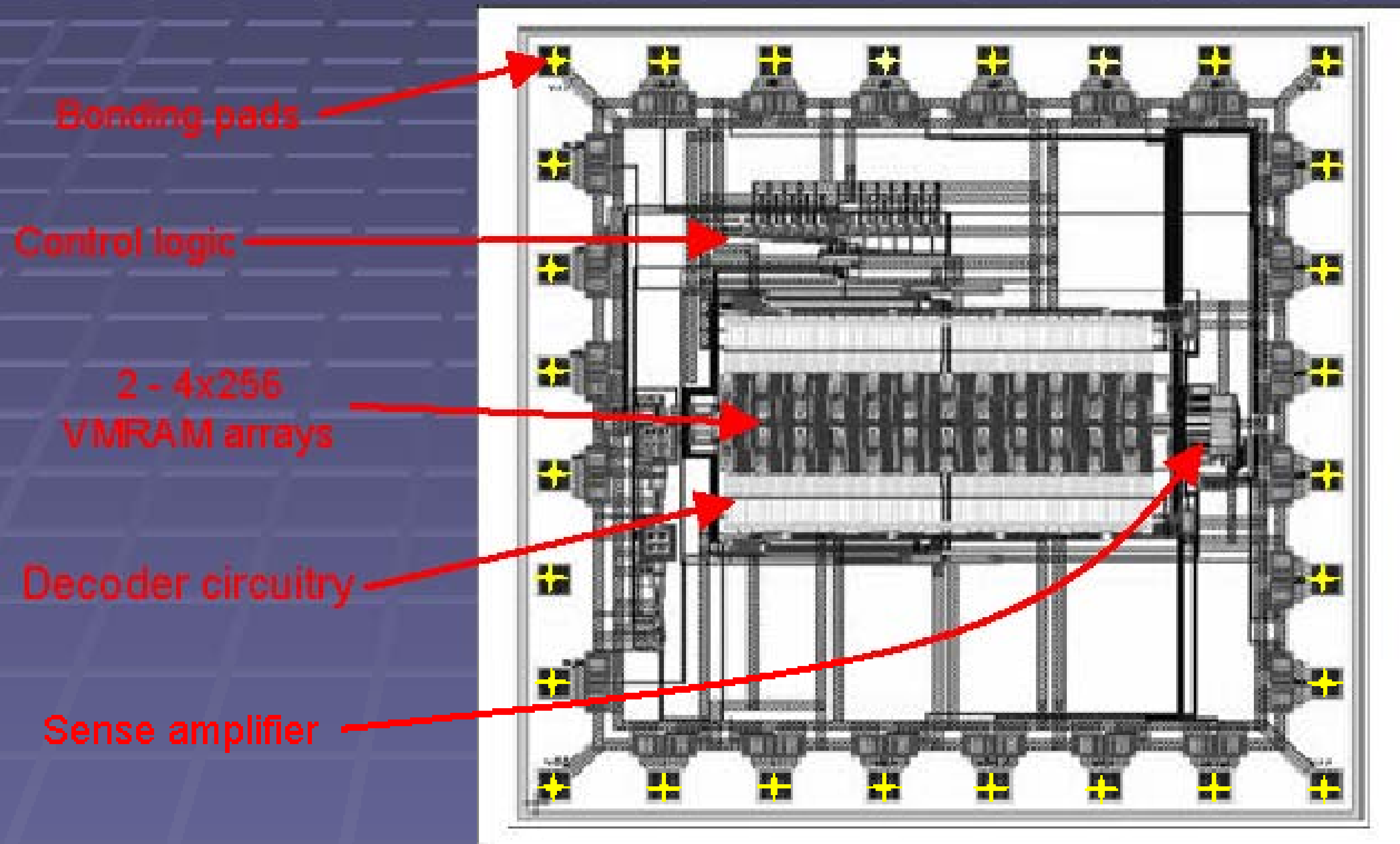


Test and Analysis – Switching Asteroid

- Soft layer operating point
  - I_{sense} = 6mA
    $I_{addr.}$ = 5mA
- Hard layer operating point
  - I_{sense} = 12mA
    $I_{addr.}$ = 10mA
- Experimental data tends toward simulated 10Å/30Å combination



VMRAM 2K IC Prototype Design



VMRAM vs. HDD (Projected)

- VMRAM Density at $\lambda = 0.01\mu m$ node
  - Best case: $16\lambda^2$ = 403 Gbits/in^2
  - Worst case: $18.77\lambda^2$ = 358 Gbits/in^2
- VMRAM compared to a 147GB HDD*
  - $\lambda = 0.09\mu m$ node
  - 9mm x 9mm PLCC package can hold 270 – 305Mb
  - HDD* FF => 4" x 5.78" x 1.03"
  - Same sized VMRAM memory module yields 65 – 75GB
  - *A VMRAM memory module built today could have ~50% the capacity of today's HDD*
  - *At $\lambda = 0.08\mu m$ (ITRS projection for 2005) capacity is ~65%*
- VMRAM has no mechanical wearout
- Smaller, rugged, more versatile form factor

*Maxtor Atlas® 15K II

Conclusion

- Four by sixty-four bit VMRAM test arrays were successfully fabricated using address lines designed for 2-D selection.
- Address-assisted switching of VMRAM cells was demonstrated
  - Soft layer switching: I_{sense} = 6mA, $I_{addr.}$ = 5mA
  - Hard layer switching: I_{sense} = 12mA, $I_{addr.}$ = 10mA
- Edge pinning in the GMR stack due to magnetic material redeposition led to low signal response and smooth transitions in unassisted MR response.
- GMR multilayer optimization is needed in order to maximize signal and ensure "singular" switching thresholds for stack magnetic layers.
- Integrated 2K VMRAM prototype design has been completed for a 0.35µm gate length semiconductor process.
- Hard and soft layer switching asteroids generated from experimental data compare well with micromagnetic simulations.

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