A Generalized HSPICE* Macro-Model for Pseudo-Spin-Valve GMR Memory Bits

by

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Outline

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- GMR Characteristics and Applications
- Pseudo-Spin-Valve Characteristics
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  - Generalized
- HSPICE Macro-Model
  - Schematic
  - Attributes
  - Simulation
- Current and Future Work
- Summary and Conclusion
Introduction to GMR Devices

- Two ferromagnetic layers separated by non-magnetic spacer layer
- **Spin-Valve**: one layer pinned by anti-ferromagnetic layer
- **Pseudo-Spin-Valve**: both the layers are free to rotate (not pinned)

- Resistance is function of difference between magnetizations
- Variations of 6%+ have been demonstrated for practical bits

\[ R \approx R_{\text{max}} - k \cdot \cos \phi \]
Typical Characteristics and Applications of GMR

• Characteristics:
  • Stable magnetic states (non-volatile)
  • Resistant to ionizing radiation
  • Significant signal improvement relative to older single-layered Anisotropic Magneto Resistance (AMR) material

• Applications:
  • Non-volatile memory (MRAM)
  • Magnetic sensors
  • Disk read-heads
  • Isolation devices
Basic GMR Bit Configuration

- Read with sense current (may stack bits)
- Write design options:
  - word current alone (small memories)
  - coincident sense and word current (large memories)
Spin-Valve Characteristics

- Hysteretic in nature
- Combination of graphs P and N. $I_W > I_P$: Graph P; $I_W < I_N$: Graph N
- Two distinct states: Graph P: St. 1; Graph N: St. 0 (or vice versa)
- $I_W > I_P$: write to St. 1; $I_W < I_N$: write to St. 0; $I_N < I_W < I_P$: read
- $I_N$ and $I_P$ are weak functions of sense current
Typical Pseudo-Spin-Valve

Bottom (harder) layer magnetization curve: higher coercive force

Top (softer) layer magnetization curve: lower coercive force
Typical Pseudo-Spin-Valve (contd.)

- Combination of two curves: one for actual top layer and the other for bottom layer
- The graph is the absolute difference of the two
- Symmetric Major and Minor loops
Macro-model

- Four terminal sub-circuit:
  - Two word line terminals, two sense line terminals

- Four simple parts:
  - Input (word) circuit
  - Bistable multivibrator or Schmitt Trigger
  - Decision circuit
  - Output (sense) circuit
Macro-model (contd.)

\[ V_{TH} = -L_-(R1/R2) \]
\[ V_{TL} = -L_+(R1/R2) \]

Eopamp : VCVS

Gd : VCR [1:1] cntl by V(7,wd0)

Gr : VCCS (+/-1) = V(4,wd0)/L [ L = L_+ = -L_-

Gb : PWL VCR cntl by V(3,wd0)

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Generalized PSV Characteristics

- Hysteretic in nature: combination of systems P and N
  \( I_W > I_{P2} : \text{System P} \); \( I_W < I_{N2} : \text{System N} \)
- Each system can be divided into two graphs
- Four distinct states can be utilized: two bit memory
**Generalized PSV Charac. (contd.)**

- As two-state memory: $I_W > I_{P2}$, $I_W < I_{N2}$: write; $I_{N2} < I_W < I_{P2}$: read
- $I_{N2}$ and $I_{P2}$ (write thresholds) are weak functions of sense current

- System $N$ can be divided into two graphs: $Na$ and $Nb$
Generalized PSV Charac. (contd.)

- System P can be divided into two graphs: Pa and Pb

- Non-symmetric Major and Minor loops
  - Major loop: Na and Pa
  - Minor loop: Nb and Pb
Attributes of the Model

- **Versatility**
  - Usable with any kind of PSV GMR elements
  - Generalized and simple: can be modified easily to represent other kinds of hysteretic characteristics

- **Flexibility**
  - All variables parameterized: `.PARAM` statements
  - No component needing power supply: non-volatile

- **Portability**
  - Subcircuit `.inc` can be included in any HSPICE netlist: great help for GMR memory testing
  - No semiconductor device: no variation with different device models
Simulation Results

- Sub-circuit simulated with HSPICE: did converge!
- Simulations give proper results
- \( \Delta R \) for the GMR bit: 5% with \( R_L = 100\Omega \), \( R_H = 105\Omega \)
- DC analysis done for a wide range of word currents
- Transient analysis shows proper major and minor loop characteristics
- Simulation of non-volatile latch structures with this GMR model
- Simulation of novel Pseudo-Spin-Valve GMR memory structures with this model (the structure can detect all four states but destructive read)
Current and Future Work

- Already done:
  - Thermal behavior (transient and dc) incorporated
  - Asteroid curve incorporated: write thresholds depend on sense current value

- In the pipeline:
  - Noise analysis (transient ?), esp. near the write thresholds
  - A universal GMR model usable for both memory and magnetic sensors (including read heads)
Summary and Conclusion

- First HSPICE circuit model for Pseudo-Spin-Valve GMR element

- Successfully modeled the resistance vs. word current characteristic of a Pseudo-Spin-Valve GMR bit
- The model is simple, flexible and versatile
- Simulations show proper results
- The model is very general in nature, can be applied to other hysteretic characteristics
- Extended to include thermal effects and sense-current-dependency of write thresholds
Questions ?