Giant Magneto-Impedance Effect in Multilayer Thin Film Sensors

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MicroE Microelectronic Engineering

I. Project Objectives

Goal: To fabricate highly sensitive multilayer thin film magnetic field sensors that operate on the Giant Magneto-Impedance (GMI) Effect

- Verify magnetic field sensing capabilities
- Achieve highest GMI ratio and sensitivity through DOE
- Demonstrate fabrication capabilities in RIT's SMFL

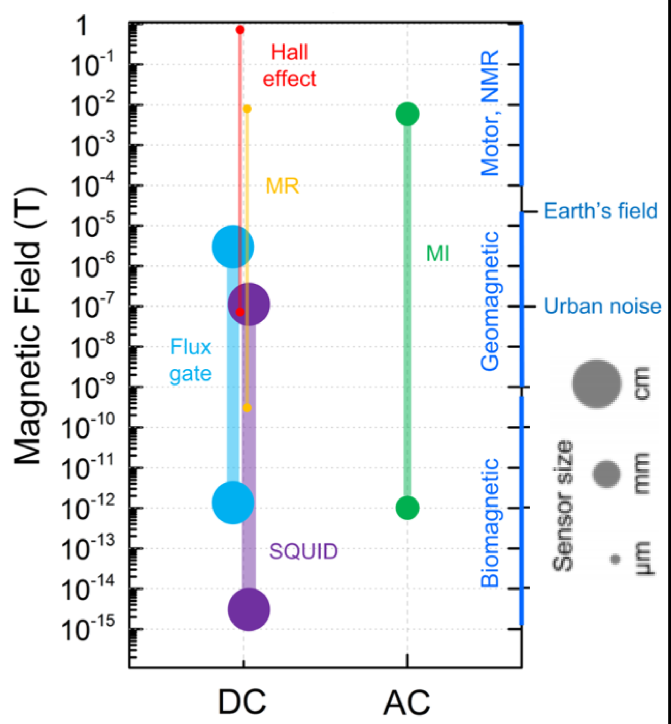
II. Motivation

1) Fabricate 1st generation of GMI effect sensors in RIT's SMFL

- Introduce new research opportunities for MEMS and materials science

2) GMI sensors are currently in the R&D phase for industry

- High sensitivity, large operating range, and low cost solution to GMR and other magnetic sensors
- Wide-variety of applications, especially in the medical field



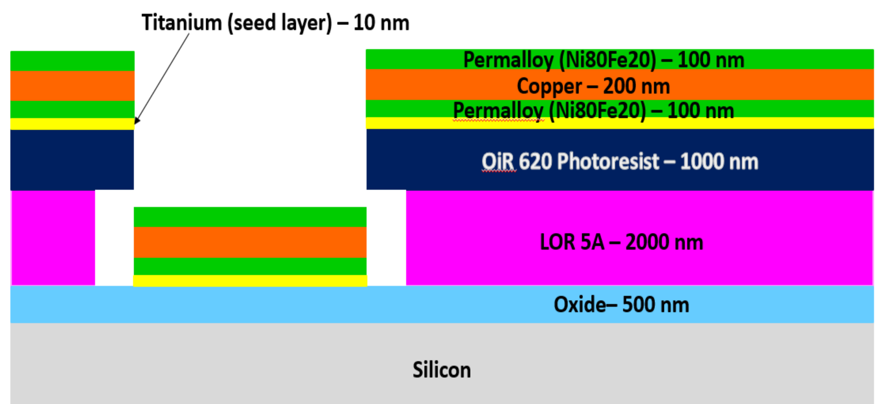
Sensor Type and Operating Range [1]

III. Overview & Theory

Overview:

- Fabricated multilayer thin film stack GMI sensors
  - Conductive layer, Cu, sandwiched between two soft ferromagnetic films, Permalloy (Py: Ni 80%, Fe 20%)
  - Sensors measure change in magnetic field and outputs impedance

Sensor Design:



- Why Permalloy and Copper?
  - Py: low coercivity and ability to achieve high remnant magnetization
  - Cu: low resistivity
- Geometric Design Goals:
  - To Induce **transverse anisotropy** (perpendicular magnetic domain alignment to the longitudinal direction)

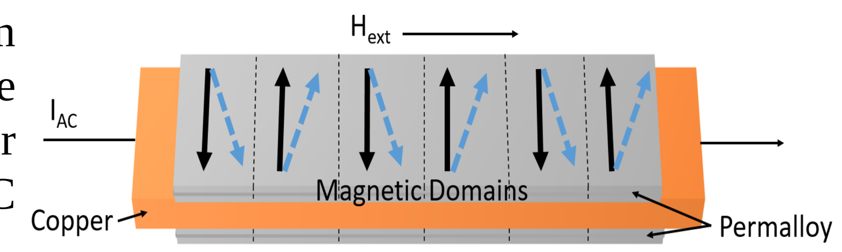
Film Thickness (Py / Cu/ Py) [nm]	Width [um]	Length [mm]
50 / 200 / 50	50	1
100 / 200 / 100	100	2
200 / 200 / 200	200	4

  - As domains are aligned more perpendicularly, performance increases
  - **Shape Anisotropy:** Tendency of domains to randomly align in lowest energy state
    - Can be overcome through design and processing
  - **Experimentation**: Varying width, length, and Py thickness (table above)
  - Target dimensions for max transverse domain alignment
    - Best performance seen at higher frequencies (300 – 500 MHz)
  - Must consider trade-offs between operating frequency and performance for sensor design
- Multilayer stack can be integrated into standard CMOS processes
  - Multiple magnetic films increase overall inductive reactance

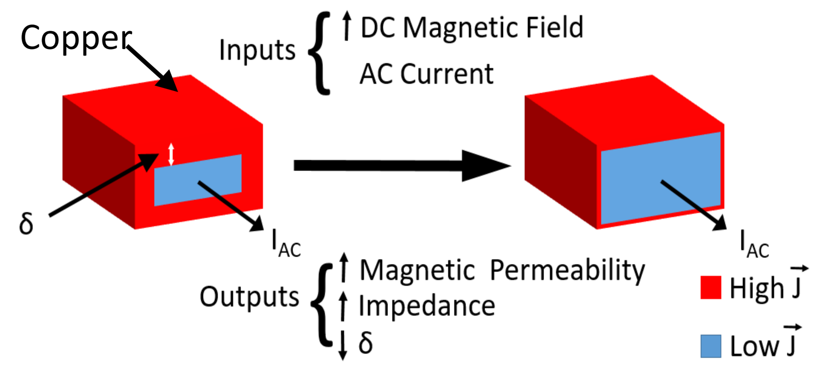
Theory (continued)

How does it work?

- **GMI Effect**: Change in complex impedance, Z, of the magnetic material while under bias by an external DC magnetic field, H_{ext}
- H_{ext} causes magnetic domain wall rotation in the Permalloy films of the sensor
- Shifting of the domains changes permeability, μ
- Increase in μ results in decrease in skin depth, δ, resulting in increasing Z



Skin Effect



Sensor characterization:

- Performance criteria:

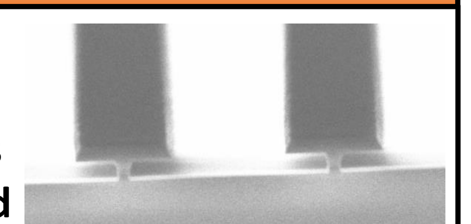
$$\text{GMI Ratio} = \frac{\Delta Z}{|Z_0|} = \frac{(Z_{H_{ext}=H} - Z_{H_{ext}=0})}{Z_{H_{ext}=0}}$$

$$\%\ \text{Sensitivity} = \frac{d\left(\frac{\Delta Z}{Z_0}\right)}{dH_{ext}} * 100$$

$$\begin{cases} Z = R_{DC} * \frac{kt}{2}\coth\left(\frac{kt}{2}\right) \\ k = \frac{i+1}{\delta}\ ,\ \delta = \sqrt{\frac{2\rho}{\omega\mu}} \end{cases}$$

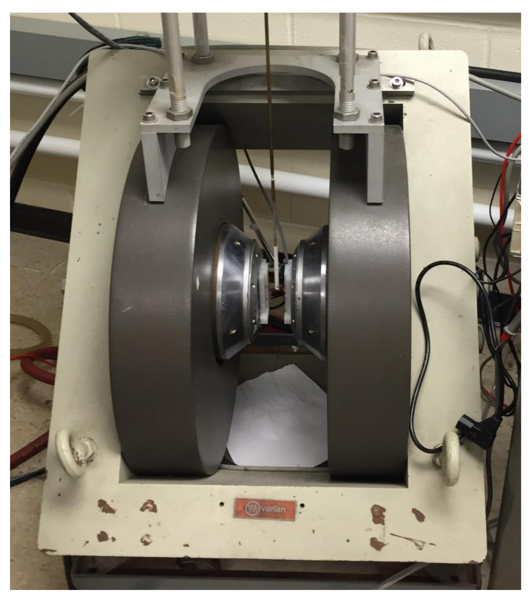
IV. Process

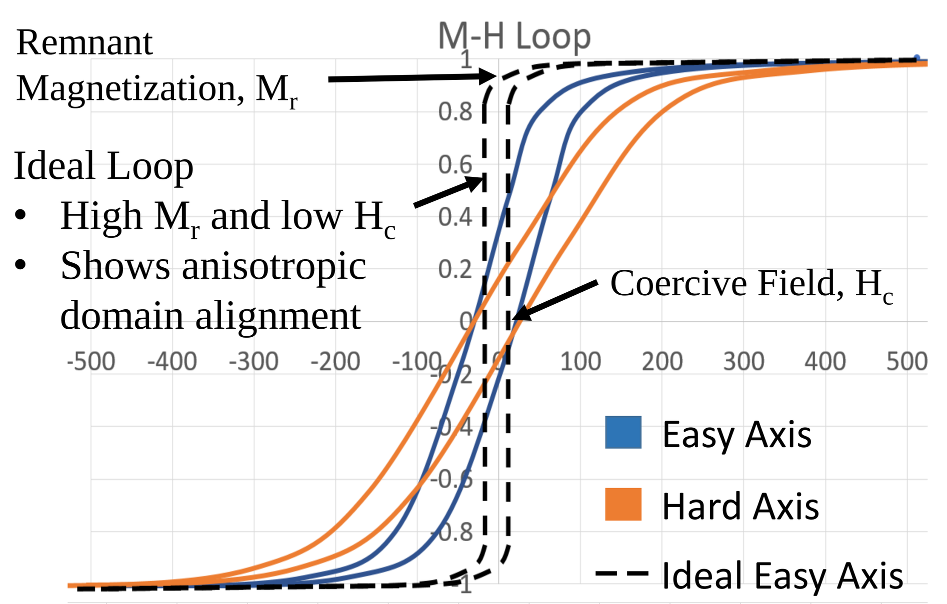
- E-beam evaporation in presence of magnetic field
  - ~45 mT magnetic field
- Permalloy exhibited lots of stress and adhesion issues
- Variables: hardbake, descum, LOR thickness, **Ti seed layer**, magnet spacing, and piece processing



SEM: Lift-Off Profile

V. Experimental Results



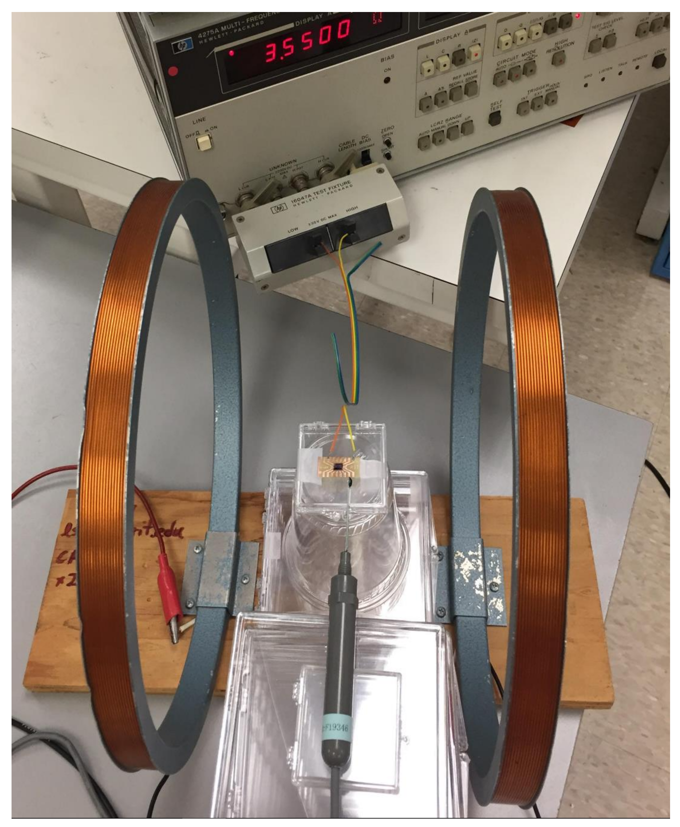


Domain Alignment Testing

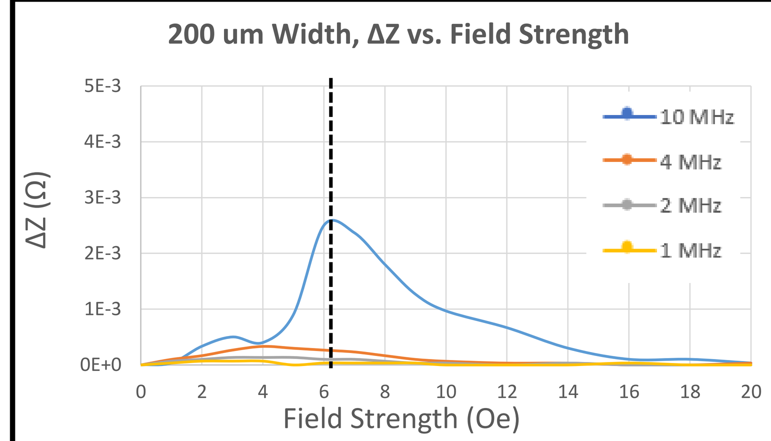
- Tested using a Vibrating Sample Magnetometer (Upper Left)
- Vibration generates an electromotive force (EMF)
- EMF picked up by sense coils
- Signal conditioned by amplifier to readout magnetic moment vs. field, hysteresis loop (Upper right)

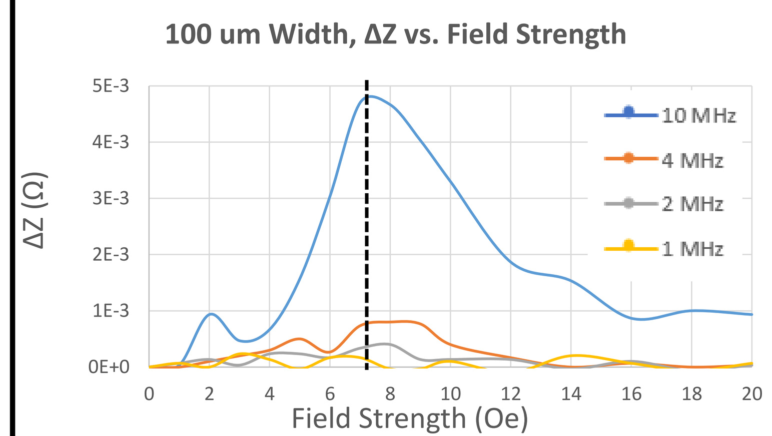
Impedance Test Setup

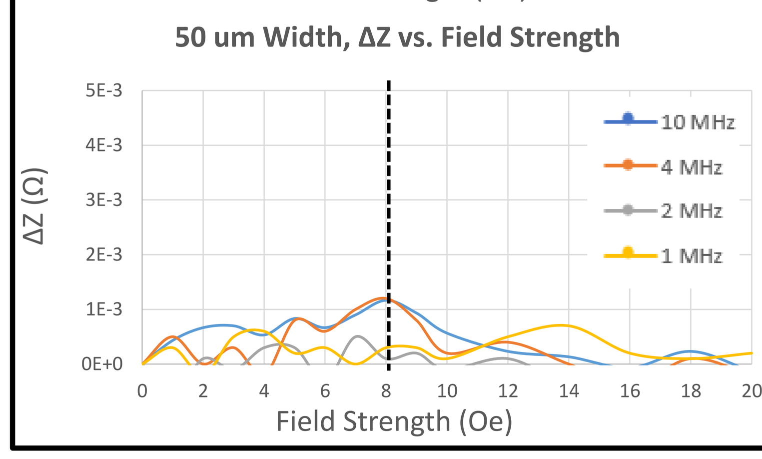
- Applied uniform magnetic field using Helmholtz coil set (Right)
- Wirebond GMI sensor onto PCB
- Sweeped field, 0 – 20 Oe, measured Z at multiple frequencies



Results (continued)







- Measured only 2 mm sensors with varying widths due to process issues
- Sensors made for higher frequencies of 300 -500 MHz
  - Lacked proper instrumentation
  - Only captured small signal
- 100 um feature width @ 10 MHz exhibits best ΔZ response
- Max ΔZ between 6 – 8 Oe
  - Ferromagnetic resonance occurs in this range for 10 MHz
  - Here δ is significantly smaller than conductor thickness
- 200 um feature showed smaller ΔZ
  - Due to some shape anisotropy
- 50 um feature yielded poor ΔZ
  - Shape anisotropy more difficult to overcome in smaller features

10 MHz Sensor Performance		
Width	GMI Ratio	Sensitivity
200 um	0.015 %	0.009 %/Oe
100 um	0.028 %	0.010 %/Oe
50 um	0.007 %	0.002 %/Oe

VI. Applications

- **Electronic Compasses** – Low power and size solution to currently used flux-gate sensors for geomagnetic field sensing
- **High-Density Magnetic Memory** – Reading module in magnetic storage drives. Reads localized remnant magnetization bits. Currently lower sensitivity GMR sensors used for magnetic memory.
- **Magnetic Immunoassay** – Detection of pathogens and other biomolecules with magnetic bead labels

VII. Conclusions

- Processing Permalloy was proven very difficult and resulted in loss of test structures for experimental design
- Successfully fabricated GMI sensors of 2 mm length and varying width
- Best performance in 100 µm wide sensor. Performance lower than expected due to insufficient domain alignment and inclusion of Titanium layer.

Future Work

- Determine functional process without Titanium seed layer
- Perform DOE on sensor geometries to find optimum performance criteria
- Study the effect on performance and frequency from inserting an inter-dielectric layer between conductive and magnetic films

References

[1] L. Kraus, "Theory of giant magneto-impedance in the planar conductor with uniaxial magnetic anisotropy." J. of magnetism and magnetic materials, 195(3): 764-778, 1999.

[2] L.V. Panina, K. Mohri, "Magneto-impedance in multilayer films," Sensors and Actuators A: Physical, 01-Apr-2000. [Online].

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