Microssistemas e Nanotecnologias

Development of a Wafer Level Process Control Tool for Performance Prediction of Magnetoresistive Sensors

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Motivation

Importance of xMR

- High sensitivity, low power consumption, scalability, and compatibility with standard microfabrication processes

Some applications of xMR

- Acquire incremental or absolute position information, offering robustness and accuracy in industrial, automotive and aerospace systems
- Capable of characterizing fault locations and operational states of power transmission lines

Problems of TMR

- “The yield rate for TMR sensor wafers is currently around 82%, compared to over 95% for Hall sensors, resulting in higher per-unit production costs”
- “As of 2024, over 65% of small and medium-sized enterprises in sensor manufacturing cited cost and scalability issues as primary reasons for not entering the TMR segment.”

What I want to do

- Aim to develop and explore two tools that address the main manufacturing and scalability challenges of TMR microfabrication, namely yield and uniformity

Introduction

Tunnel Magnetoresistance (TMR) relies on spin-dependent quantum tunnelling through an ultra-thin insulating barrier, typically MgO, placed between two ferromagnetic layers.

Ru, 10.00 nm
Ta, 5.00 nm
Ru, 5.00 nm
Ta, 5.00 nm
CoFeB, 1.70 nm
MgO, 1.60 nm
CoFeB, 2.00 nm
Ru, 0.70 nm
CoFe, 2.20 nm
MnIr, 8.00 nm
Ru, 5.00 nm
Ta, 5.00 nm
Ru, 15.00 nm
Ta, 5.00 nm
Ru, 15.00 nm
Ta, 5.00 nm
Ru, 15.00 nm
Ta, 5.00 nm
Ru, 15.00 nm
Ta, 5.00 nm
Ru, 15.00 nm
Ta, 5.00 nm

Cap	Serves to protect the underlying magnetic layers from oxidation and contamination.
Free Layer	Magnetization responds to external magnetic fields.
Non-Magnetic Spacer	Acts as the tunnel barrier enabling spin-dependent electron tunnelling.
SAF	Consisted of two ferromagnetic layers, the pinned and reference layers, to achieve zero magnetic moment.
AFM	Placed adjacent to one of the ferromagnetic layers, fixes its magnetization direction up to higher fields.
Buffer	Responsible for providing the appropriate crystalline texture, low resistivity and controlled surface roughness.

Introduction

Sensitivity (S)

Output change per unit magnetic field

Saturation Field (H_{sat})

Magnetic field required to fully align the free layer

Coercive Field (H_c)

Magnetic field required to switch the magnetization of the free layer

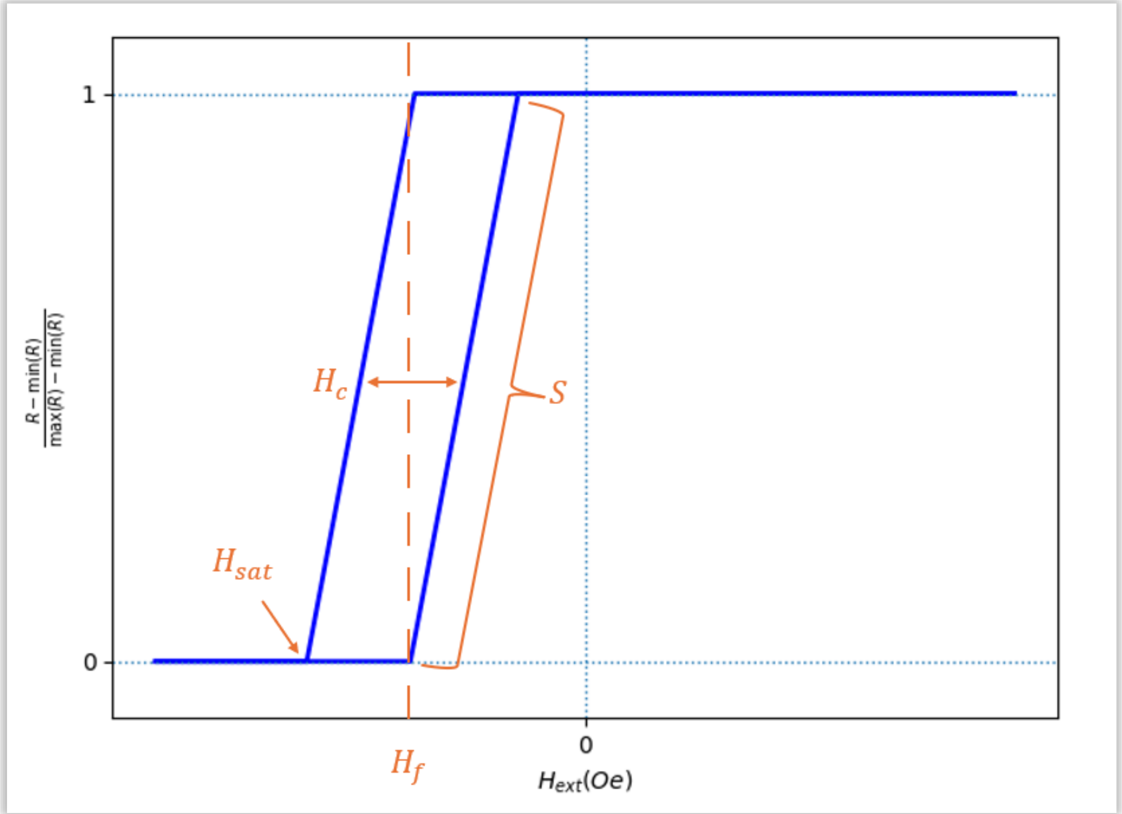
Offset Field (H_f)

Magnetic field required to bring the sensor resistance to the midpoint

TMR

Relative resistance change between parallel and antiparallel state

The transfer curve of a MR sensor represents the relationship between the sensor resistance and the applied external magnetic field, $R(H)$.

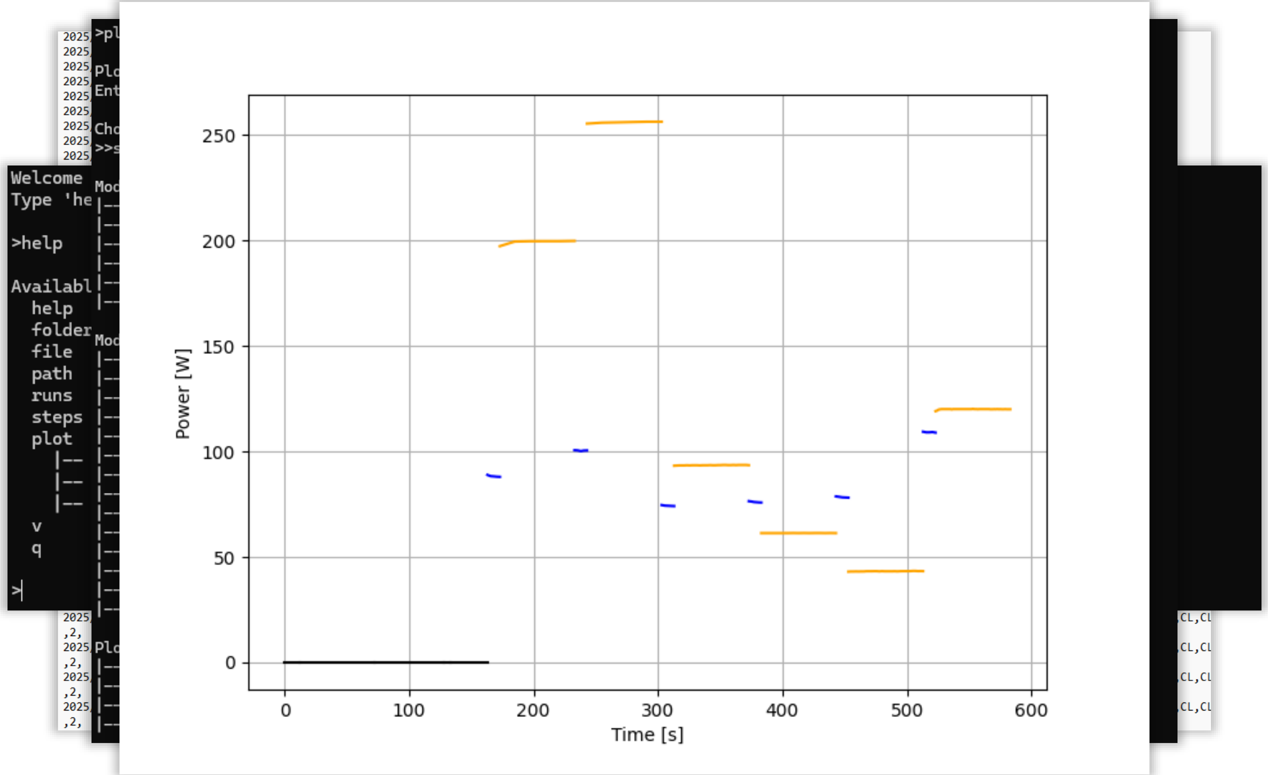


Tools Developed

In-line Deposition Parameters Monitoring Tool (Heimdall)

Heimdall analyses and visualizes the operational logs generated by Nordiko3600 and Nordiko8800 machines at INESC-MN.

Heimdall supports the assessment process reproducibility within and across fabrication batches, contributing to improved process optimization and reliability of the deposition systems.



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Tools Developed

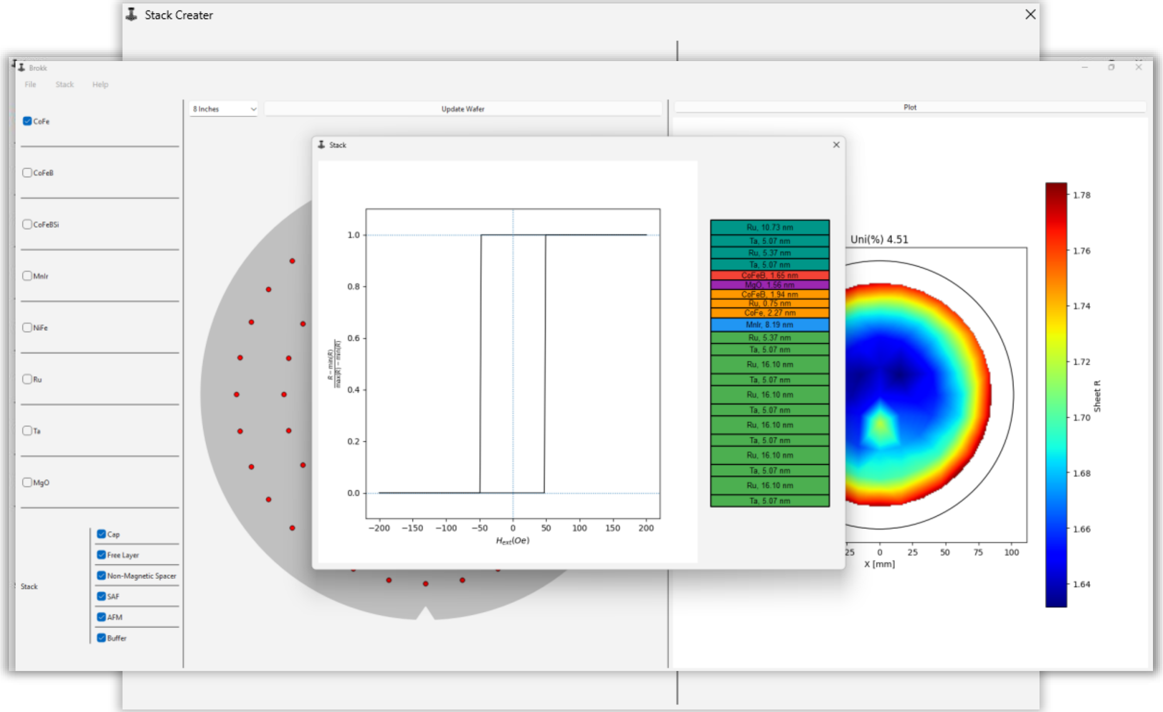
Wafer Level Process Control Tool (Brokk)

Brokk is designed to analyse and visualize the impact of deposition non uniformities in thin films, with particular relevance to TMR stacks.

The data files used by Brokk are obtained from two main characterization techniques, resistivity mapping and profilometry.

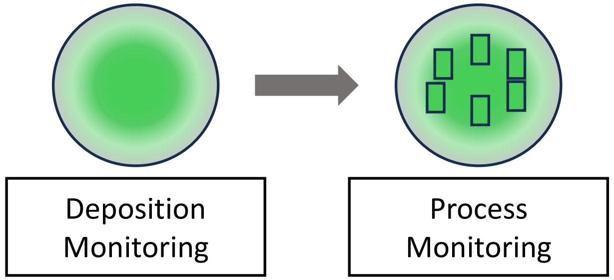
$$\rho = R_s \cdot t$$

Brokk uses Stoner-Wolfarth Model to compute the transfer curve of a magnetoresistive sensor, $R(H, \theta_H)$



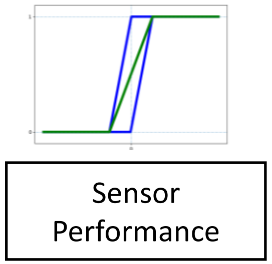
Future Work

Heimdall


Deposition Monitoring
Process Monitoring

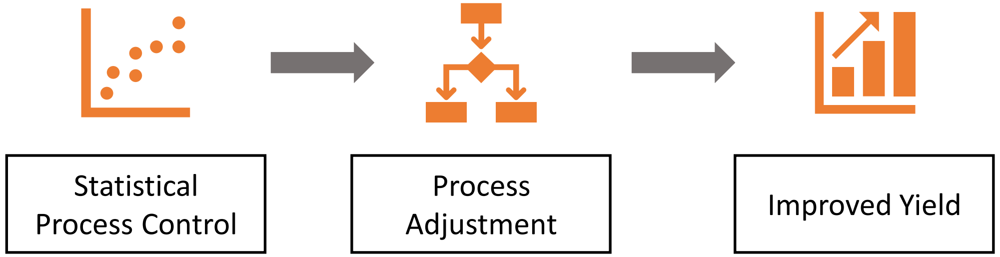
- **Heimdall** currently ingests data from **Nordiko3600** and **Nordiko8800** tools.
- Enable **compatibility** with **additional** process **equipment**.

Brokk


Sensor Performance

- **Brokk** focuses on non-uniformities arising from **thin-film** stack **deposition**.
- **Extend analysis** to downstream fabrication stages (e.g., pillar definition).

M.Sc.


Statistical Process Control
Process Adjustment
Improved Yield

- Transition **Brokk** from a **descriptive to a diagnostic platform.**
- **Correlate spatial data** across deposition, lithography, and etching steps.
- **Perform sensitivity analyses** to identify yield-critical process phases.
- For example, determine whether $R \cdot A$ variability is driven primarily by MgO barrier thickness or by patterning-induced geometric deviations.

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THANK YOU FOR YOUR ATTENTION

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