Extending Spintronic Research: Undergraduate Analysis of Mn_4N Thin Films via SP-STM

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Summary:

After growing a thin Mn_4N film, using spin-polarized scanning tunneling microscopy (SP-STM) possible spin valve properties were observed. The original work was conducted by Dr. Andrew Foley, an Ohio University alumni. He grew this film and first observed these properties. As my undergraduate project I took Andrew's draft of a publication and reanalyzed it. Dr. Smith and I found evidence supporting the spin valve hypothesis, including features consistent with a magnetic hysteresis response under varying external fields.

In Layman's Terms…

- What is SP-STM?

Spin-polarized STM is a technique that measures how electron spin affects tunneling current. It maps magnetic properties at the atomic scale, not just surface height.

- What is a Spin Valve?

A spin valve is a magnetic switch that changes resistance depending on the direction of magnetic layers. It's used to read data in hard drives and other spintronic devices.

- What is a Hysteresis curve?

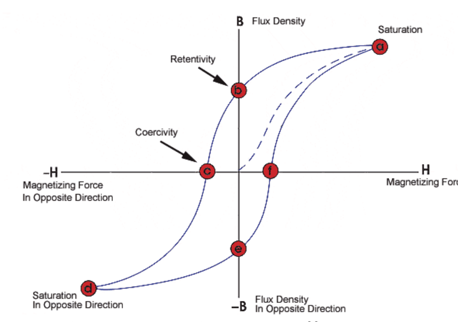

Figure 1: Hysteresis curve Illustration. Acquired from NDE-Ed.org

Experimental Setup:

- Growth Technique: ε-Mn_4N thin films were grown epitaxially on MgO(001) substrates using RF plasma-assisted molecular beam epitaxy (MBE).
- Measurement Conditions: Spin-polarized STM (SP-STM) measurements were performed at 13 K in UHV (~10^{-11} Torr) using Cr-coated W tips.
- Magnetic Field Control: An out-of-plane magnetic field was varied between ±1 T to examine contrast changes in spin-resolved conductance (dI/dV).
- SP-STM Imaging: Both topography and spin-resolved dI/dV maps were acquired simultaneously to correlate structural and magnetic properties at the nanoscale.
- Spectroscopy Details: Lock-in technique used for dI/dV measurements with bias modulation of 10 mV RMS at 8.4 kHz.

Revival Method:

- Raw Data Recovery: Located original raw STM and spectroscopy datasets on the lab archive drive; securely duplicated across multiple storage locations for preservation and ease of access.
- Software Modernization: Re-analyzed historical STM/SP-STM data using WSxM for color scales and ImageJ for thresholding, masking, and mesa/valley identification.
- Reconstruction of Project Context: Mapped raw data to previous figure references, interpreted legacy notes, and matched files with Dr. Foley's original layouts.
- Format & Accessibility Upgrade: Converted legacy Word- and Origin-based drafts into LaTeX format, improving long-term editability and reproducibility.
- Modern Interpretations: Reinterpreted older datasets using current physical models and updated material parameters for ε-Mn_4N and spin polarization effects.

LT-STM

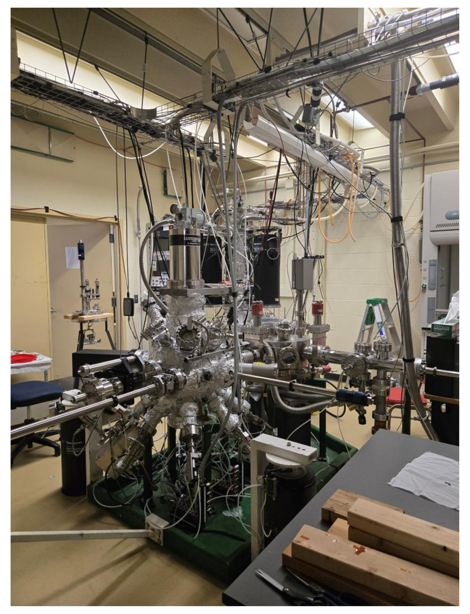

Figure 2: Full Low Temp STM Photo

STM Chamber

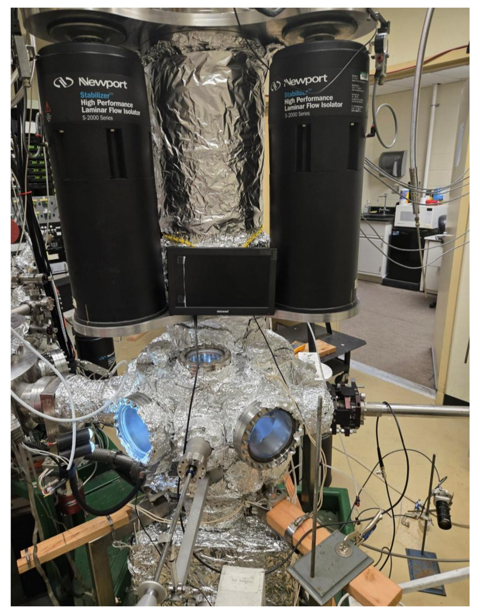

Figure 3: STM Chamber Photo

Results:

This research is still ongoing. So far, we have found evidence to support Dr. Foley's original claims and have developed new interpretations through deeper data analysis. We recreated all figures from scratch, reprocessed raw STM and dI/dV images using modern tools, and clarified how the data correlates with both magnetic field direction and electronic structure.

Key milestones include:

- Rewriting and formatting the original draft into LaTeX for publication
- Reorganizing and labeling previously unlabeled data sets
- Creating automated workflows for thresholding and ROI extraction using ImageJ and Python
- Revealing contrast switching behavior in dI/dV under forward vs. reverse field sweeps

Our work puts a modern lens on previously unexplored aspects of the Mn_4N thin film system and sets the stage for future spintronic research based on domain-specific electronic contrast.

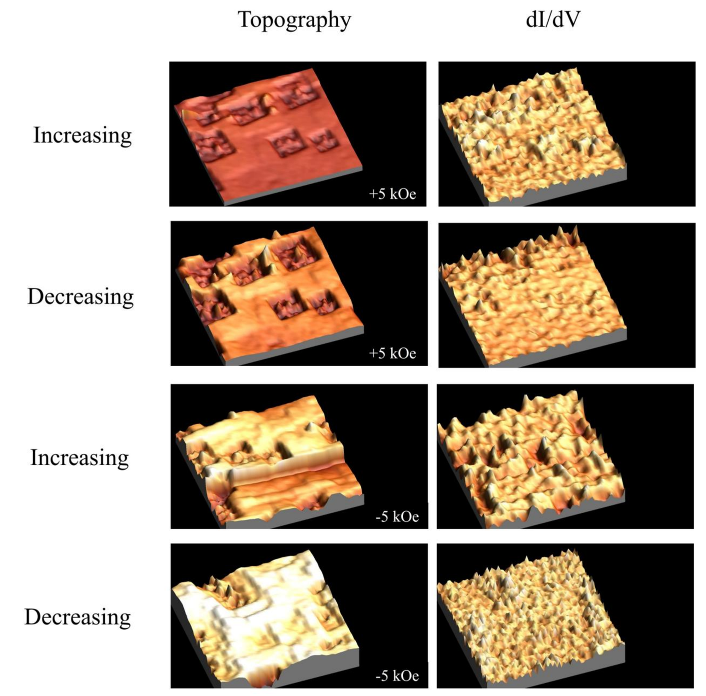

Figure 4: 3D Topographic vs. dI/dV Maps Under Varying Magnetic Field Condition

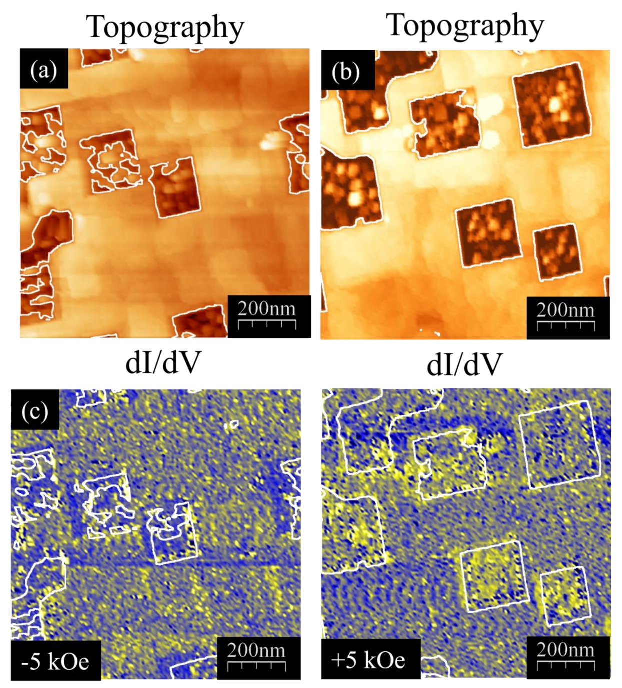

Figure 5: 2D "Top-down" Topographic vs. dI/dV Maps, highlighting regions

Future Implications:

- Advances understanding of spin valve behavior at the nanoscale, enabling more precise control over spin-polarized current in thin films
- Supports development of spintronic devices that are faster, more energy-efficient, and more scalable than traditional electronics
- Lays groundwork for non-volatile magnetic memory technologies (like MRAM) with higher density and lower power consumption
- Provides tools for engineering magnetically active materials used in logic gates, memory cells, and neuromorphic computing
- Helps miniaturize magnetic components by mapping domain behavior and contrast switching at the atomic scale
- Contributes to the push for smaller, faster, and cooler-operating electronics through improved magnetic material design
- Enables future integration of Mn_4N-based spin valves in compact quantum and data storage technologies

Acknowledgements:

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