Optimizing Sputtering Parameters to Minimize Roughness in Permalloy Thin Films

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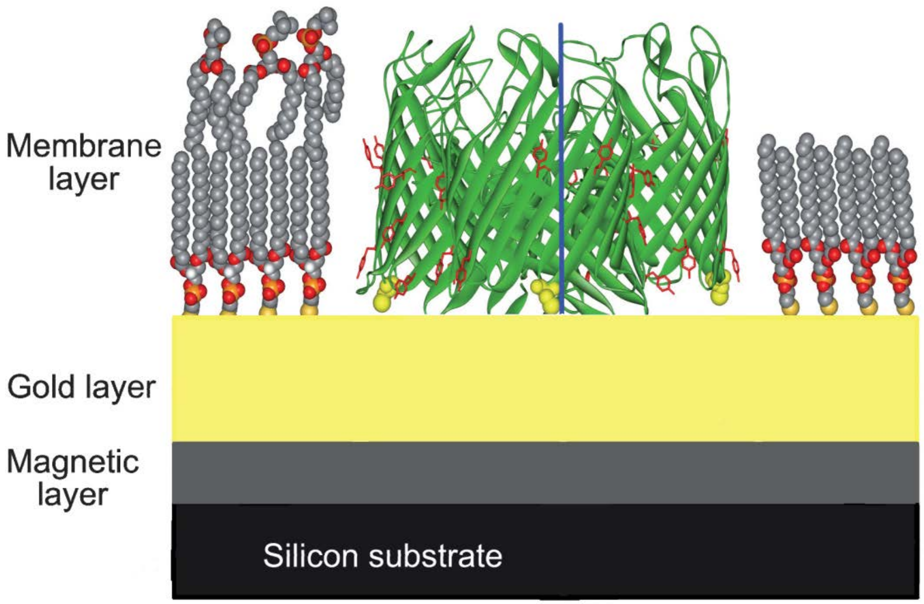
Presentation Outline

1. Motivation for project
   1. Lipid Membranes
   2. Permalloy
   3. Thin Film Roughness
2. Overview of Sputtering
3. Literature
4. Results
5. Summary and Future Research

Motivation – Lipid Membranes

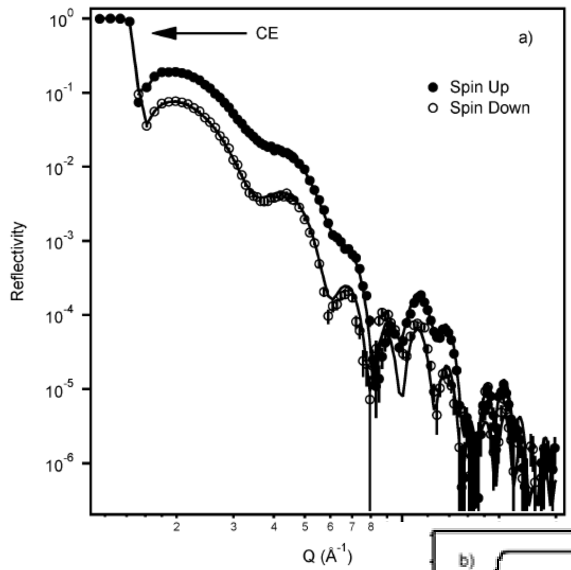
- NCNR uses neutron reflectivity to study membranes and proteins.
  - HIV
  - Alzheimer's
- Biofilms are assembled on gold thin films.
- Magnetic layers are used under the gold to increase accuracy.



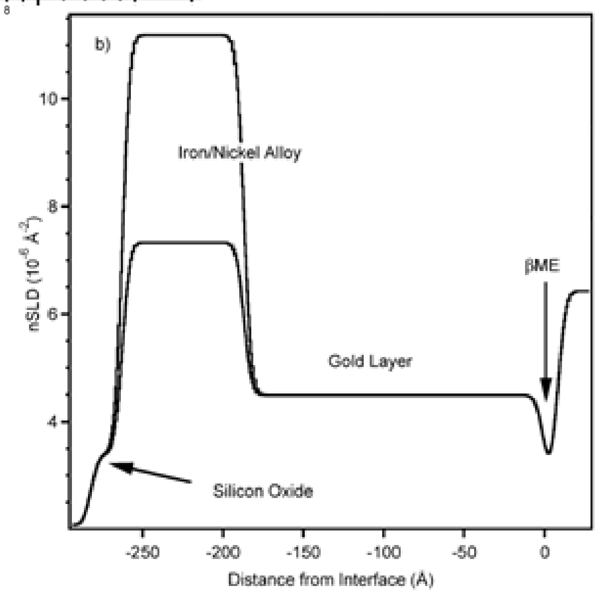
Thin film sample used to study lipid membranes and proteins in using neutron reflectivity.
Stephen A. Holt et al

Motivation - Permalloy

- Permalloy: 81% Nickel 19% Iron, Magnetic alloy
- Neutrons have two spin states (up & down) that interact differently with magnetized layers resulting in different scattering length densities (SLD).
- The permalloy layer will provide two distinct reflectivity curves when scanned with spin up vs. spin down neutrons.
- The two resulting data sets can be fitted simultaneously, reducing fit uncertainties.

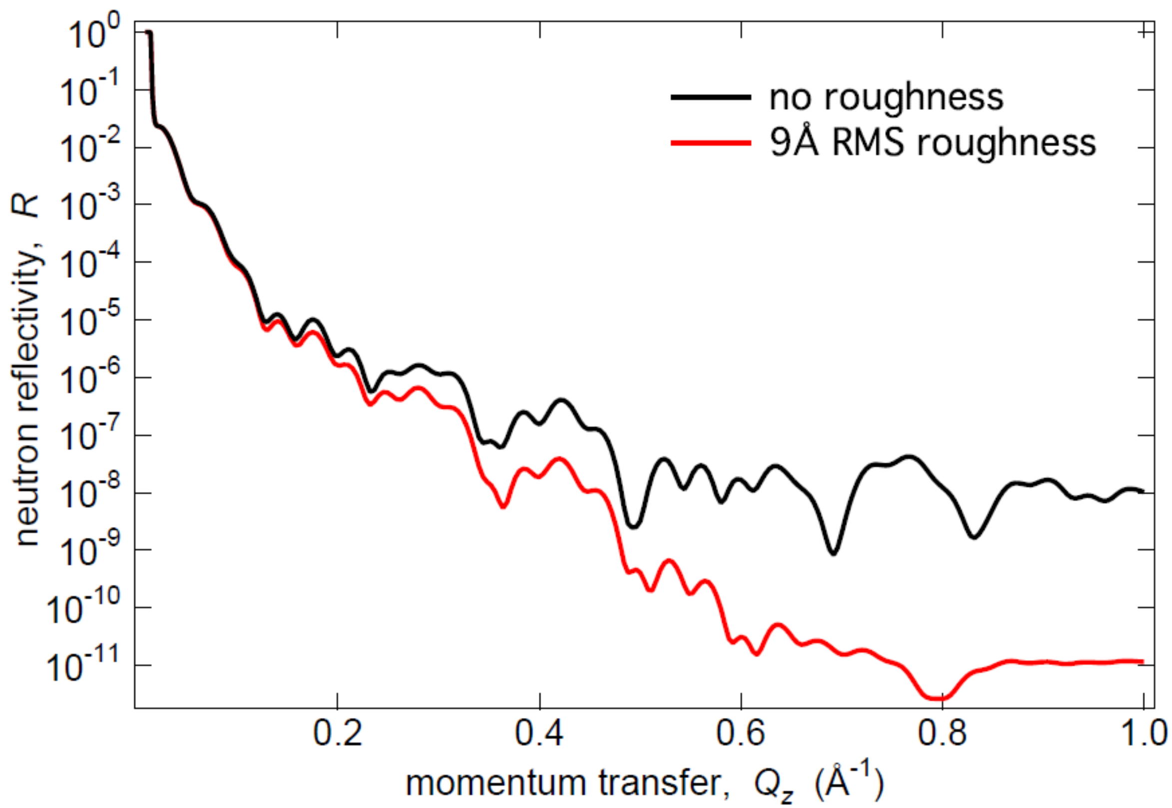


Sample neutron reflectivity data (left). SLD profile based on fitted data (below).
Stephen A. Holt et al



Motivation - Roughness

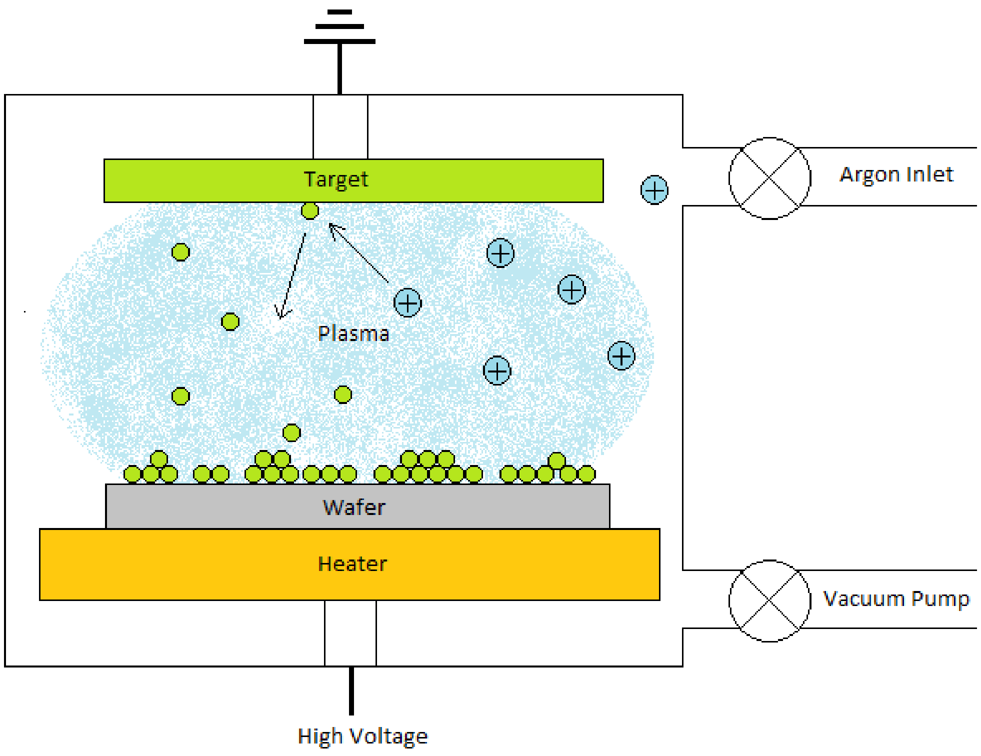
- Surface roughness in a lower layer will influence the surface roughness of all layers deposited onto it.
- If permalloy surface roughness is too large it will obscure the layer being studied.



Charles F. Majkrzak et al

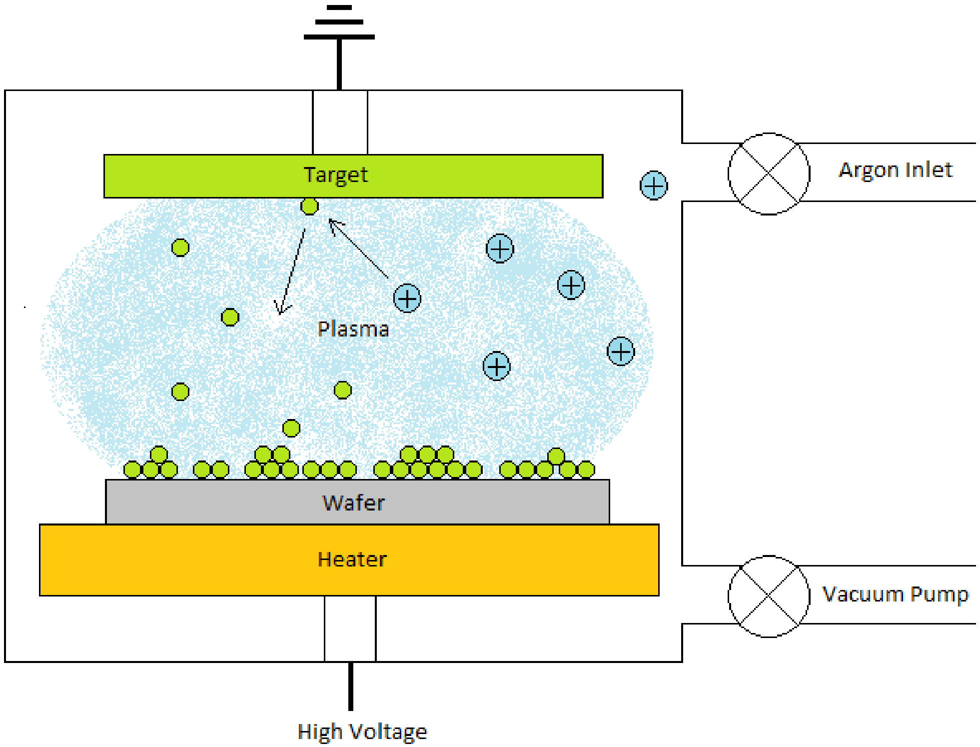
Sputtering

- Wafer is cleaned and placed in the chamber.
- Chamber is pumped down to ~10^{-6} Torr.
- Argon is pumped in and platform begins to rotate.
- Voltage difference ignites argon gas into plasma .
- Argon cations collide with target causing atoms to be ejected.
- Atoms deposit onto the wafer.



Sputtering Parameters

- Wafer preparation
- Sputter 1 vs. Sputter 2
- Wafer temperature
- Power
- RF vs. DC
- Vacuum pressure
- Argon flow rate

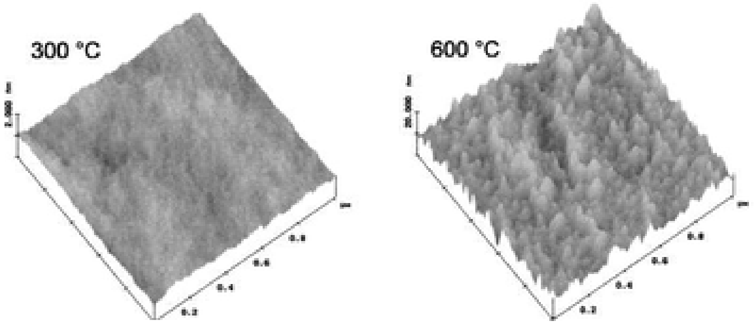


Current formula: NiFe(81/19) target, Sputter 2, room temperature, 90watts, DC sputtering

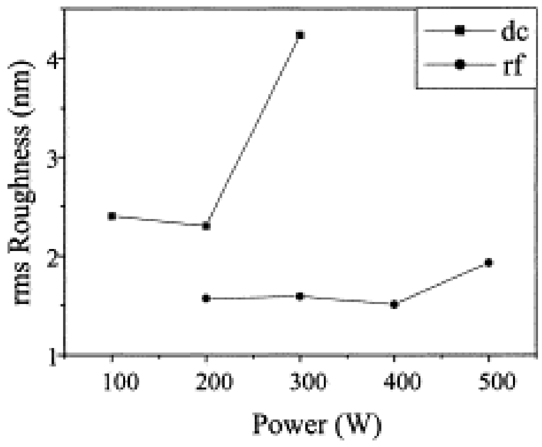
Current RMS Roughness> 20Å

Literature

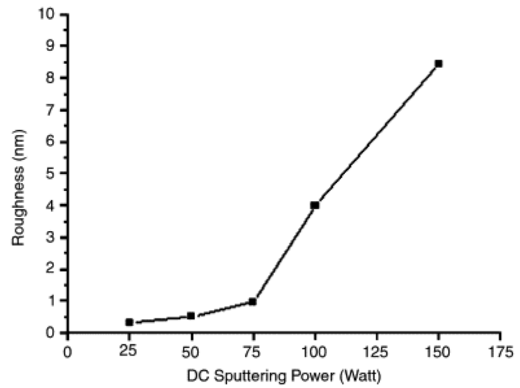
- Michelini, F. et al
  - Substrate: MgO(001) single crystals
  - Target: Ni(79%)Fe(18%)Cu(1%)Mo
  - Roughness increases with temperature.



- Paul, A. et al
  - Substrate: high speed steel
  - Target: Cr3C2
  - RF sputtering produces lower roughness than DC sputtering.



- Chan et al
  - Substrate: p-type Si
  - Target: Cu
  - Roughness increases with sputtering power.



Experimental Plan

1. Preparation Method
   - Micro-90, Acid, Alcohol wash
   - Micro-90, Alcohol wash, Argon Etch
   - Micro-90, Alcohol wash

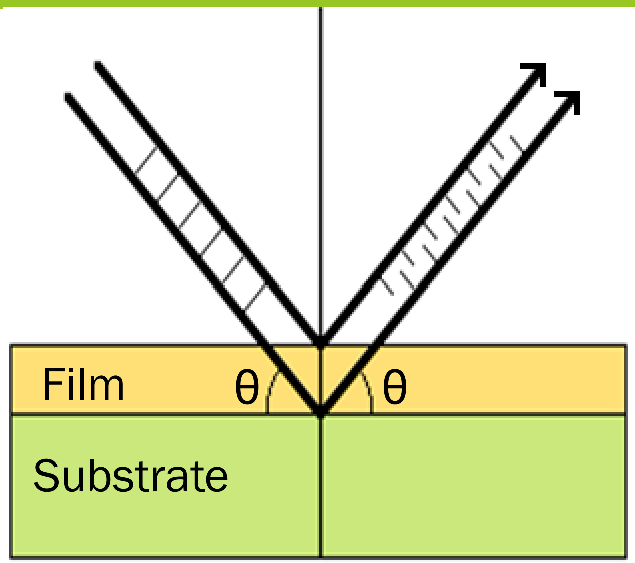
2. DC Power
   - 90w, 60w, 35w, and 10w (sputter 1, DC)

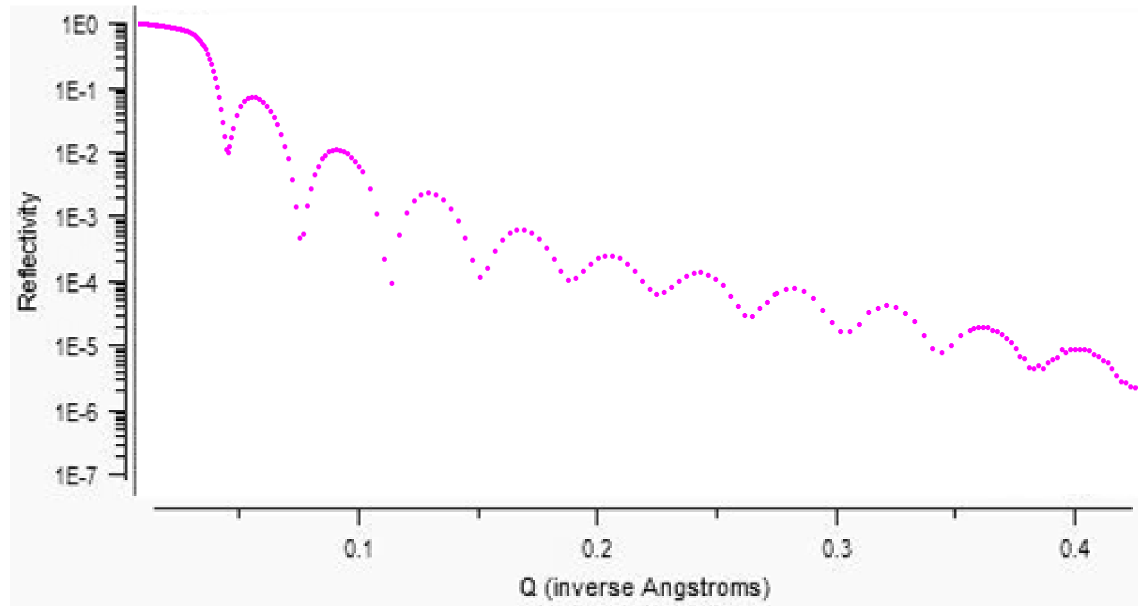
3. Sputter 1 vs. Sputter 2
   - 90w, 60w, 35w, and 10w (sputter 2, DC)

4. Substrate Temperature
   - Room Temperature, 100˚C, 200˚C, and 300˚C

5. RF vs. DC Power
   - 100w, 200w, and 300w (sputter 2, RF)

X-Ray Reflectometry





- Thickness is inversely proportional to width of oscillations.
- Roughness is determined by dampening of oscillations.
- Scattering length densities and absorption can also be determined.

Effect of Preparation

Preparation methods

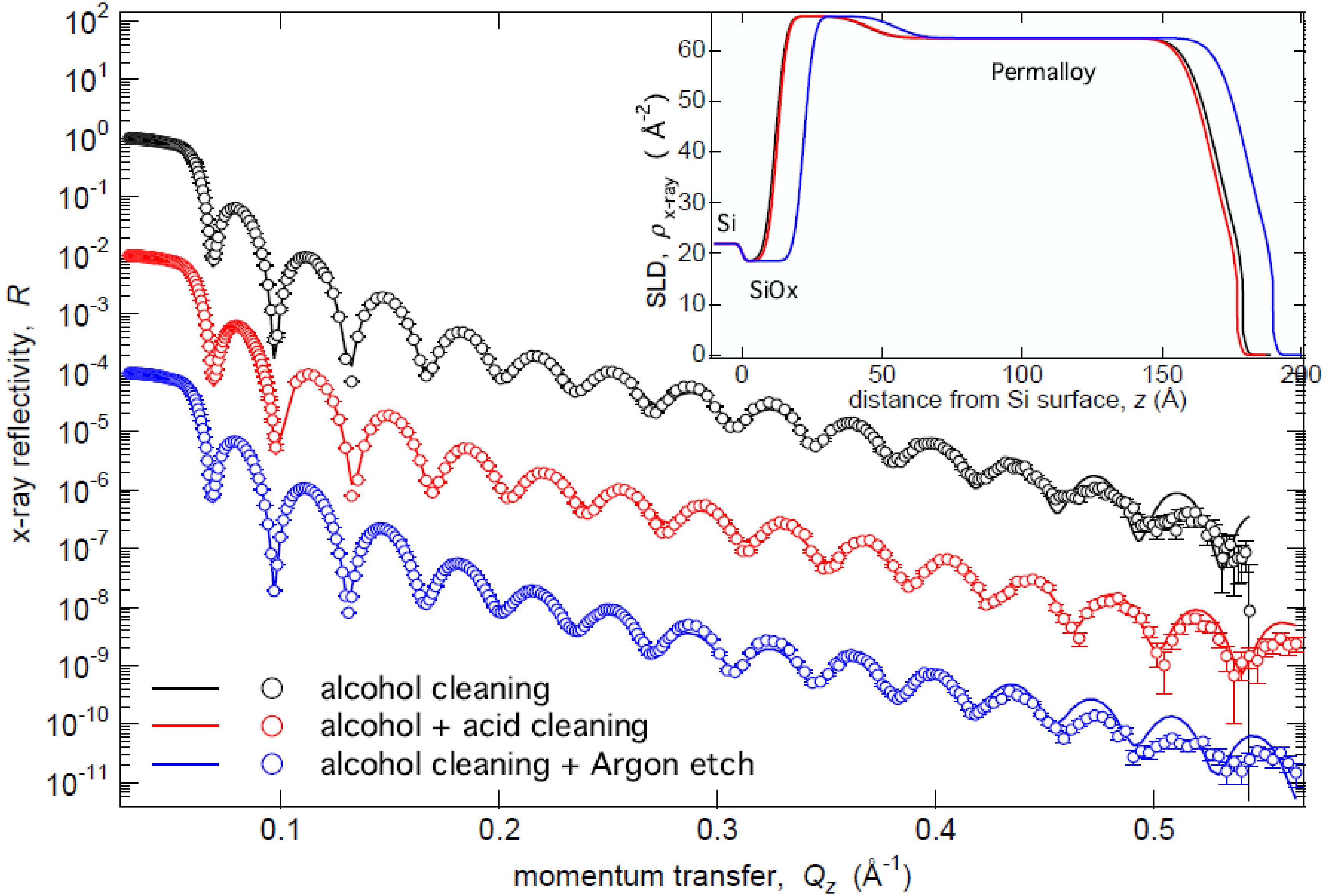
- Sample A: micro-90, ethanol rinse, methanol rinse
- Sample B: acid wash, ethanol rinse, methanol rinse
- Sample C: micro-90, ethanol rinse, methanol rinse, argon etch for 134s at 50 watt

Conclusion

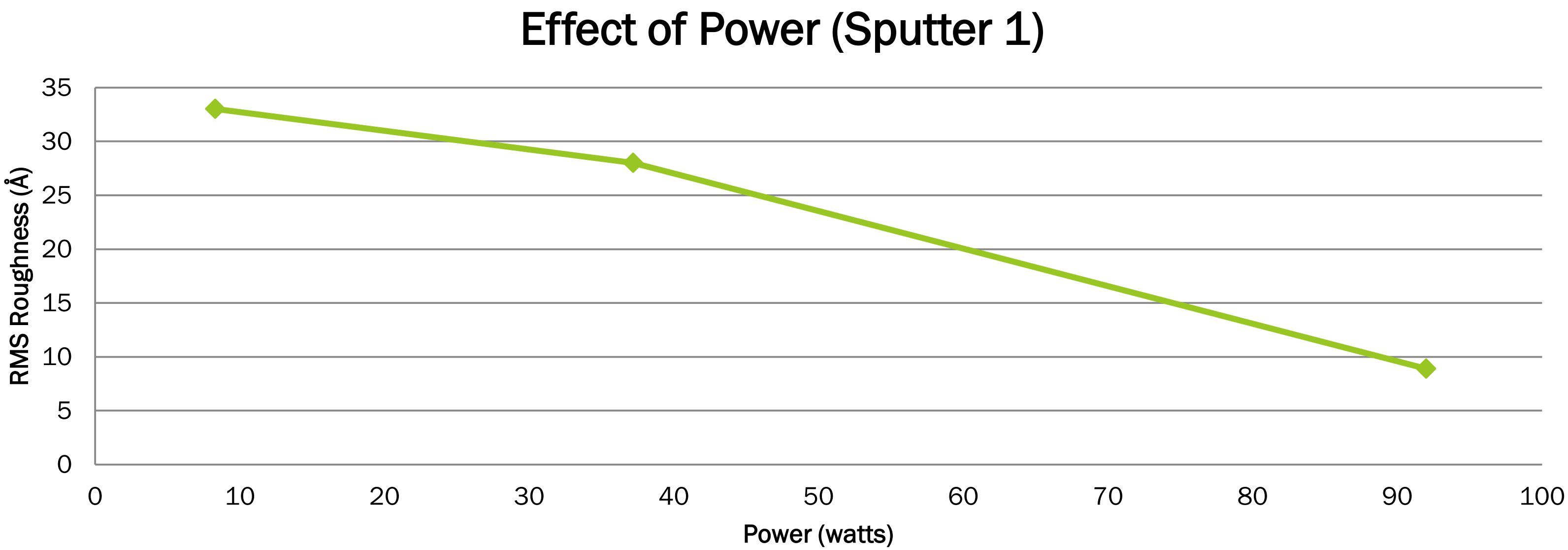
- Cleaning method has no great effect on roughness.
- Surface RMS roughness values:
  - A- 8.885 ±0.024 Å
  - B- 8.572 ±0.027 Å
  - C- 8.83 ±0.018 Å

Effect of Preparation

Reflectivity curves and SLD profile of samples A, B, and C.



Effect of Power

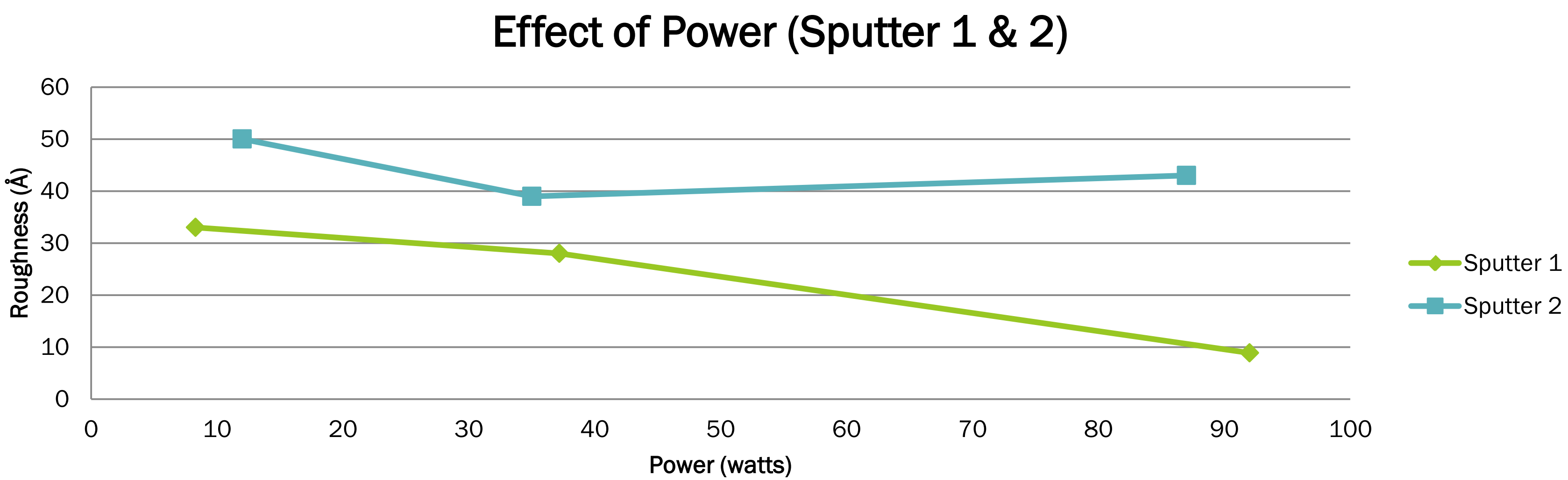


The above graph shows the effect of power on roughness for Permalloy samples deposited using DC sputtering at room temperature on sputter 1. The data is shown in the chart below.

Power (Watts)	RMS Roughnes (Å)
8.3	33
37.2	28
92	8.885

- Roughness clearly decreases as power increases.
- Trend is opposite to literature findings.
- Roughness at 90W (8.885 Å) is better then previous values (>20 Å).

Sputter 1 vs. Sputter 2



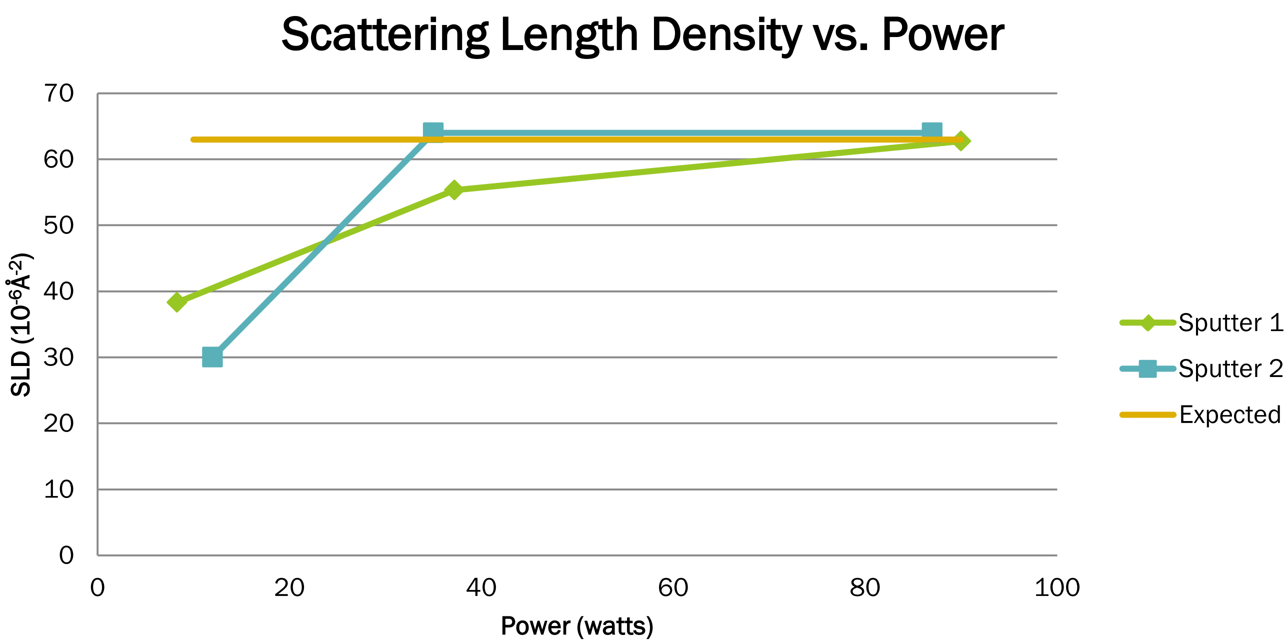
The above graph compares roughness values at various powers for Sputter 1 and Sputter 2. Samples are all Permalloy thin films deposited using DC sputtering at room temperature. The data is shown in the chart below.

Power S1 (watts)	Roughness S1 (Å)	Power S2 (watts)	Roughness S2 (Å)
8.3	33	12	50
37.2	28	35	39
92	8.885	87	43

- Roughness is consistently higher for samples deposited using sputter 2.
- Sputter 2 supported plasma ignition at lower pressures.

Scattering Length Density

- Scattering length density decreases at low powers.



- Sputtering rate depends on power.
- Low sputtering rates may have caused island formation or other defects.

Future Research

Conclusions

- Preparation method does not have a significant effect.
- Higher powers provide lower RMS roughness values.
- Sputter 1 works better than Sputter 2.

Areas that need further study:

- Power values higher than 90 Watts
- Difference between sputter 1 and sputter 2
  - Effect of gas flow
- Effect of substrate temperature
- RF sputtering vs. DC sputtering
  - Sputtering rate for RF is extremely slow
- AFM scans
  - Current probe tip does not work with samples

Special Thanks to:

Frank Heinrich

Jamie White

Julie Borchers

SURF Directors

National Science Foundation

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Questions?

Sputter 1 (NIST NanoFab)

X-Ray Diffractometer (NIST NCNR)

Bibliography

Chan, Kah-Yoong, and Bee-San Teo. "Atomic Force Microscopy (AFM) and X-ray Diffraction (XRD) Investigations of Copper Thin Films Prepared by Dc Magnetron Sputtering Technique." *Microelectronics Journal* 37.10 (2006): 1064-071. *Sciencedirect.com*. 13 June 2006. Web. <http://www.sciencedirect.com/science/article/pii/S0026269206000735>.

Eden, Tim. "Sputter Deposition." The Applied Research Laboratory at Penn State. Web. 19 July 2011. <http://www.arl.psu.edu/capabilities/mm_mp_ct_sd.h tml>.

Holt, Stephen A., Anton P. Le Brun, Charles F. Majkrzak, Duncan J. McGillivray, Frank Heinrich, Mathias Lösche, and Jeremy H. Lakey. "An Ion-channel-containing Model Membrane: Structural Determination by Magnetic Contrast Neutron Reflectometry." Soft Matter 5.13 (2009): 2576-586. Web.

Michelini, F., L. Ressier, J. Degauque, P. Baulès, A. R. Fert, J. P. Peyrade, and J. F. Bobo. "Permalloy Thin Films on MgO(001): Epitaxial Growth and Physical Properties." *Journal of Applied Physics* 92.12 (2002): 7337-340. *Scitation*. American Institute of Physics. Web. 28 July 2011. <http://scitation.aip.org/journals/doc/JAPIAU-ft/vol_92/iss_12/7337_1.html>.

Paul, A., Jongmin Lim, Kyunsuk Choi, and Chongmu Lee. "Effects of Deposition Parameters on the Properties of Chromium Carbide Coatings Deposited onto Steel by Sputtering." *Materials Science and Engineering A* 332.1-2 (2002): 123-28. *ScienceDirect*. 30 May 2002. Web. 28 July 2011. <http://www.sciencedirect.com/science/article/pii/S0921509301017257#sec3>.