Modeling Studies in Magnetostrictive Nanoellipses for New Magnetic Memory Applications

Stephanie Cantu, Jessica Bainbridge-Smith, Scott Keller, Gregory Carman

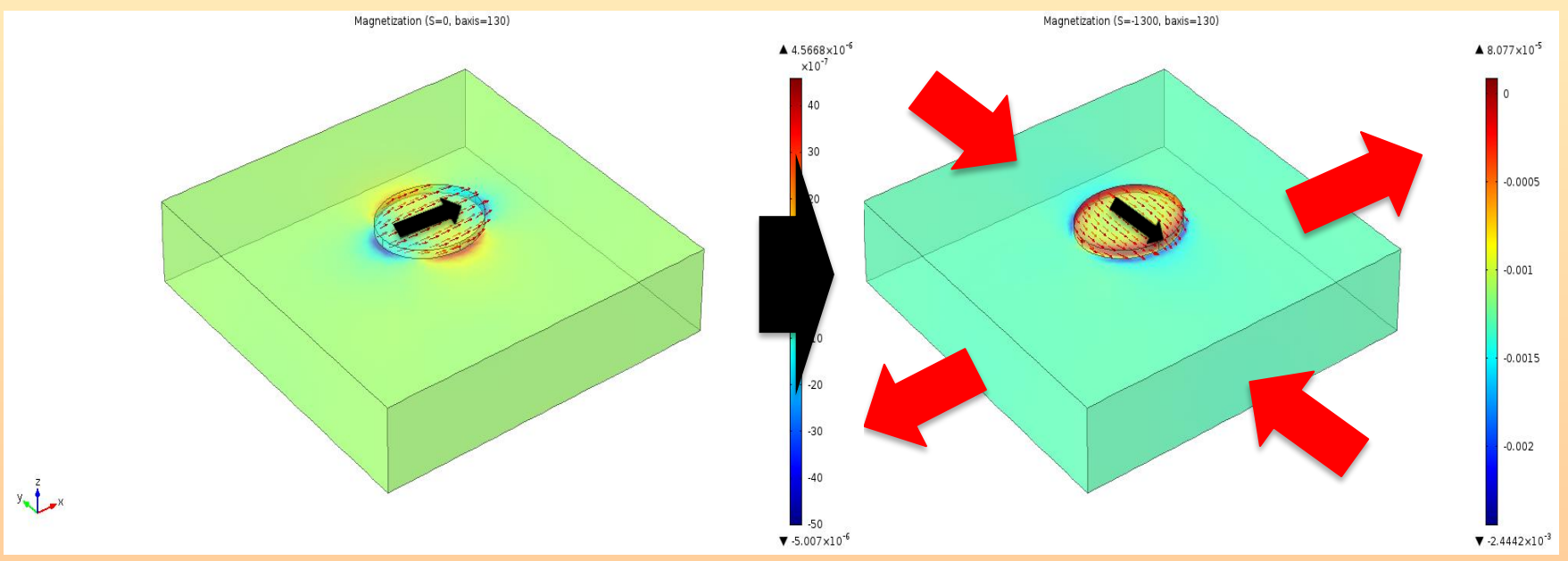
University of California, Los Angeles, Department of Mechanical and Aerospace Engineering

Abstract

Magnetostrictive materials have the unique property of changing their magnetic moment when a mechanical strain is applied to them. Placing a magnetostrictive nickel nanoellipse on a piezoelectric substrate, and applying a strain to the substrate, will in turn cause the magnetic moment of the nanoellipse to rotate. Varying the geometric properties of the nanoellipse will have a significant influence on how much the magnetic moment of the nanoellipse shifts. The diameter, thickness, and eccentricity of the nanoellipse were all varied in this study in order to determine which set of parameters yielded a rotation greater than 85°. Using COMSOL Multiphysics, it was determined that thinner nanoellipses, as well as those with a lower eccentricity, produced the desired rotation when compared to studies of thicker and more eccentric geometries. By achieving a 90° rotation, this optimized nanoellipse can eventually be used as a low energy memory element or a magnetic motor.

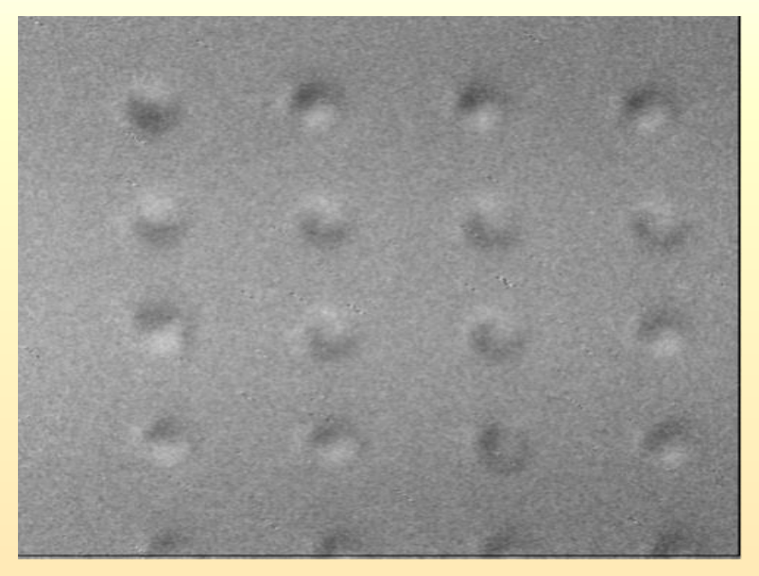
Objective

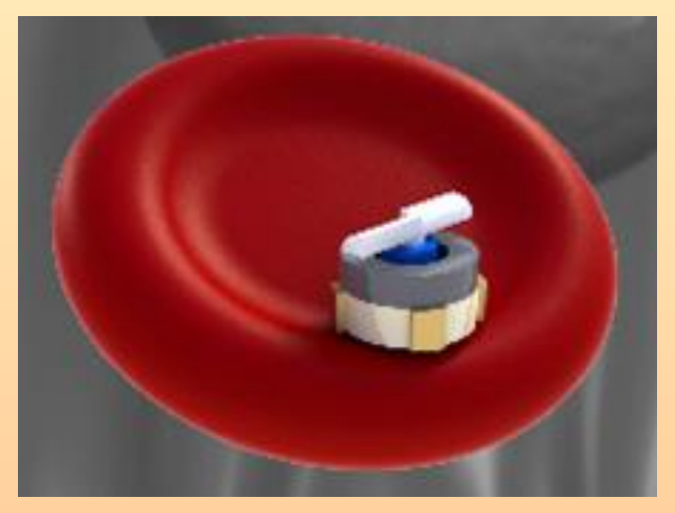
- Vary geometric parameters of the nanoellipse to find which combinations will yield a 90° rotation in single domain magnetic elements
- Examine the relationship between the geometric parameters and the rotation of the magnetic moment



Motivation

- Using a multiferroic memory system allows memory elements to be packed more densely, which necessitates a 90° magnetic rotation





- A geometry that rotates effectively could be applicable to future magnetic rotation studies, including nanomotors

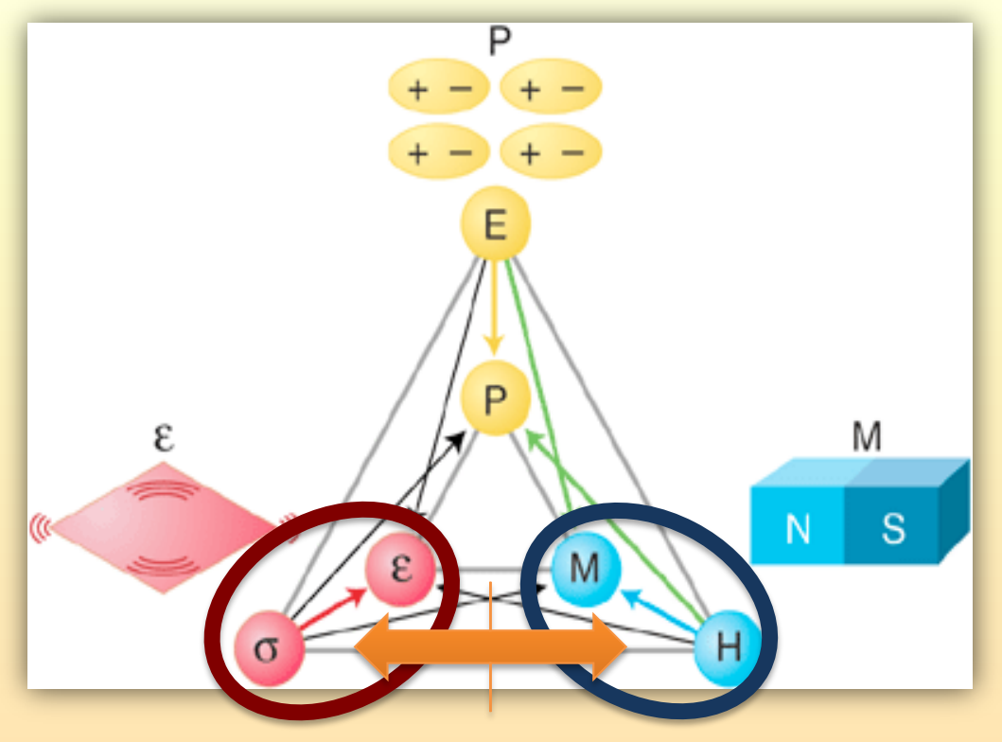
Background

Landau-Lifshitz-Gilbert Equation

$$\frac{\partial \underline{M}}{\partial t} = \gamma_G\left(\underline{M}\times\underline{H}_{eff}\right) - \frac{\alpha_G}{M_s}\left(\underline{M}\times\frac{\partial \underline{M}}{\partial t}\right)$$

Elastodynamic Equation

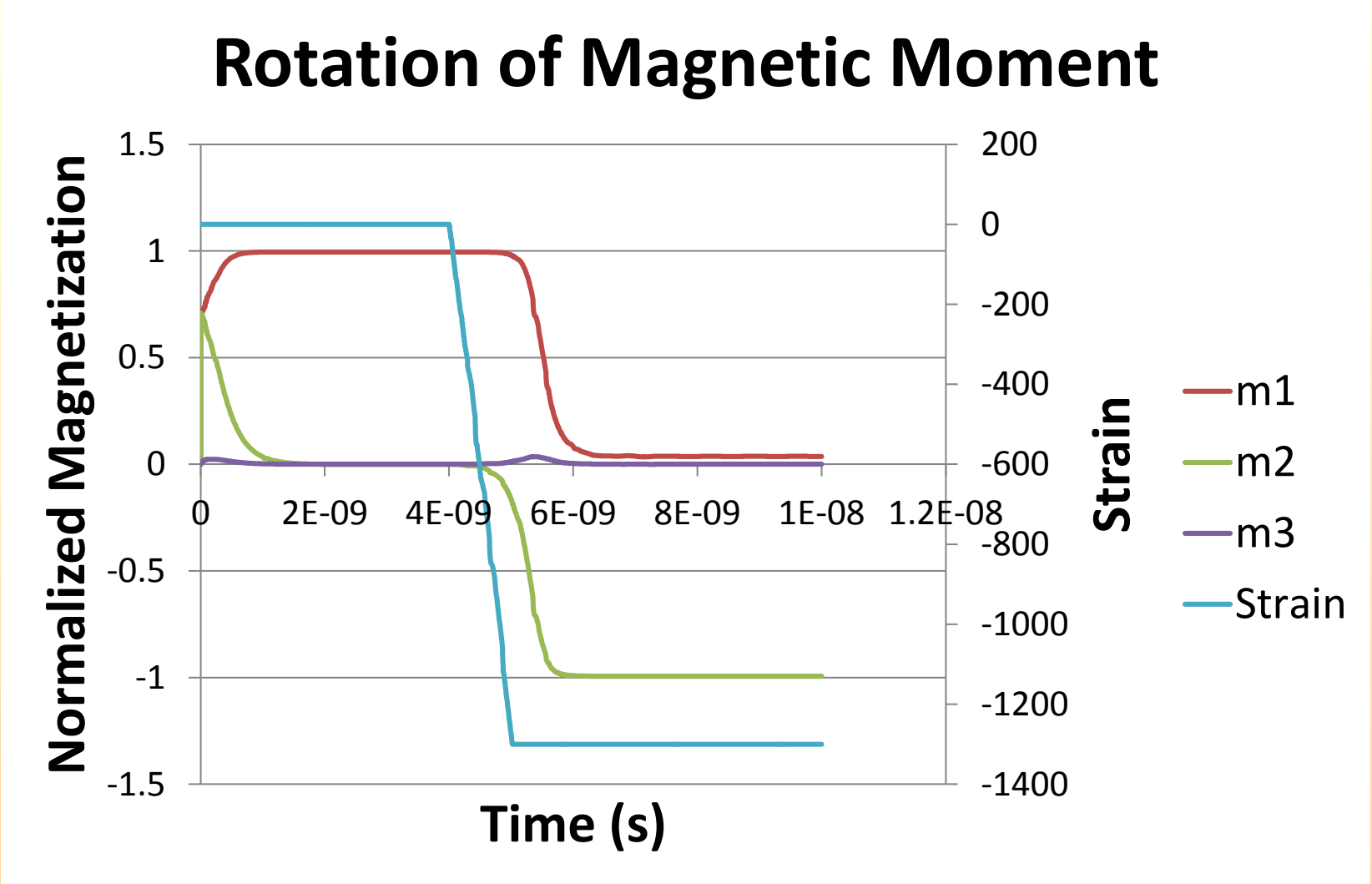
$$\nabla\cdot\underline{\sigma} + \underline{f} = \rho\underline{\ddot{u}}$$



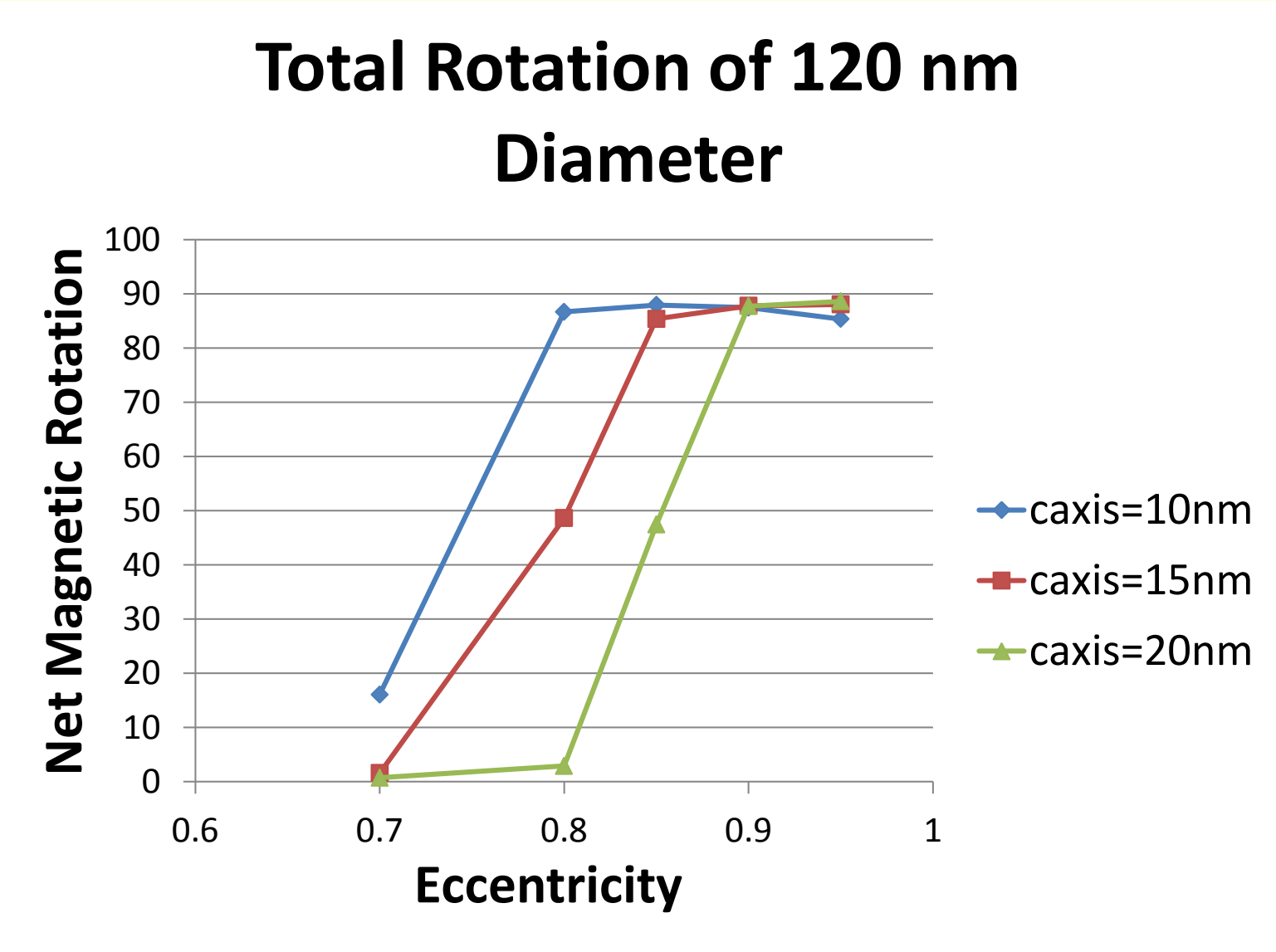
- These equations accurately define the model in both mechanical space and magnetic space
- After being expanded these equations are put into COMSOL and iteratively solved using the finite element method

Data Analysis

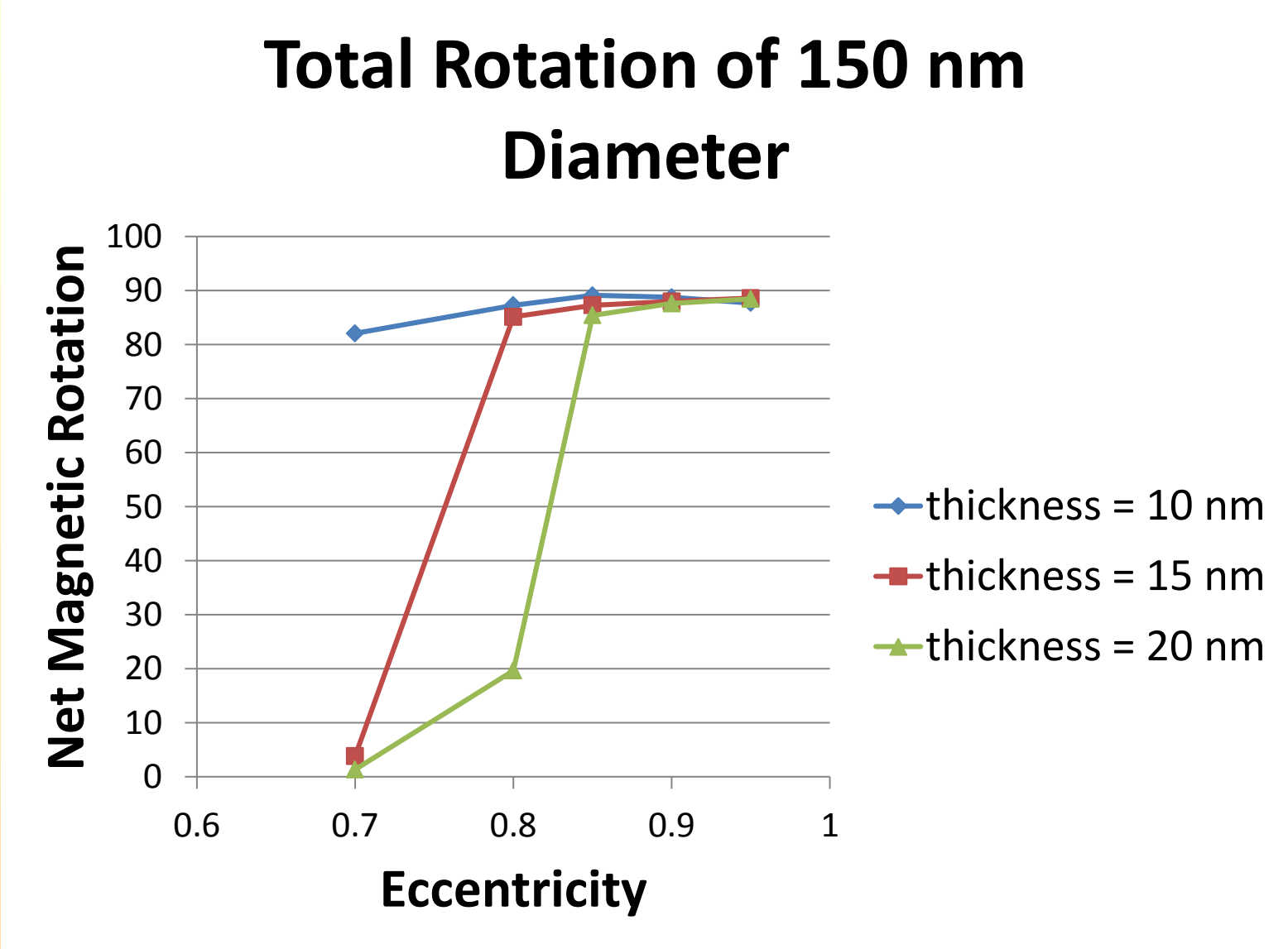
- Plotted components of magnetic moment over time
- Calculated pre-strain angle at 4 nanoseconds
- Ramped strain for a duration of one nanosecond
- Calculated post-strain angle as an average over last 0.5 nanoseconds



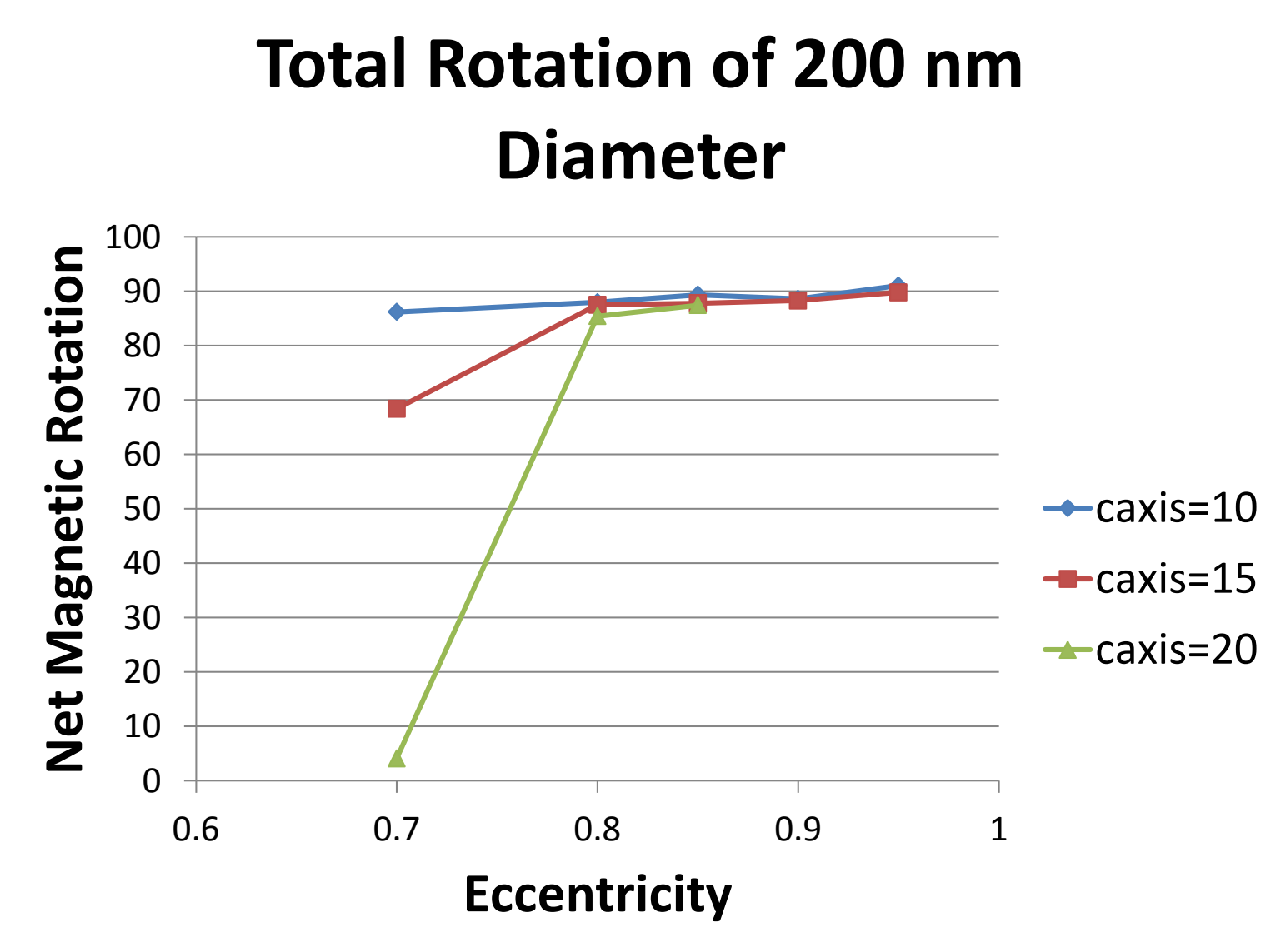
Results



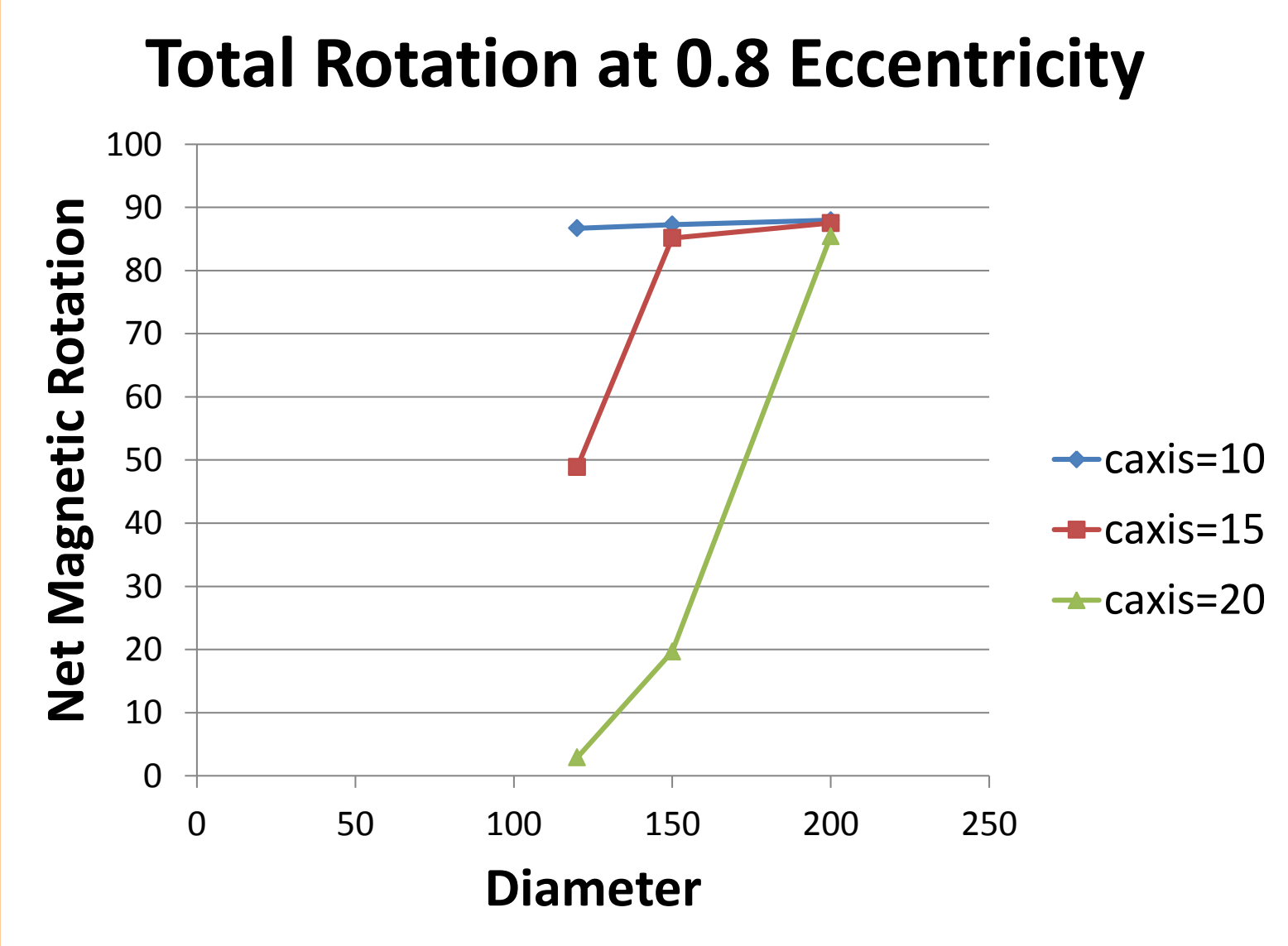
Between an eccentricity of 0.7 and 0.8, the magnitude of rotation depends upon thickness.



As diameter increases and thickness decreases, the magnetic moment flips regardless of eccentricity.



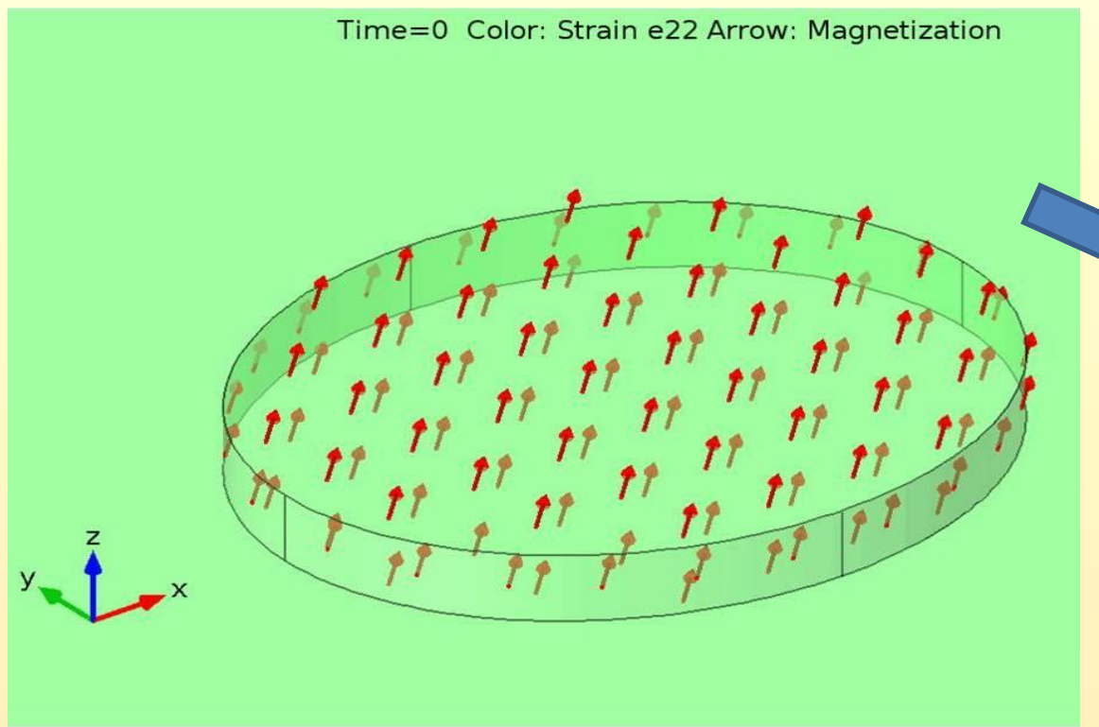
At this specific diameter, all models with a thickness of 0.15 nm rotated a significant amount.



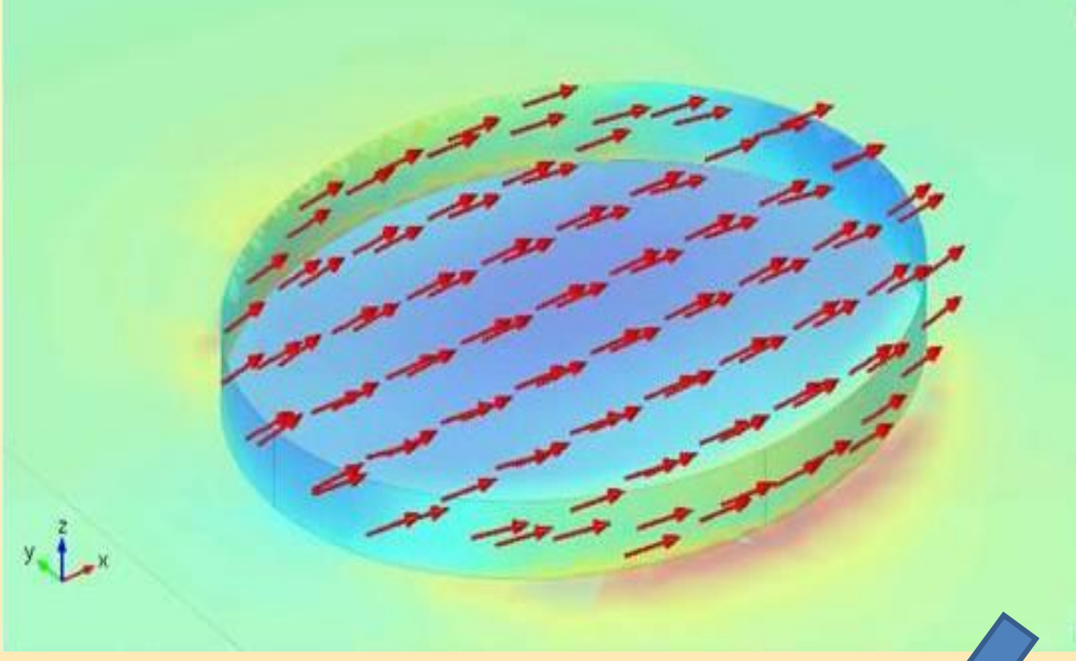
The total amount of rotation is more dependent on thickness, rather than the diameter of the nanoellipse.

Conclusion

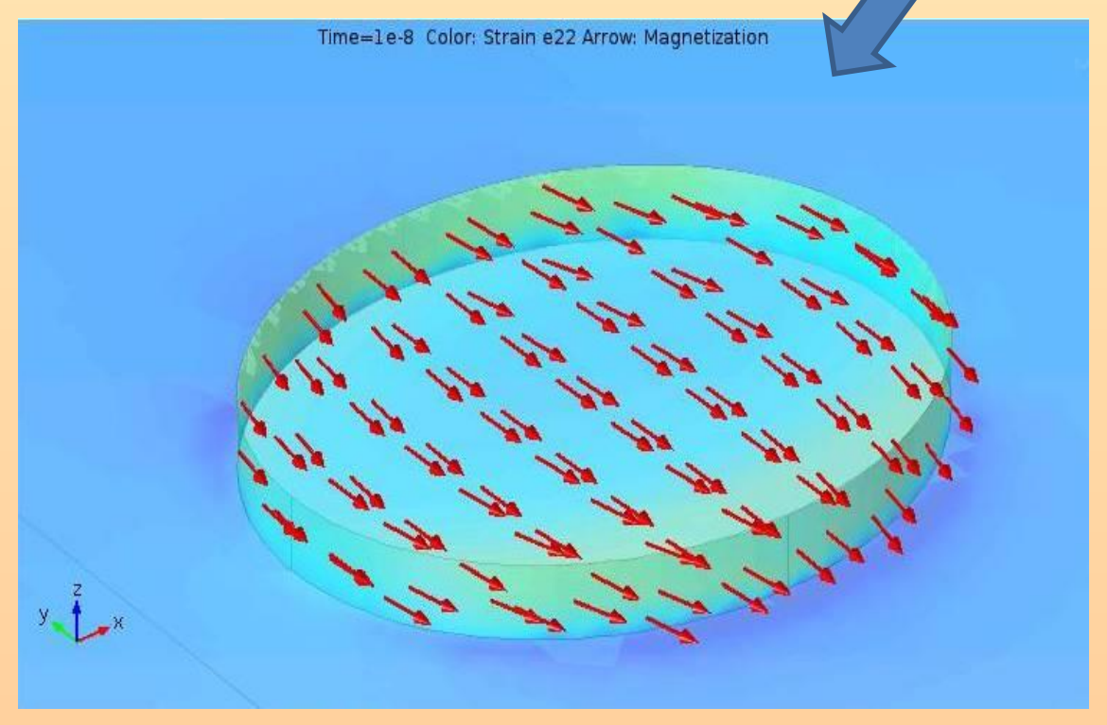
Initial



Equilibrium



Steady-State

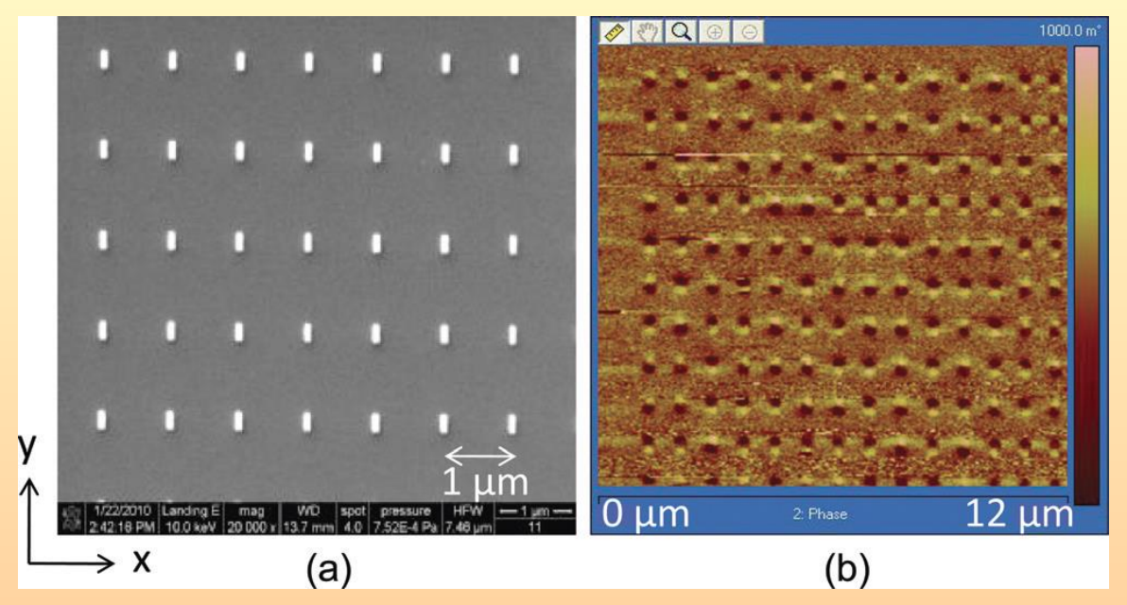


- Based on trends present in a multitude of studies, the recommended geometry of a nanoellipse for maximum rotation includes:
  - Major axis=150 nm
  - Thickness=15 nm
  - Eccentricity=0.85

Future Work

- Run more complex models based off current work and compilation of data
- Fabricate devices for experimental verification

EXPERIMENT



References

[1]A. Bur, T. Wu, J. Hockel, C. J. Hsu, H. K. D. Kim, T. K. Chung, K. Wong, K. L. Wang, and G. P. Carman, "Strain-induced magnetization change in patterned ferromagnetic nickel nanostructures," *Journal of Applied Physics,* vol. 109, Jun 15 2011.

Acknowledgements

This work was supported by Intel and the Semiconductor Research Corporation Education Alliance through the SRC Education Alliance Grant 2009-UR-2035G, Amendment No. 3
This work was supported by the National Science Foundation through the Cooperative Agreement Award EEC-1160504 for Solicitation NSF 11-537 (TANMS) managed by Dr. Deborah J. Jackson
The researchers also wish to acknowledge the UCLA Center for Excellence in Engineering and Diversity (CEED)—Enrique (Rick) Ainsworth, Director