Heterostructure Materials and Devices Group M.I.T.

Simulation and Design of Forces during Magnetically Assisted Fluidic Self-Assembly using Maxwell 3D

automating micro-scale hybrid integration

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Outline

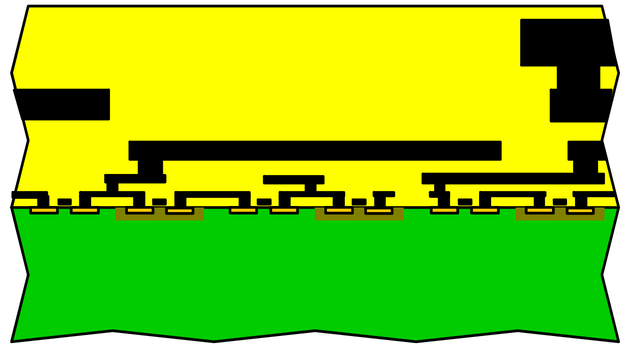
- Motivation for Research
  - RM^3 Integration Techniques
- Past Integration Methods
  - Pick and Place
  - Fluidic Assembly
- Prior Modeling
- SmCo Film Collaboration
- Ansoft Environment
- Simulations
  - Retaining Forces
  - Aligning Forces
  - Layer Structures
- Design
  - Pill Design
  - Recess Design

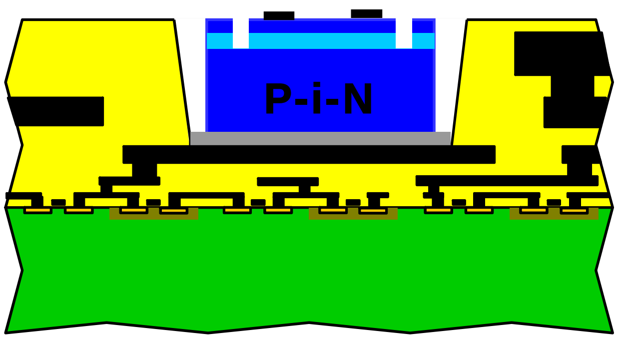
Motivation/background

RM³ Integration - Recess Mounting with Monolithic Metallization

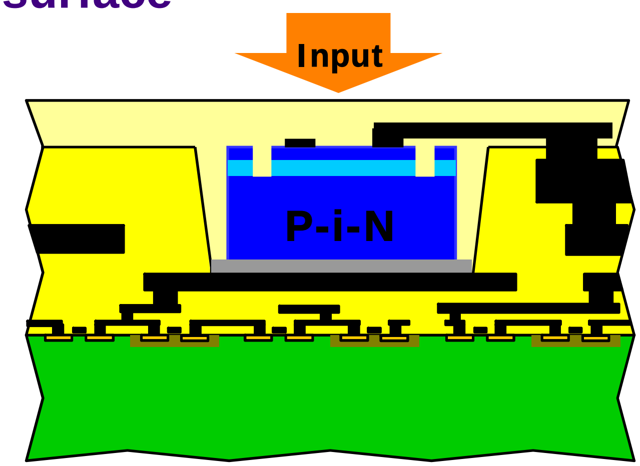
A micro-scale hybrid integration technique yielding monolithic performance

Commercially processed, custom-designed IC wafer with areas left for forming recesses and integrating photonic devices





Heterostructure devices located in recesses formed on wafer surface



Surface replanarized, vias opened, and photonic devices interconnected with underlying electronics

Modular	**Wafer level**	**Monolithic**
Planar	**Flexible**	**3-d Ready**

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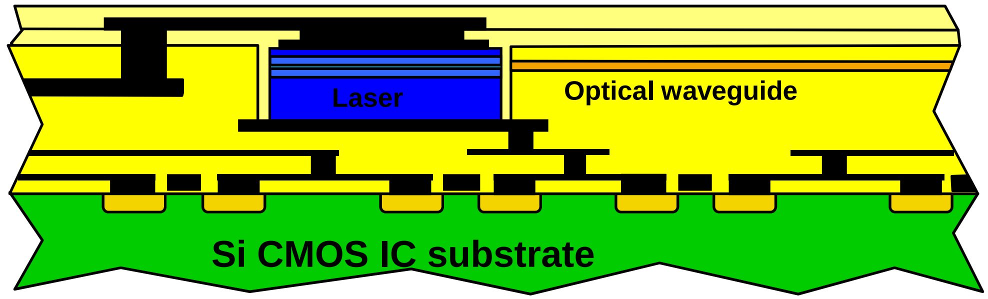
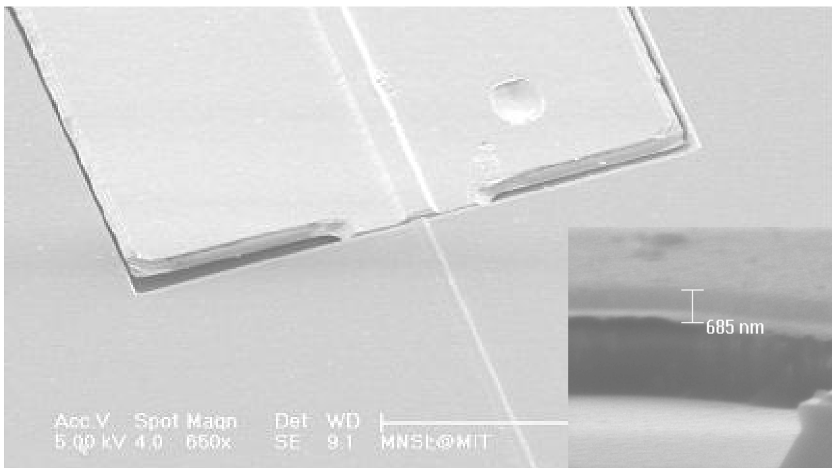
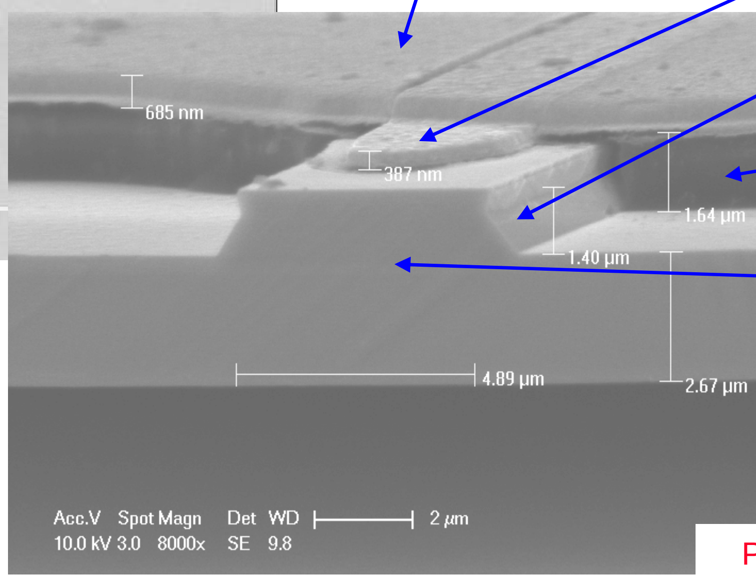
RM³ Integration Example #1:

EEL Platelets RM³ Integrated with SiO_xN_y Waveguides on Si Substrates

Approach: Co-axial alignment of ridge guide lasers with dielectric guides on Si CMOS ICs







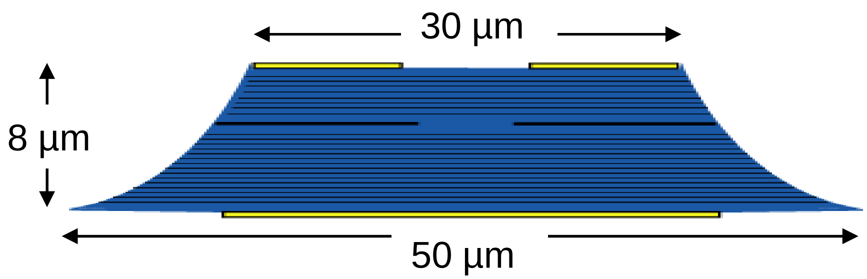
Above: Platelet aligned with waveguide for passive characterization.

Right: Micro-cleaved end-facet on 1.55 µm laser diode platelet.

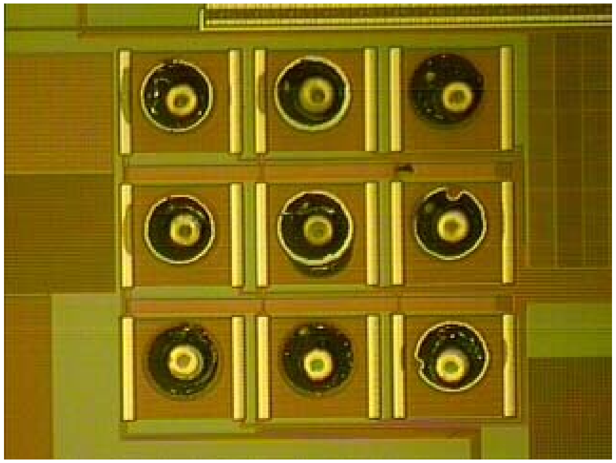
Ph.D. research of Joseph Rumpler and Dr. Ed Barkley

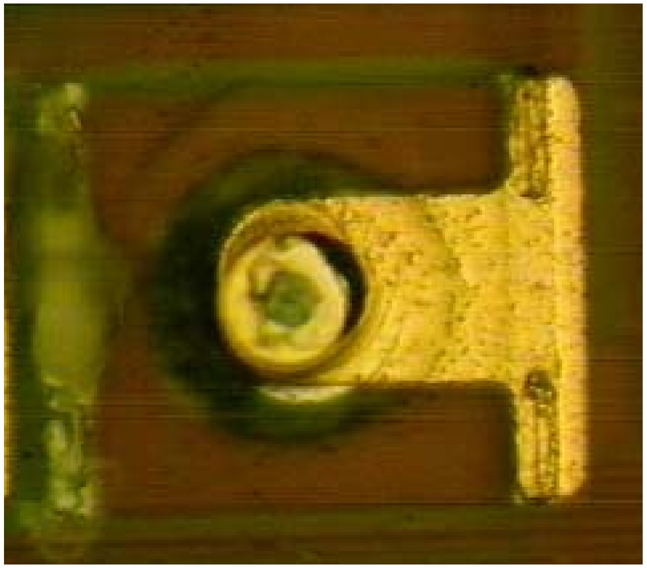
RM³ Integration Example #2:

VCSEL Pills RM³ Integrated with Si-CMOS

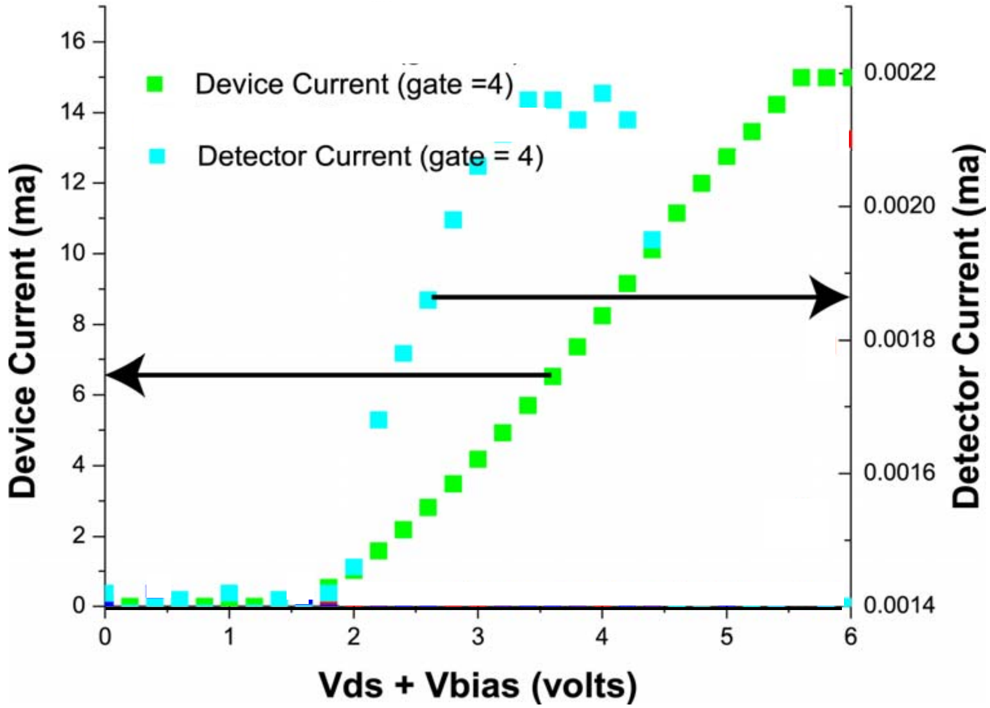


Above: Oxide aperture VCSEL pill (cross section).
Right: Nine pills assembled in recesses on a CMOS IC prior to via etch and interconnect metal deposition.





Above: Close-up photomicrograph of a fully integrated VCSEL.
Right: On-chip drive characteristics of an integrated VCSEL (I_{Th} = 1 mA).



Ph.D. research of Dr. James Perkins

Implementing RM ^{3} Integration:

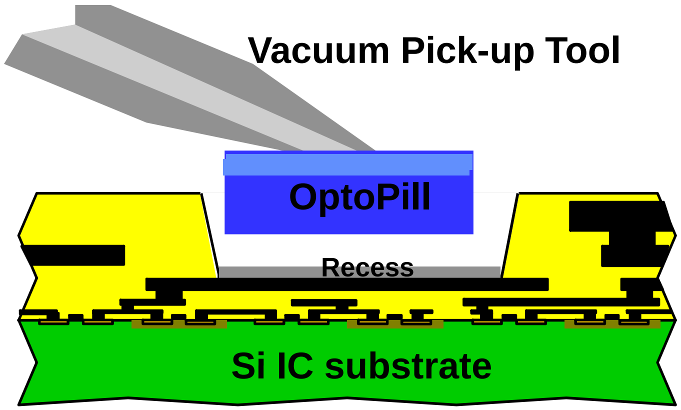
Micro-scale Pick and Place (MPAP)

(Present approach)

Micropipette used as a pick-up tool to place pills in recesses

Problems: piece-by-piece, slow

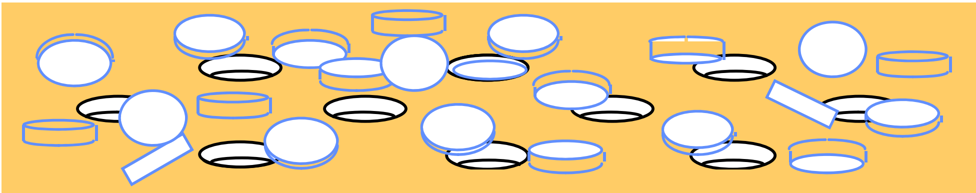
Solution: fluidic self-assembly



Fluidic Self-assembly (FSA)

(Automated assembly)

Pills tumbled over wafer until all the recesses are filled



Problems: keeping the pills in the recesses, orienting and aligning the pills

Solution: use magnetic forces to position and hold pills

Magnetically Assisted Self-assembly (MASA)

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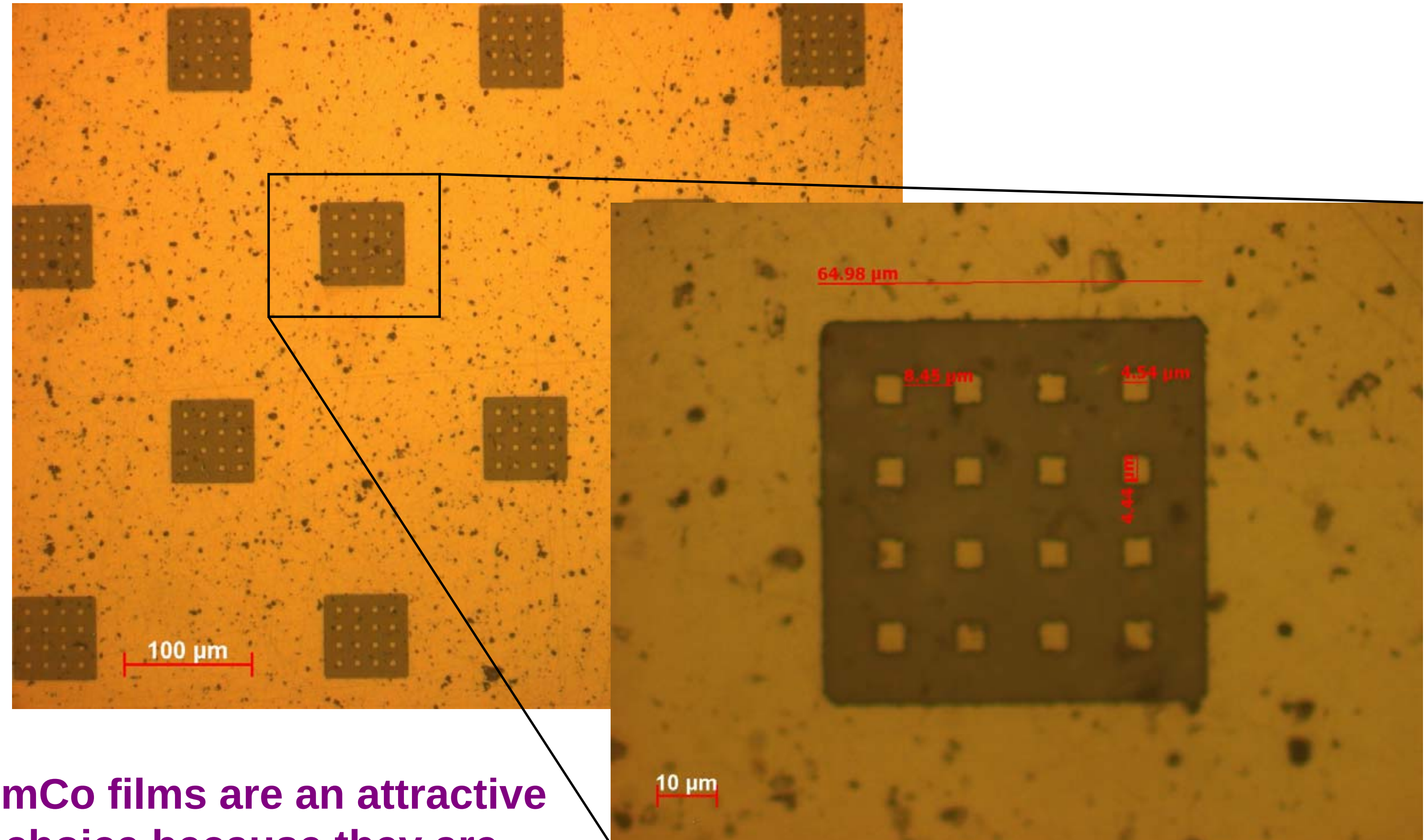
Patterned hard magnetic films: SmCo films sputter deposited on heated substrates under magnetic bias

(by Prof. Fred Cadieu, Queen College, N.Y.)

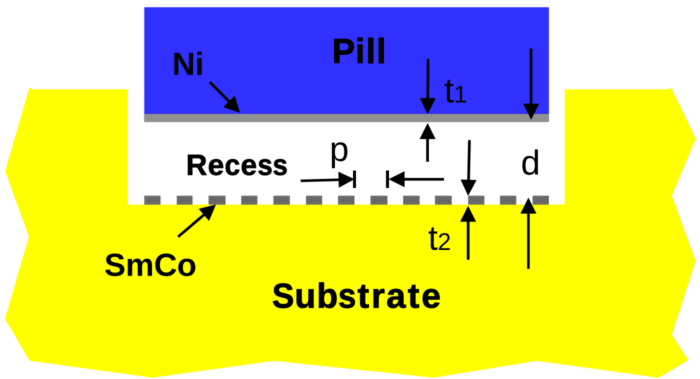


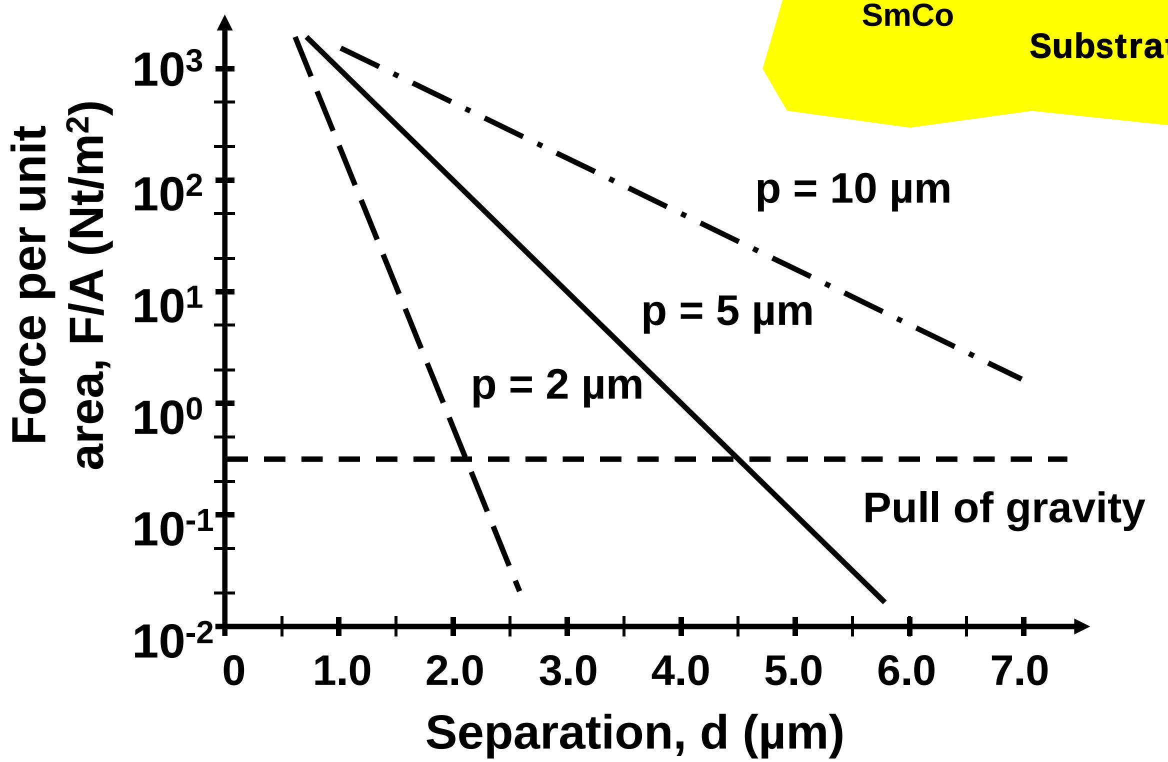
SmCo films are an attractive choice because they are…

…far easier to produce than more exotic "modern" materials
…can easily be wet etched and patterned to micron-levels
…are well suited to depositing and patterning in recesses

Prior Modeling:

MATLAB calculation of the attraction of a periodic array of magnetized SmCo stripes for a soft-magnetic Ni film

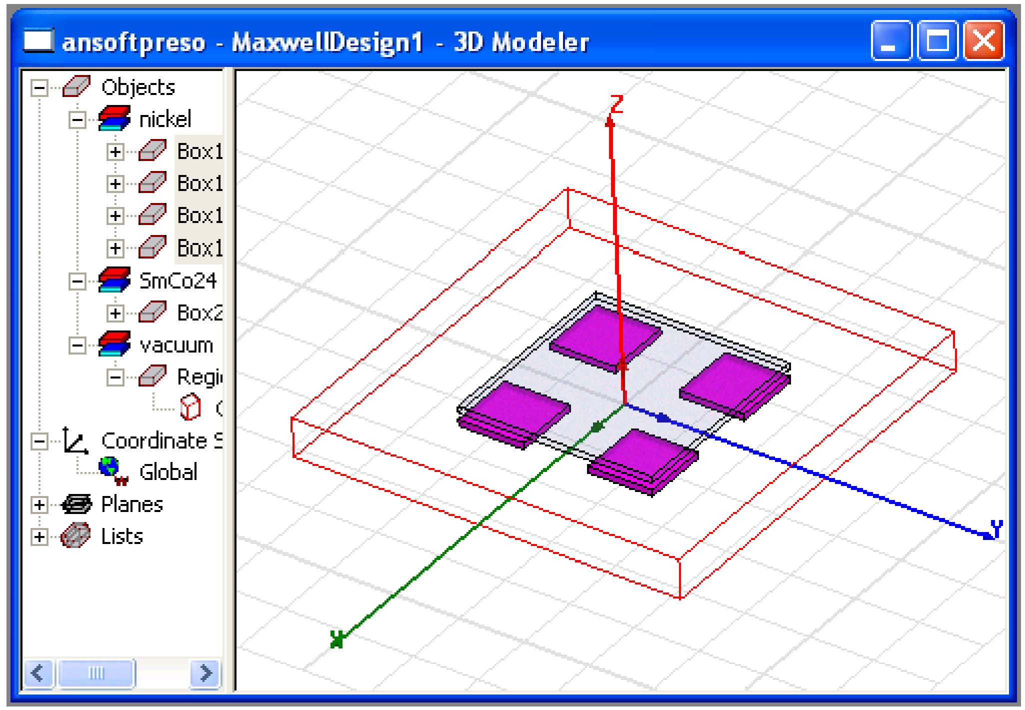




OBSERVATION: The strength and extent of the attractive force can be engineered, and tailored as needed through the design of the pattern of the hard magnetic film.

Setup Ansoft Environment

- Model
- Boundaries
- Excitations
- Parameters
- Mesh Operations
- Analysis
- Optimetrics
- Results
- Field Overlays



Setup Ansoft Environment

- Model –Materials

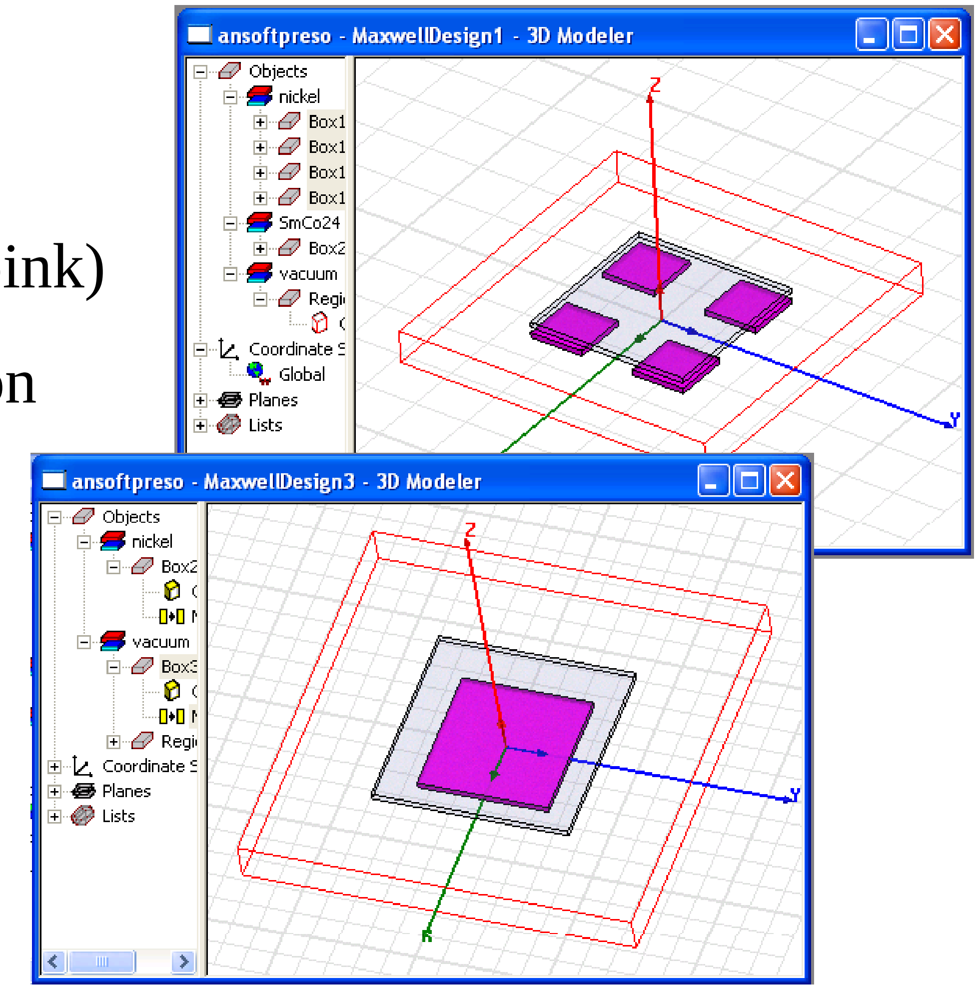
-Ni 0.5µm thick (clear)

-SmCo24 0.5µm thick (pink)

X direction polarization

-Global Coordinates

-Vacuum Region 50%



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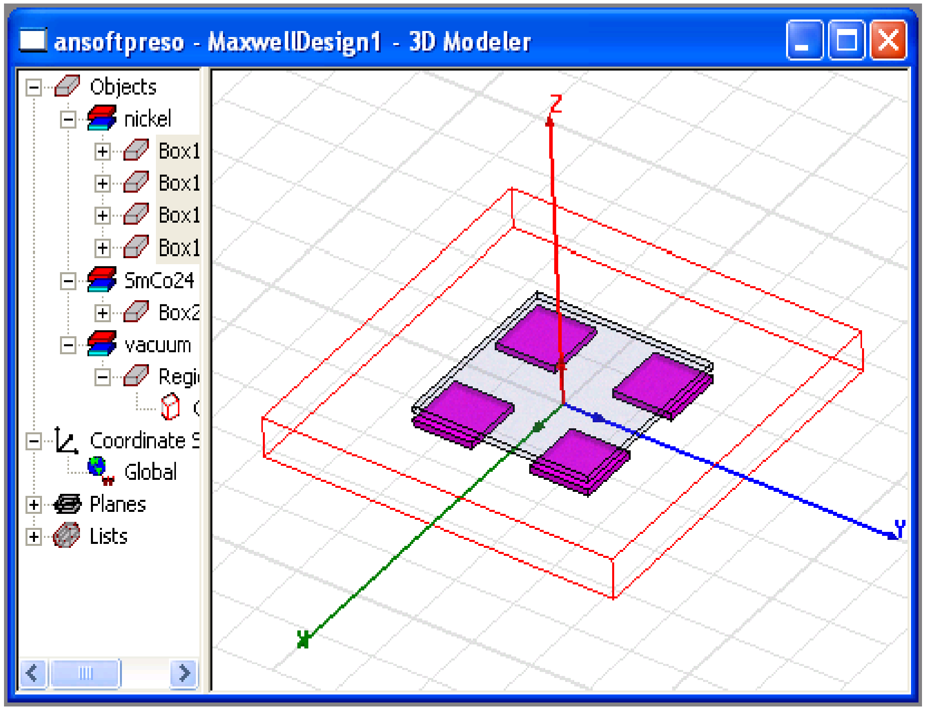
Setup Ansoft Environment

- Model
- ~~Boundaries~~
- ~~Excitations~~
- Parameters
- ~~Mesh Operations~~
- Analysis
- ~~Optimetrics~~
- Results
- Field Overlays



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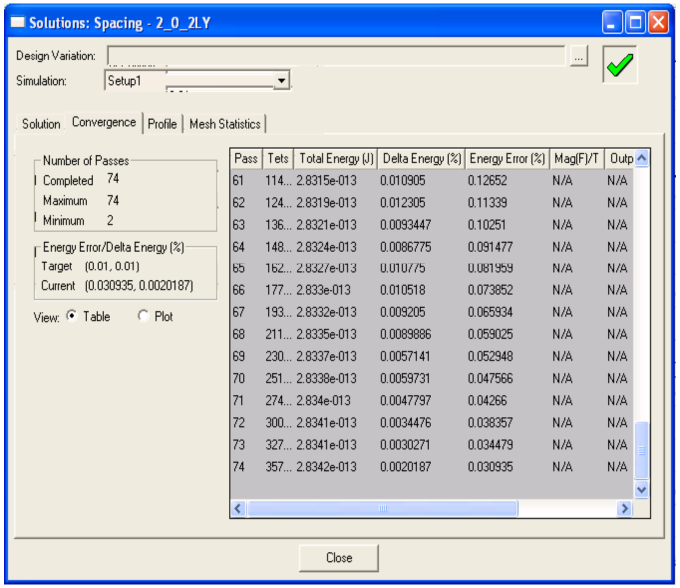
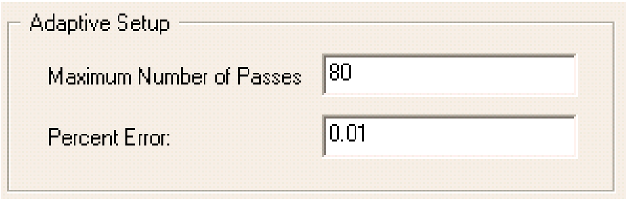
Setup Ansoft Environment

- Analysis
- Results

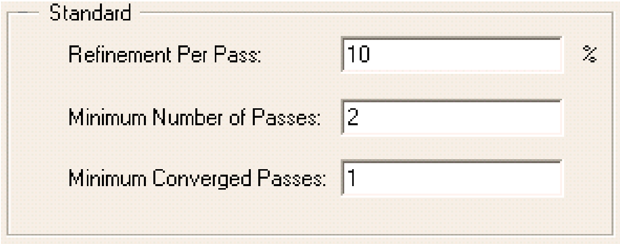
-Energy error (%) lower then 0.03 accepted



General



Convergence



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Setup Ansoft Environment

- Field Overlays

  - Used to verify correct polarization and accuracy of Force and Torque values.

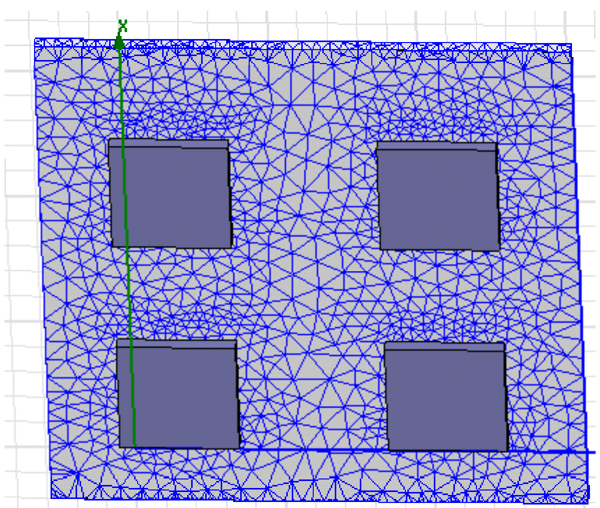


Figure: Mesh points on Nickel Plate showing tet points

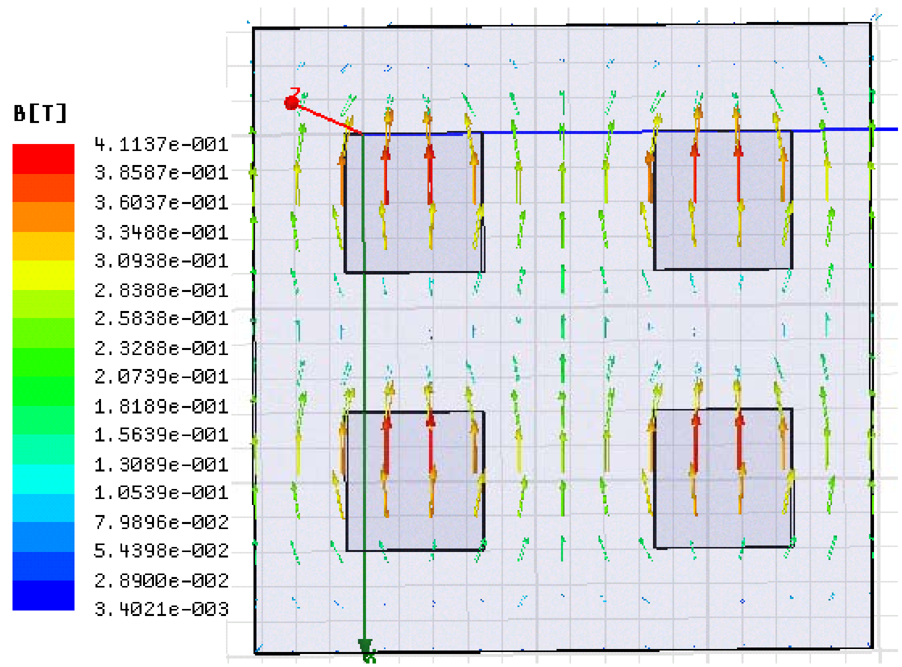


Figure: B vectors on Ni Plate produced by SmCo grid .5µm below

Simulations

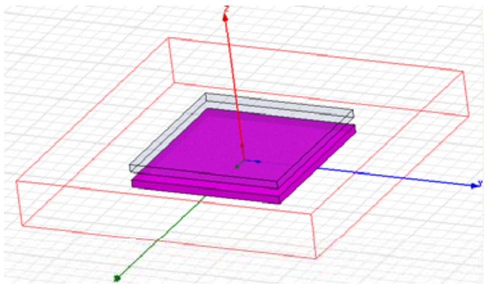
I. Retaining forces
   a) Squares vs discs
   b) Force relative to pill weight, 5 µm square
   c) Variation with square size (1, 3, 5 µm)
      1) linear scale
      2) logarithmic scale
   d) Optimizing pill size vs SmCo squares
   e) Additive squares
   f) Grids

II. Aligning forces
   a) Displacement in x direction
   b) Displacement in y direction
   c) Rotational alignment

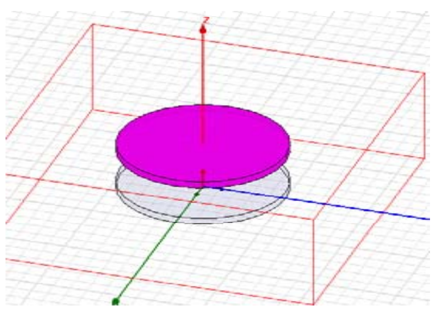
III. Layer structure
   a) Optimum magnetic layer thicknesses
   b) Impact of gold bonding layers

Simulations: *Square vs. Circle*

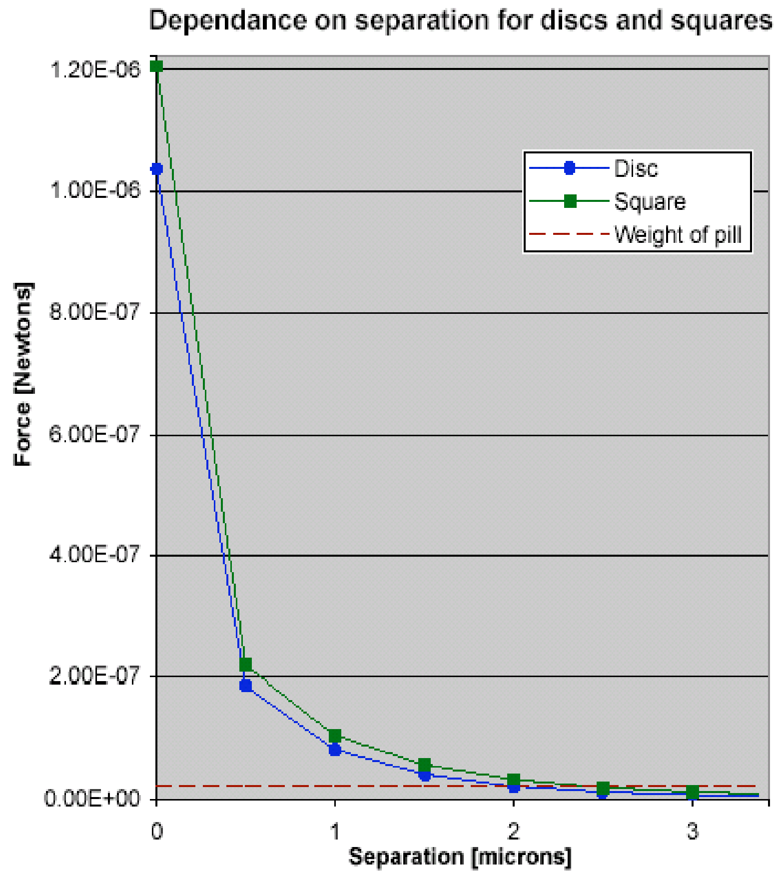
Questions: Which geometric shape provides most conclusive data?



5 µm by 5 µm squares



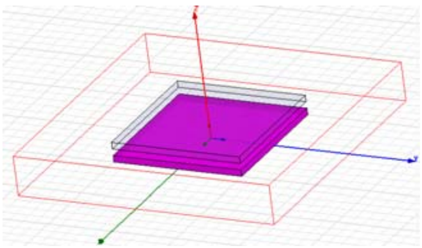
5 µm diameter discs



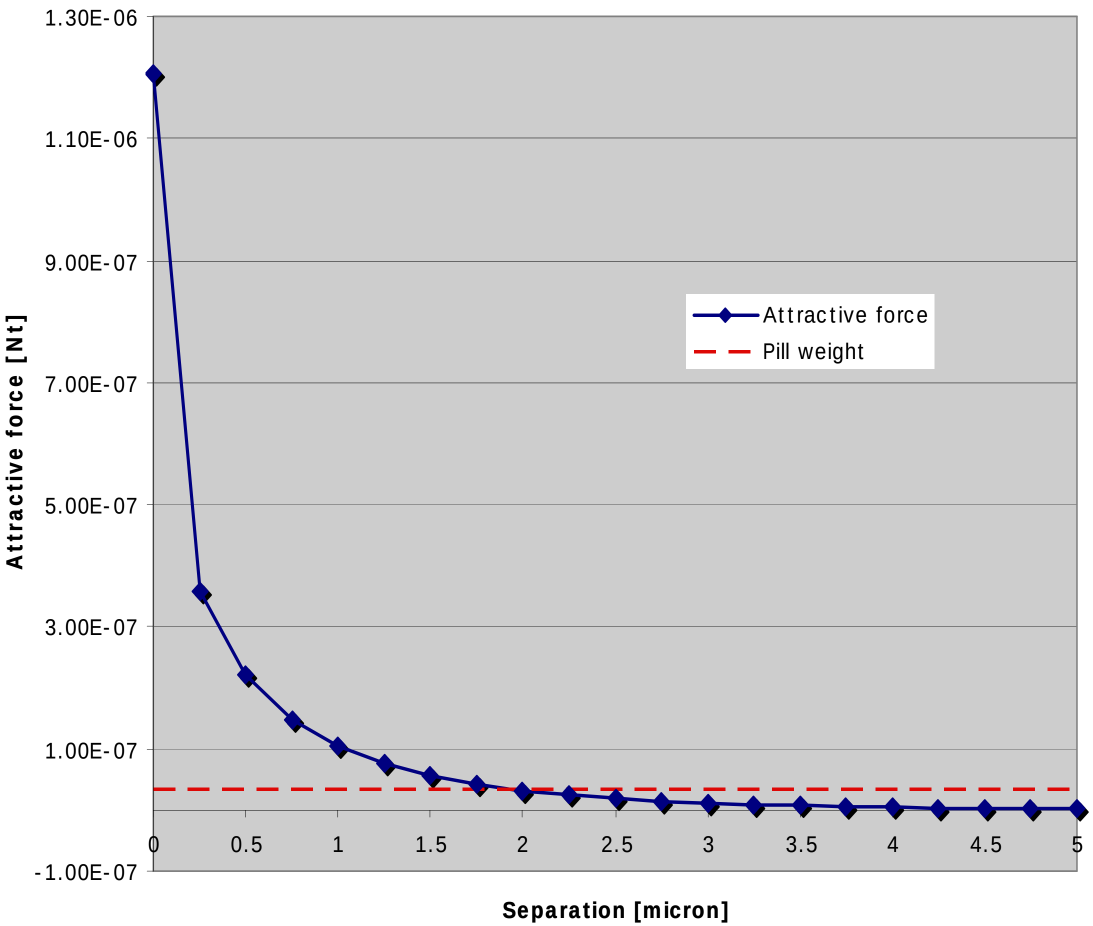
Conclusion: Squares innately have orientation thus orientation and placement in recesses can be tested.

Simulation: Force relative to Pill Weight

Questions: Is there enough attraction between 5µm squares to hold a pill on? How does it vary with separation?



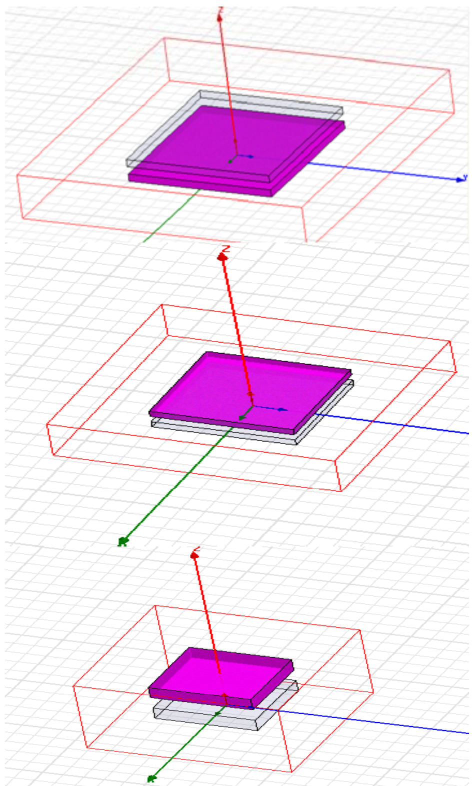
5 µm by 5 µm squares

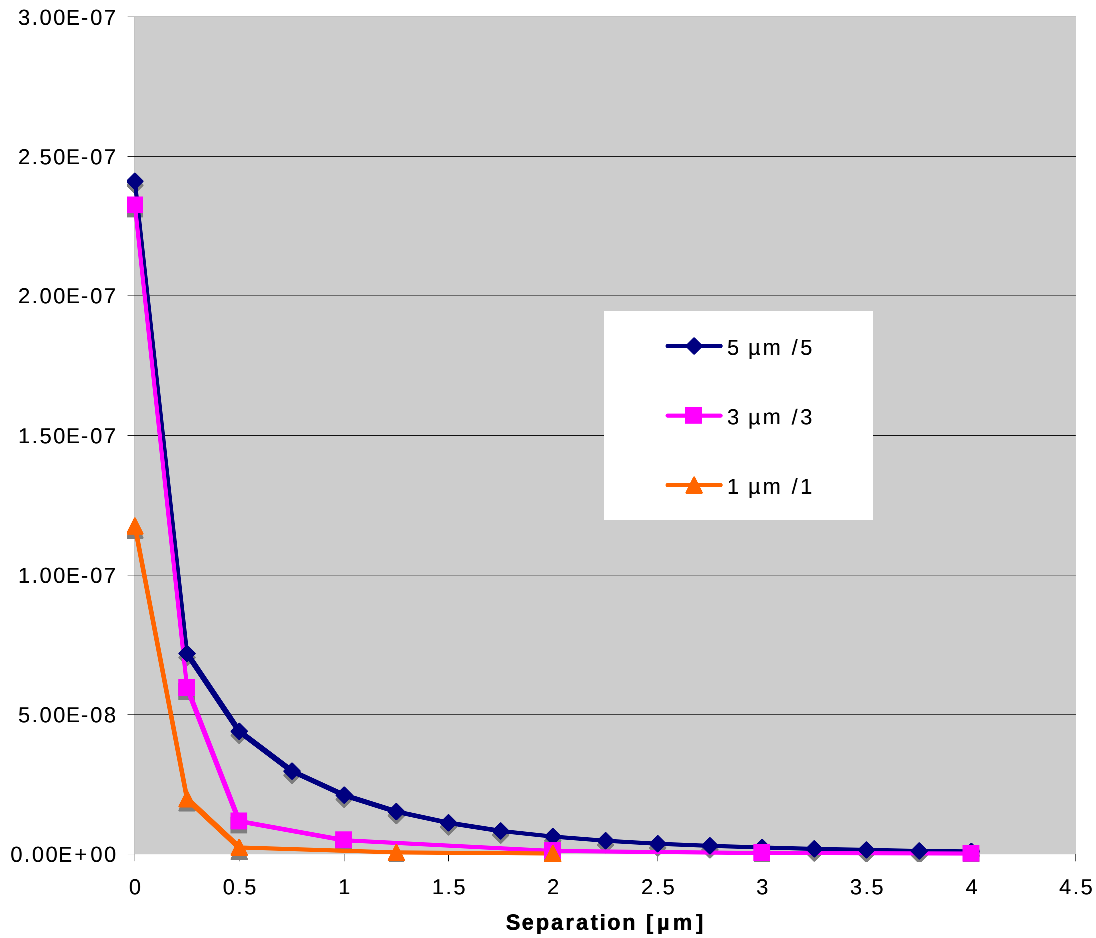


Conclusion: If separation is < 2 µm, there is enough force.

Simulation: Variation with square size

Question: What difference does the square size make?

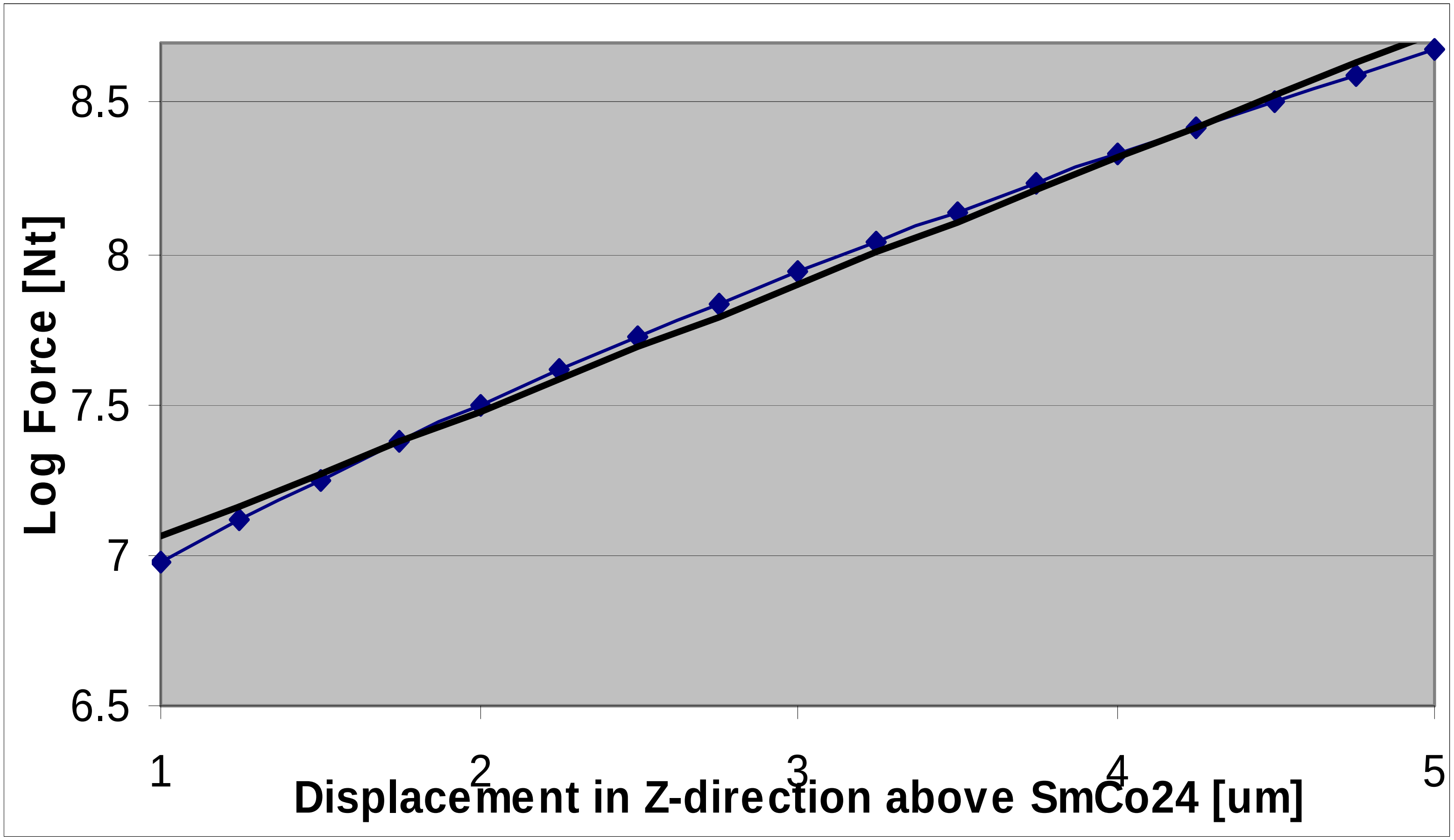




Conclusion: The extend of the field can be engineered: smaller squares lead to more rapid fall-off.

Simulation: Variation with square size

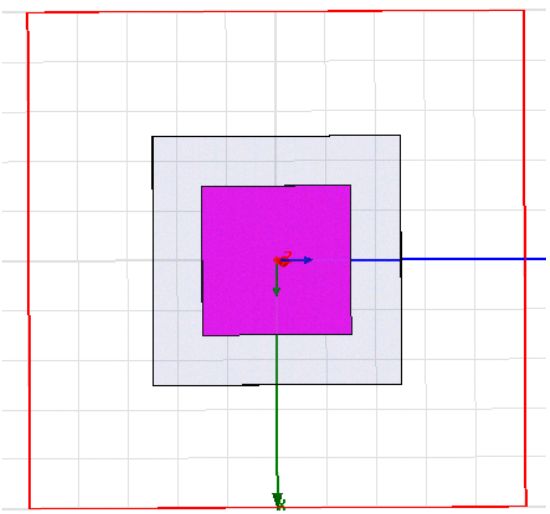
Question: Characteristic of force vs. distance



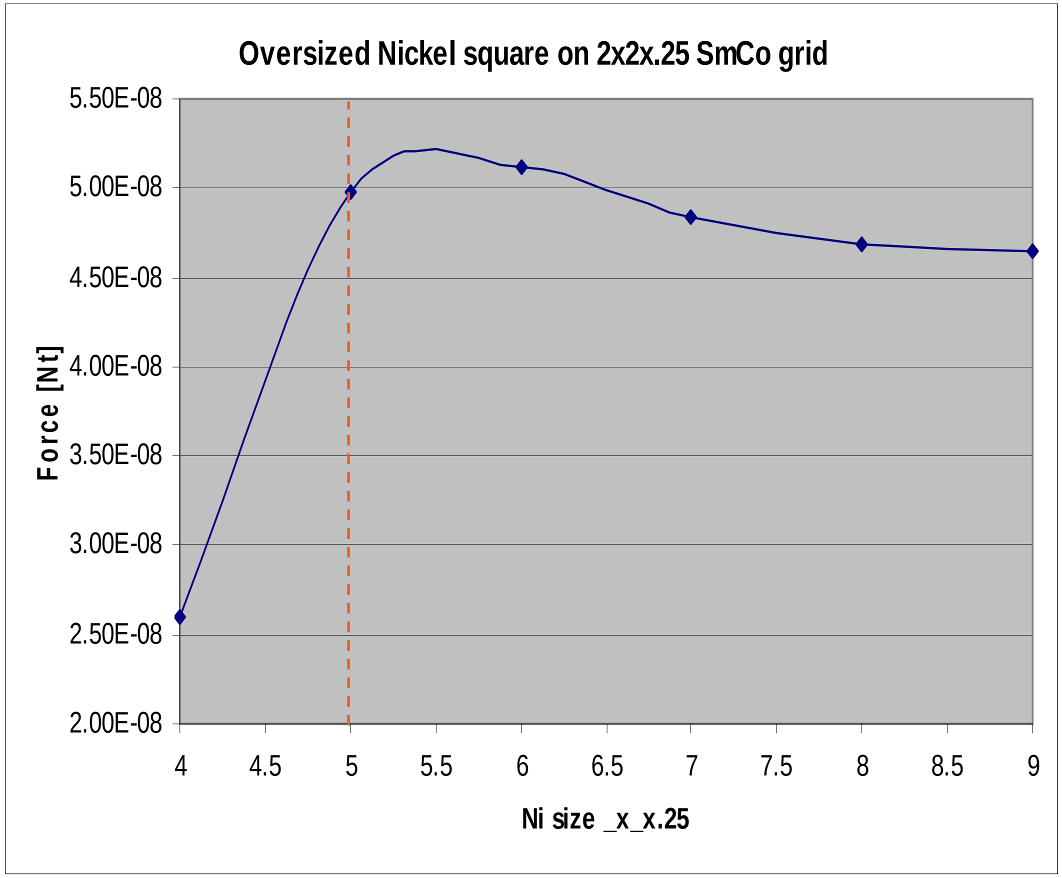
Conclusion: Logarithmic relationship between distance and force on nickel plate.

Simulation: Optimizing pill size vs SmCo squares

Question: What is the optimal size of pill over a 5µm x 5µm x 0.25 SmCo square



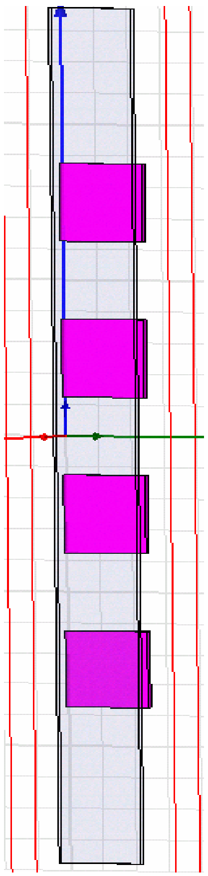
5µm x 5µm x 0.25 SmCo square with a 7µm x 7µm x 0.25 Nickel square on top

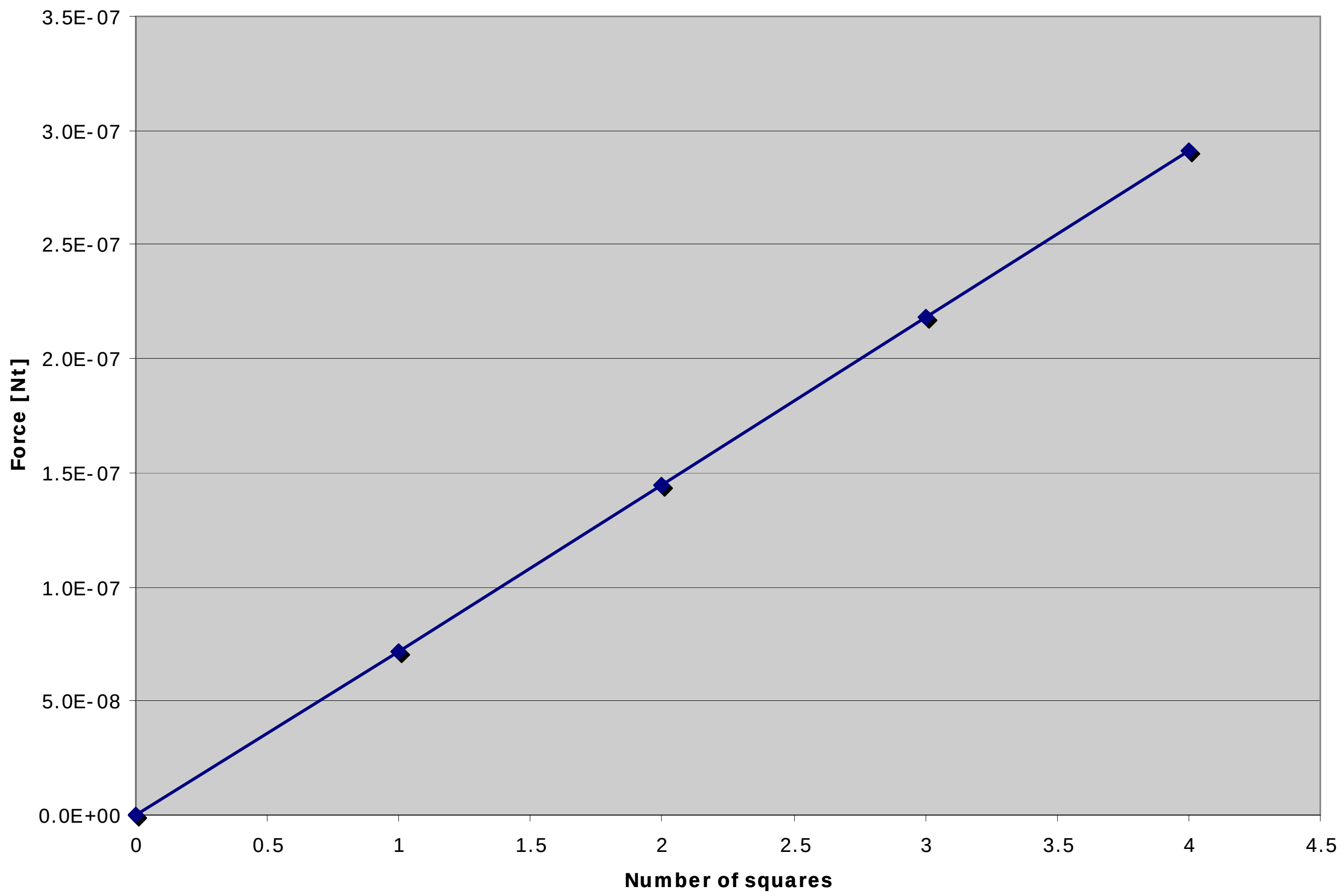


Conclusion: An oversized pill feels about the same force as the 5µm pill; a smaller pill feels much less.

Simulation: Additive squares

Question: Is the force from multiple squares additive?

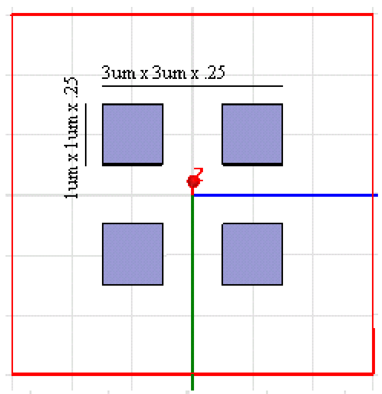


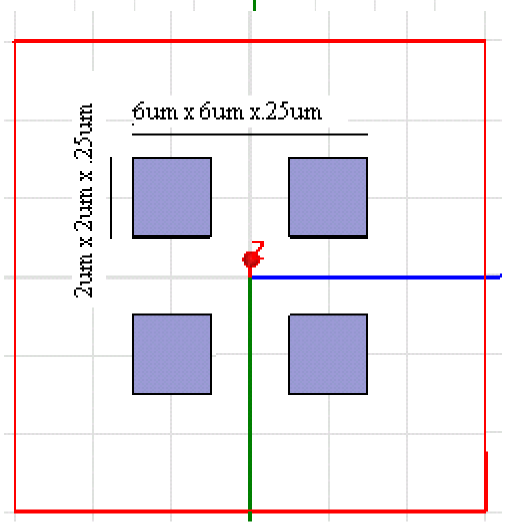


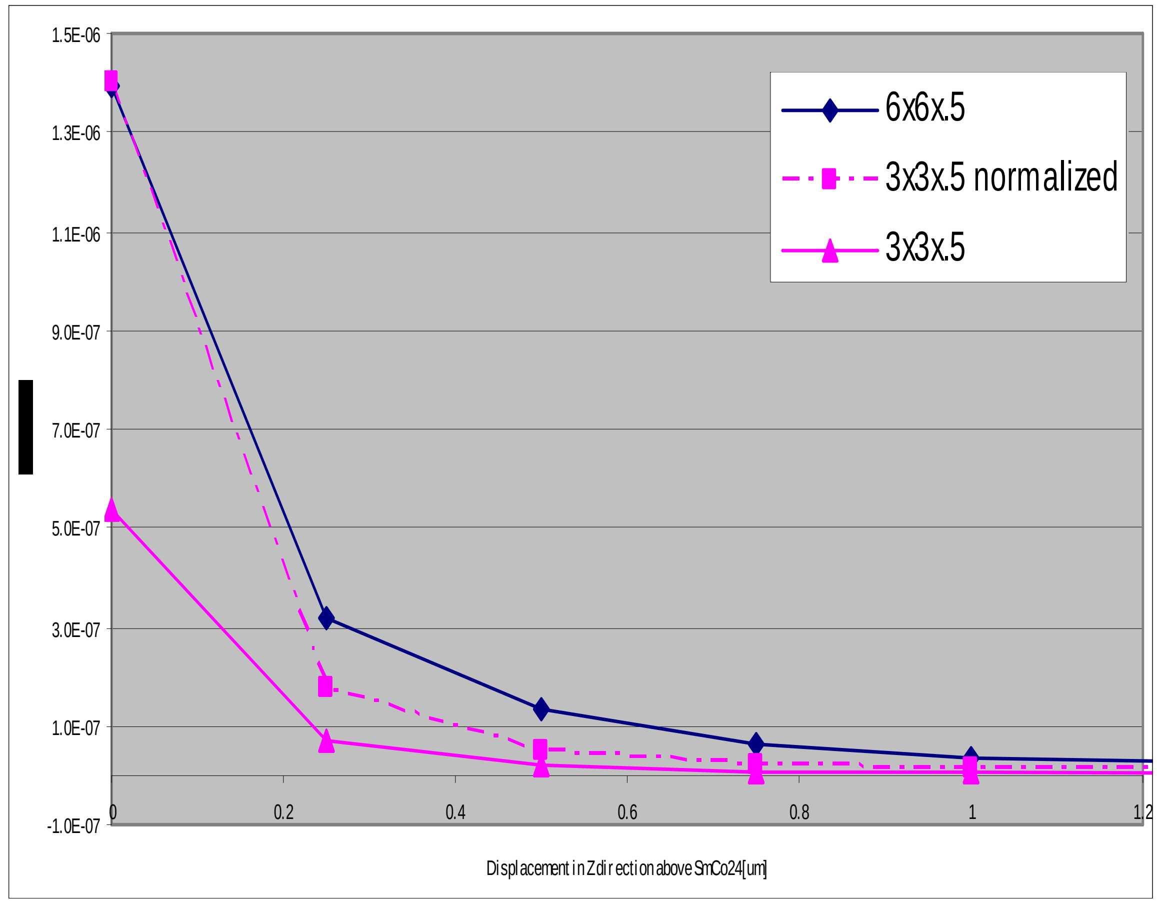
Conclusion: The force increases linearly with the number of SmCo squares.

Simulation: Variation with square size on a grid of four squares

Question: What difference does the square size make in a grid?



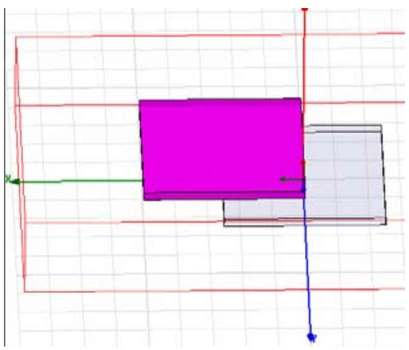


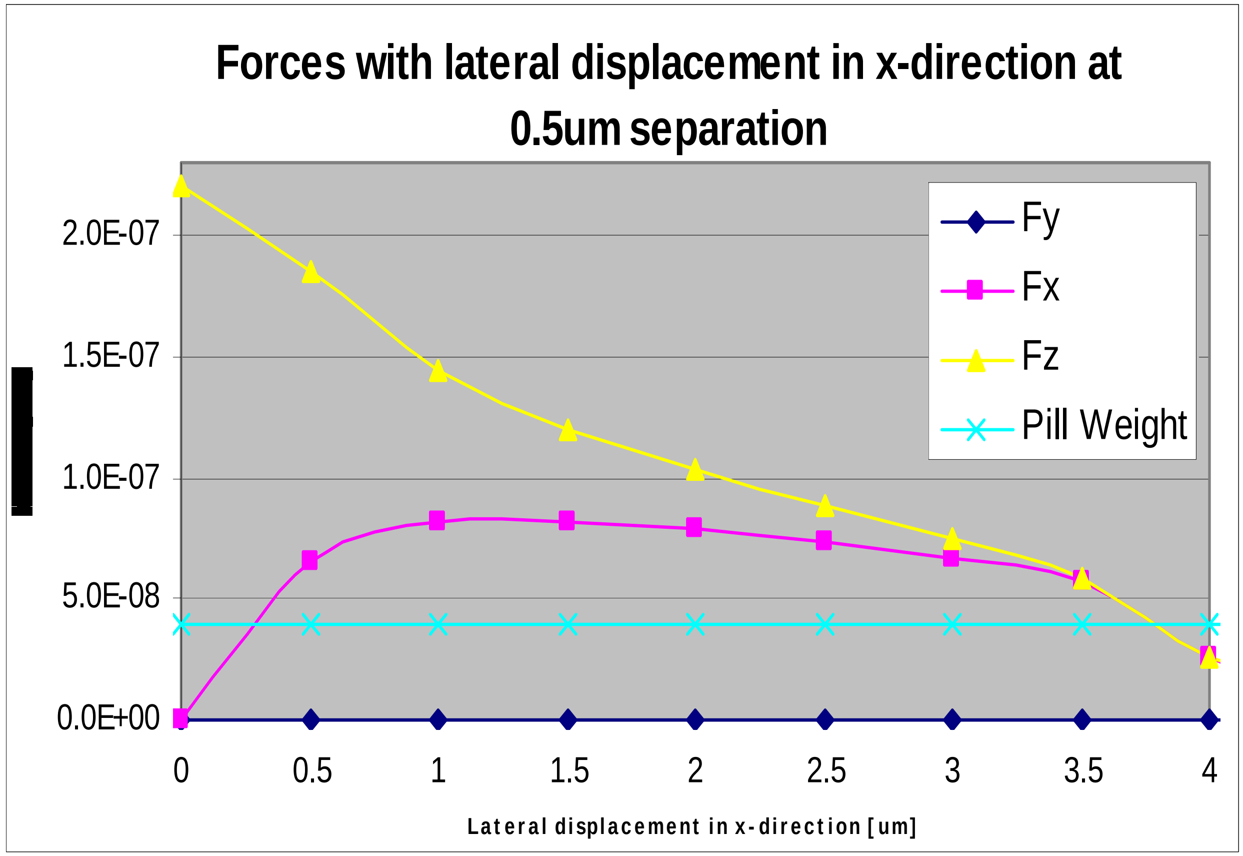


Conclusion: The extend of the field can be engineered: smaller squares still lead to more rapid fall-off.

Simulation: Displacement in x-direction

Question: What is the effect of displacement in the x direction?

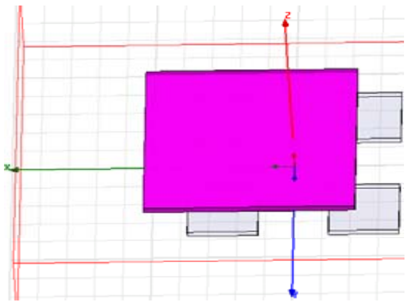


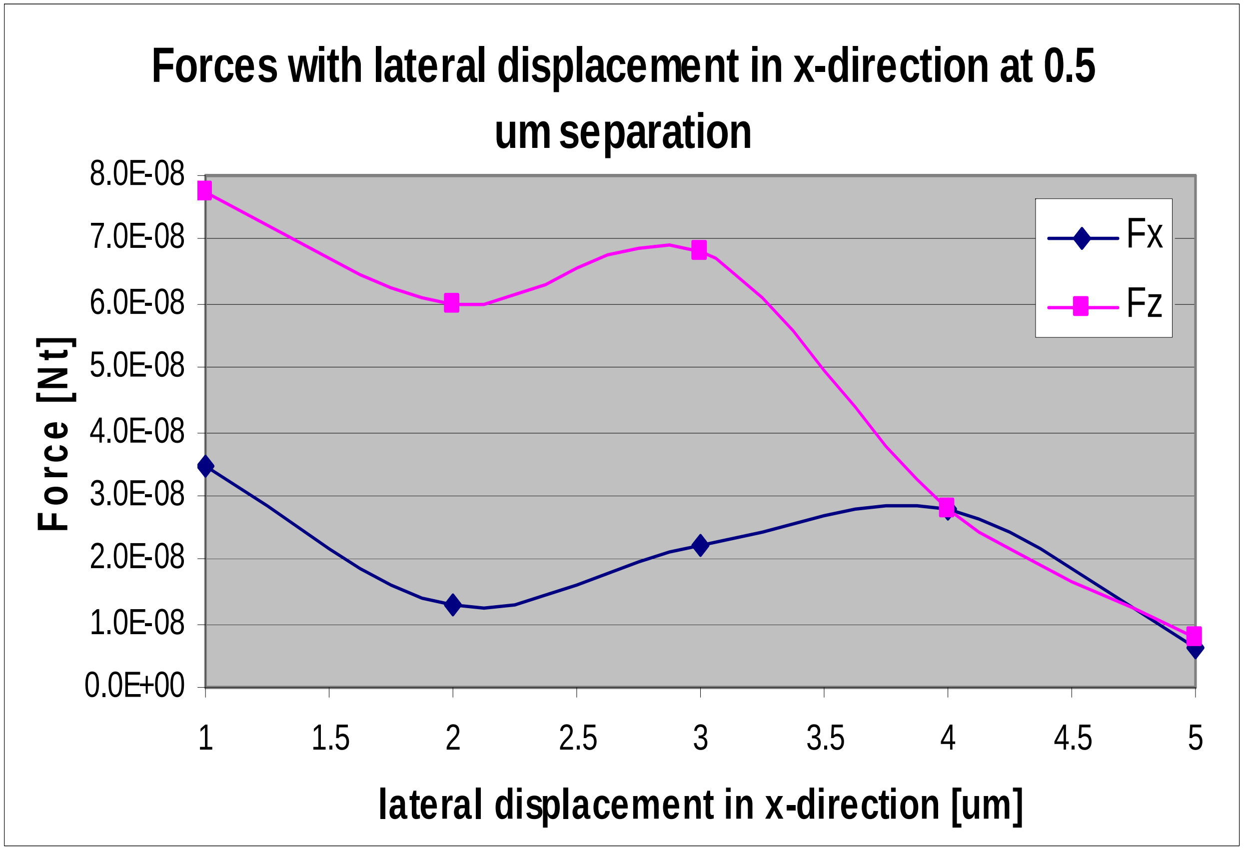


Conclusion: F_x forces are greater then the pill weight at > 0.25µm displaced. If pills slide readily, precise alignment is more probable.

Simulation: Displacement in X-Direction on Grids

Question: What is the effect of displacement in the x direction on grids?

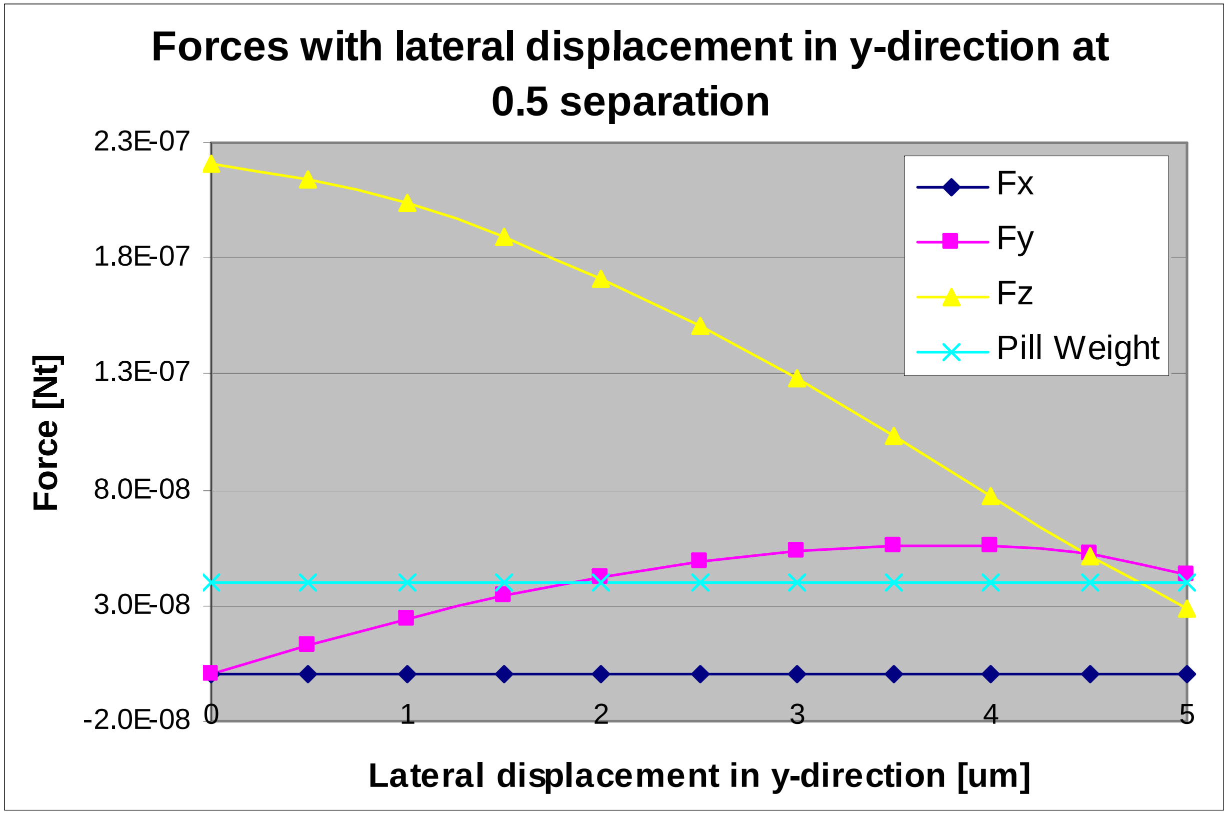




Conclusion: Local maximums and minimums can cause pills to attract to misaligned orientations.

Simulation: Displacement in y-direction

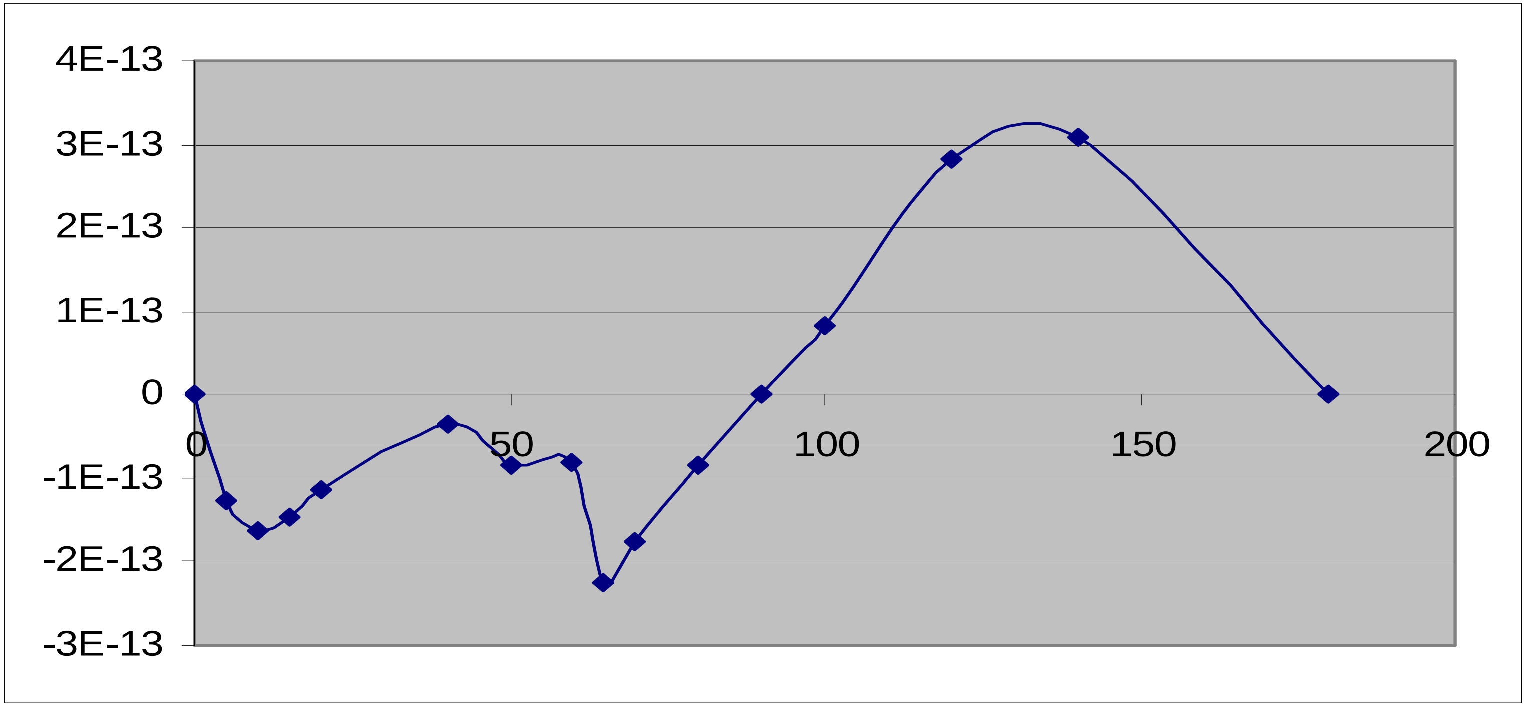
Question: What is the effect of displacement in the y direction?



Conclusion: For displacement in the y direction, the forces are smaller but still significant.

Simulation: Rotational misalignment

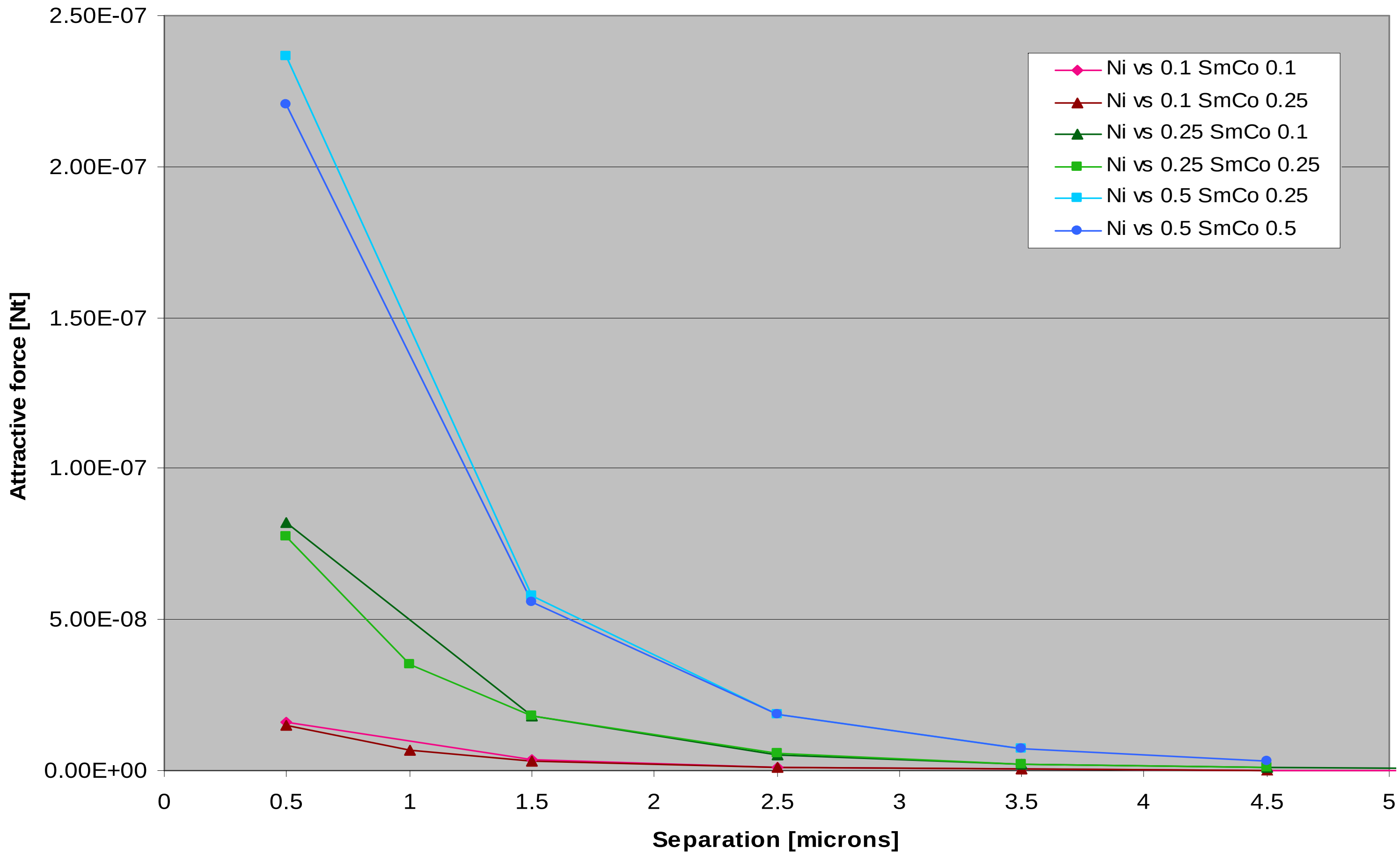
Question: What is the restoring torque is a 5 by 10 µm pill is rotationally misaligned?



Conclusion: There is a restoring torque, but the modeling is problematic. The predictions at certain angles do not make intuitive sense, and we are still trying to under- stand how to either explain or correct this.

Simulation: Optimum magnetic layer thicknesses

Question: What are the optimum thicknesses of the Ni and SmCo layers?

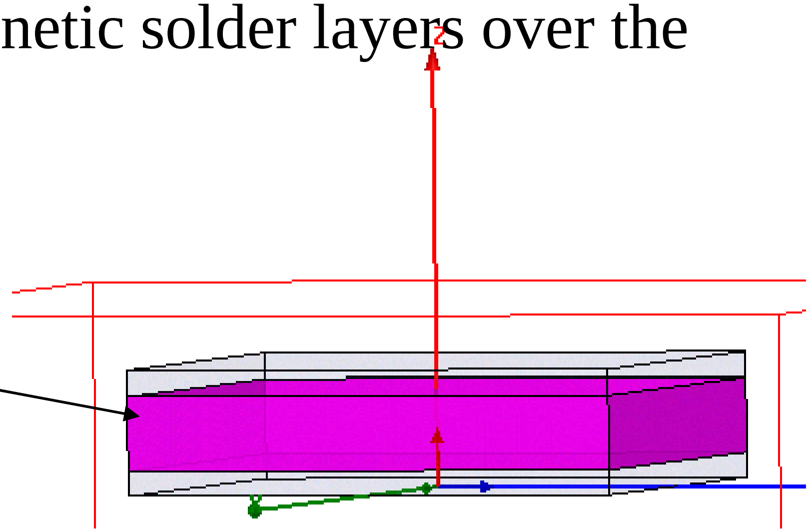


Conclusion: Making the Ni thicker doesn't do much, but making the SmCo thicker increases the force.

Simulation: Impact of gold bonding layers

Question: Can we put non-magnetic solder layers over the magnetic layers?

1.5 µm gold layer between Ni and SmCo

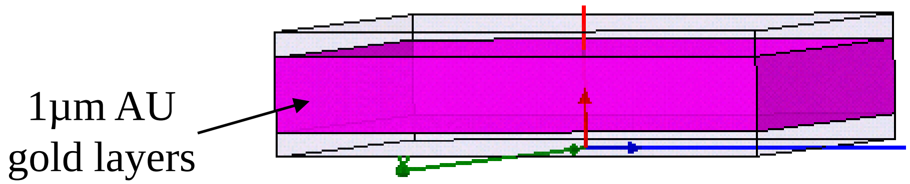


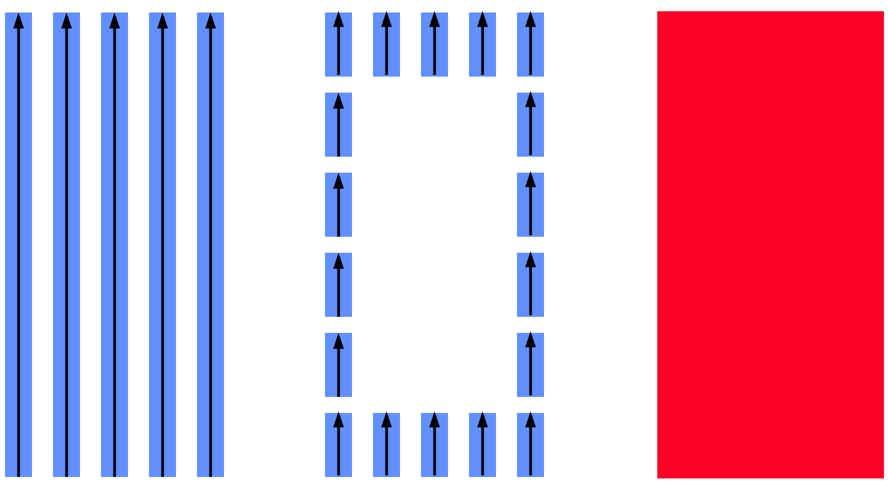
	Attractive force [Nt]
Without Au	3.53 E-8
With Au	3.54 E-8

Conclusion: No difference; solder layers such as gold and tin between the magnetic layers will be transparent to the magnetic fields.

Results- Design

Less then 875 µm^2 x 0.25 µm for a distance of 1 µm above the SmCo layer to avoid misaligned pills.

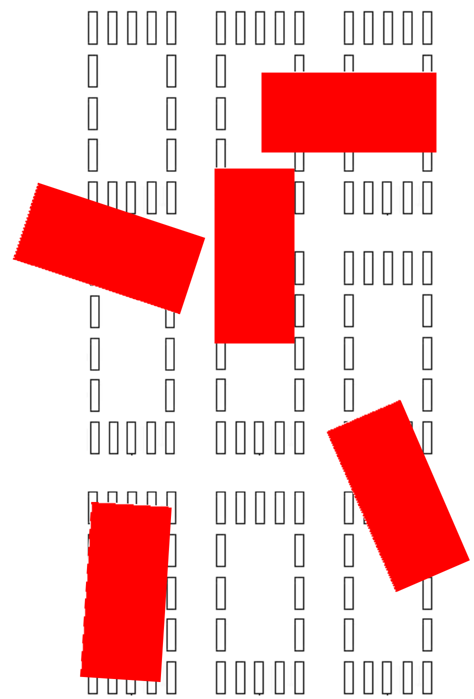




5 x 100 x 0.25 µm SmCo pattern

5 x 10 x 0.25 µm SmCo patterns

50 x 100 x 5 µm Pill with 0.25 µm Ni



Misaligned attractions

Summary of Simulation Results

I. Magnetic attraction can greatly exceed gravitational forces
II. Force increases exponentially with decreasing separation
III. Smaller squares lead to more rapid drop-off
IV. Maximum attraction when Ni and SmCo similar size; little penalty if make Ni pattern larger
V. Forces increase linearly with number of SmCo squares
VI. Squares experience orienting and aligning forces
VII. In-plane aligning forces are large; precision of final alignment will depend on surface friction.
VIII. Grids require more consideration with possible local force minima and maxima
IX. Nickel thickness has small impact on attraction forces; thickness of SmCo is far more important
X. Gold-based solder layers between Ni and SmCo films are transparent to the magnetic fields