Mechanical Effects and Behavior of Magnetic Nanoparticles in Alternating Magnetic Fields

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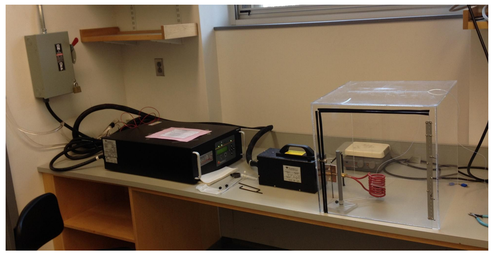
Research Overview

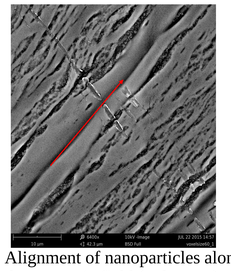
In recent years, magnetic hyperthermia has gained popularity as an experimental treatment for cancer (using heat to damage cancer cells). Using the physics behind magnetic hyperthermia, my research focuses on utilizing the rotation of the magnetic nanoparticles (Iron oxide) (MNPs) in an alternating magnetic field, to exert force in order to rupture cell membranes (or break down cells from within) without the use of high temperatures, minimizing damage to surrounding cells.

Magnetic Nanoparticle behavior in an Alternating Magnetic Field (AMF)



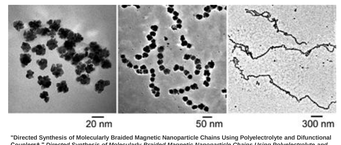
(Alternating magnetic Field (AMF) generator- Easy Heat)

Dried iron oxide nanoparticles on a silicon chip after being put in the AMF at 300 A.



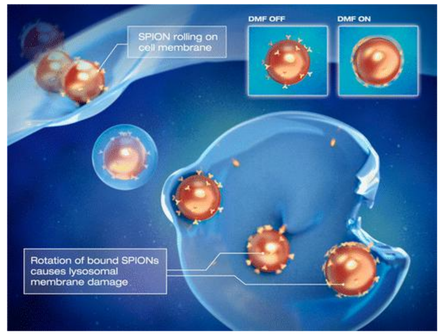
Alignment of nanoparticles along the magnetic field (red arrow) as viewed under the Scanning Electron Microscope (SEM)

Subjected to a magnetic field, MNPs tend to form chains along the direction of the field



"Directed Synthesis of Molecularly Braided Magnetic Nanoparticle Chains Using Polyelectrolyte and Difunctional Couplers†." *Directed Synthesis of Molecularly Braided Magnetic Nanoparticle Chains Using Polyelectrolyte and Difunctional Couplers.*

The MNPs were placed on silicon (non magnetic) chips which was placed in the AMF at 300 Amperes for small periods of time (15-30 seconds). The particles were then allowed to dry and viewed under the SEM for signs of chaining as well as provide light on the behavior of the nanoparticles.



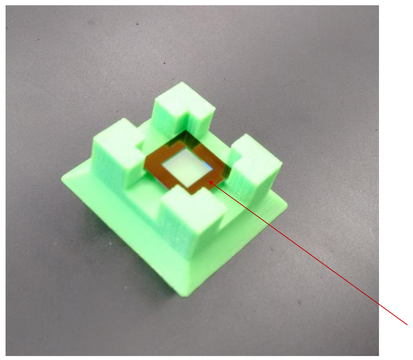
Dynamic Magnetic Fields Remote-Control Apoptosis via Nanoparticle Rotation." - *ACS Nano (ACS Publications).*

SPIONs(Superparamagnetic Iron Oxide Nanoparticles) are injected into the cancerous cells and rotated using dynamic(alternating) magnetic fields in order to destroy lysosomes within cells.

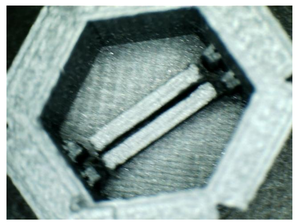
Apoptosis (programmed cell death).

Silicon Nitride Membrane Experiments

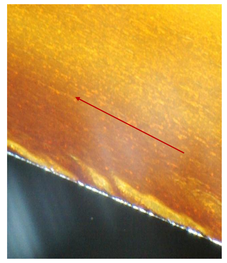
Silicon Nitride membranes(approx. 50nm thin) (surrounded by silicon frame) were used to simulate a cell membrane like structure to assess the damage (mechanical) magnetic nanoparticle rotation can cause in an AMF. 3D printed holders were designed and created for different orientations of the membrane. Nanoparticles (approximately 10 microliters solution) were placed on the membrane and placed in the AMF for short periods of time. The structural integrity of the membrane was noted. The behavior of the nanoparticles was also examined using an SEM.



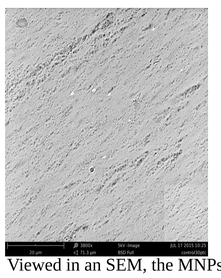
Silicon Nitride membrane(clear part) surrounded by silicon frame.

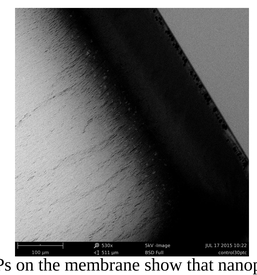


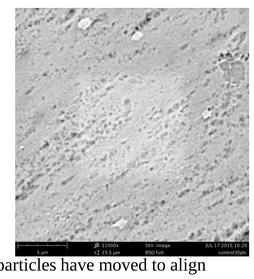
3D printed membrane holders (2 different orientations).

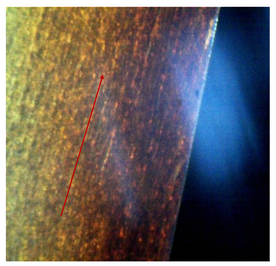


Alignment of NPs with magnetic field(red arrows) (Membrane magnification with NPs dried in AMF)







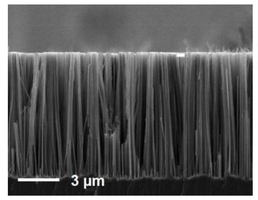


Viewed in an SEM, the MNPs on the membrane show that nanoparticles have moved to align with the magnetic field direction.

Texturing of Silicon Nanowires

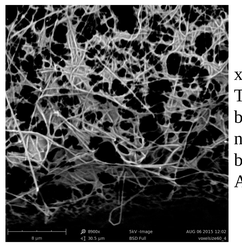
Silicon Nanowires are tiny wire like structures which protrude out of a base of silicon. We experimented with them to further analyze the behavior of MNPs in an AMF. To do so, we set up different control experiments

- Silicon Nanowire(without MNPs) in an AMF
- Silicon Nanowires with MNPs(not placed in AMF)
- Silicon Nanowires with MNPs in AMF

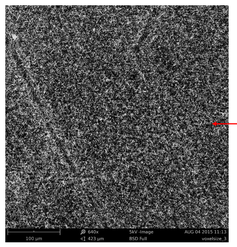


Web. 18 Sept. 2015. <http://nanotechweb.org/cws/article/lab/60931>

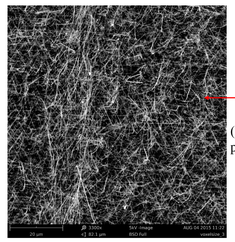
Silicon Nanowires as viewed from the side.



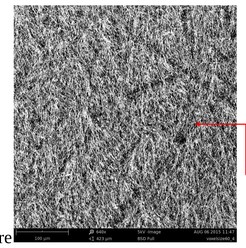
x8900 magnification The nanoparticles can be seen stuck to the nanowires (dried after being placed in the AMF).

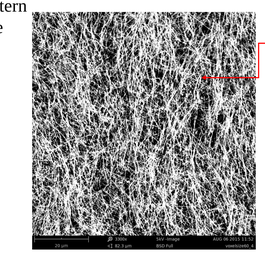


Before adding Nanoparticles to the silicon nanowires, there is no noticeable pattern or orientation of the nanowires



(The nanowires aren't pointed upwards)





After adding nanoparticles to the same silicon nanowire chip and placing it in the AMF for 15-30 seconds, it is left to dry. The resulting chip is viewed in the SEM. The wires seem to have textured along the direction of the magnetic field. There is a noticeable difference in the orientation of the wires.

When the nanoparticles are placed on the chip which is then immediately placed in the AMF, the nanoparticles exert a force on the nanowires(due to their rotation and alignment) which bends the nanowires along the magnetic field direction. This shows that nanoparticles do show forces in play at the nanoscopic level.

Future Work

Continuing with this research, we intend to do further experiments with silicon nanowires to better understand the behavior of magnetic nanoparticles. This will be followed by working with electro-spun fibers to emulate cell membrane environment to test the mechanical damage caused by the rotation of the MNPs. We expect to use OOMMF (a micro-magentics simulation program) to generate theoretical calculations for torque and force produced by the MNPs whereas piezoelectric sensors and MEMS cantilevers will be used to assess the force exerted by the rotating MNPs in AMF.

Acknowledgments

- Department of Physics
- Departments of Chemical and Biomolecular Engineering and Geology for use of Scanning Electron Microscope (SEM)
- Skillman Library for use of 3D printer for prototype membrane holders
- National Institute of Standards and Technology for iron oxide nanoparticle sample