Optimizing Magnetic Heating of Isolated Magnetic Nanowires (MNWs)
An OOMMF Based Simulation Project

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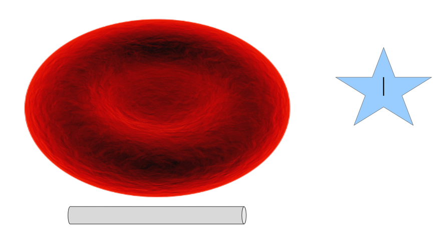
Introduction

Magnetic nanowires (MNWs) are magnetic nanomaterials with special 1D structure.



Size comparison between a red blood cell (~7 µm) and a large (gray rod) and smallest (line inside blue star) MNWs.

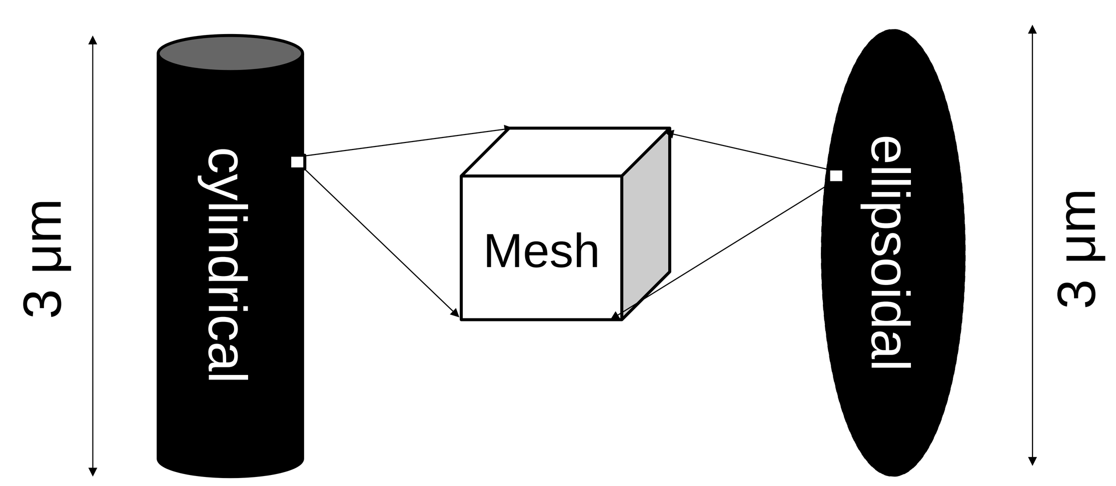
This research is focused on the factors that affect the area of the hysteresis loop and therefore heating capabilities of isolated MNWs.

The study is performed using the micromagnetic simulation software called objected oriented micromagnetic frameworks (OOMMF).

The results are in the form of hysteresis loops and arrow maps showing the moments.

Multiple runs of simulation were performed under same conditions.

Method: Simulation via OOMMF



The simulation results are obtained by minimizing the system energy which is the sum of the energy in each mesh at a given external field.

The magnetic parameters in the following table are assigned to the mesh. Different value of exchange parameter A, crystalline anisotropy K, and saturation magnetization M_s are used to represent different materials in this study.

In this simulation, there are ~15 meshes along the diameter and ~100 meshes along the length. The size of the mesh changes with the size of the wires.

<table>
<tr><th>Parameter</th><th>Exchange Parameter</th><th>Crystalline Anisotropy</th><th>Saturation Magnetization</th></tr>
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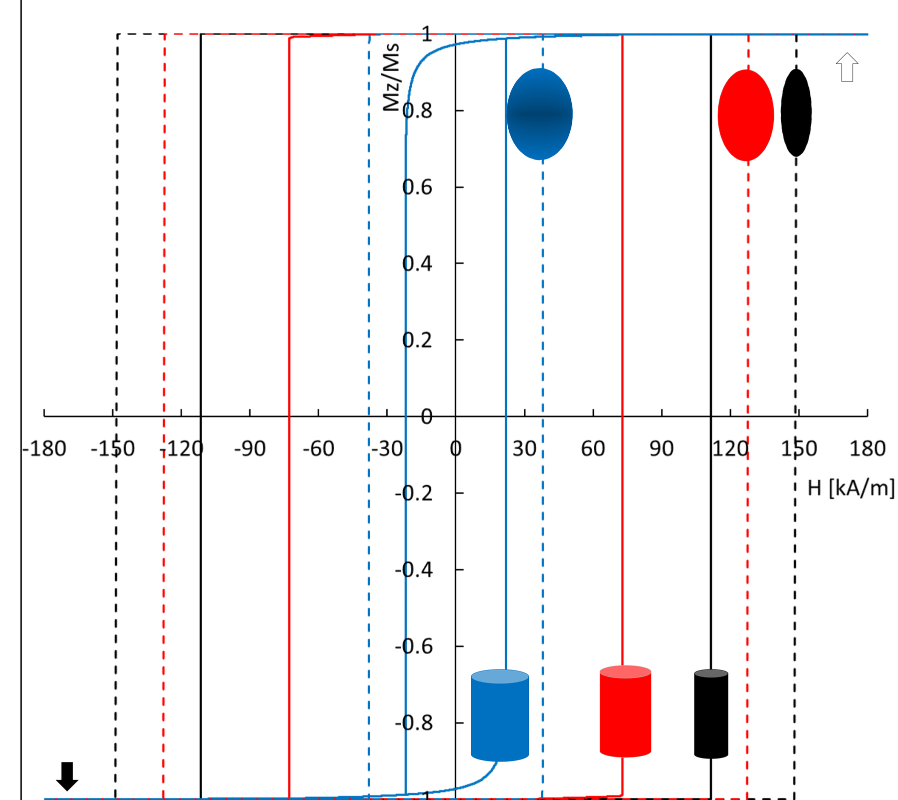
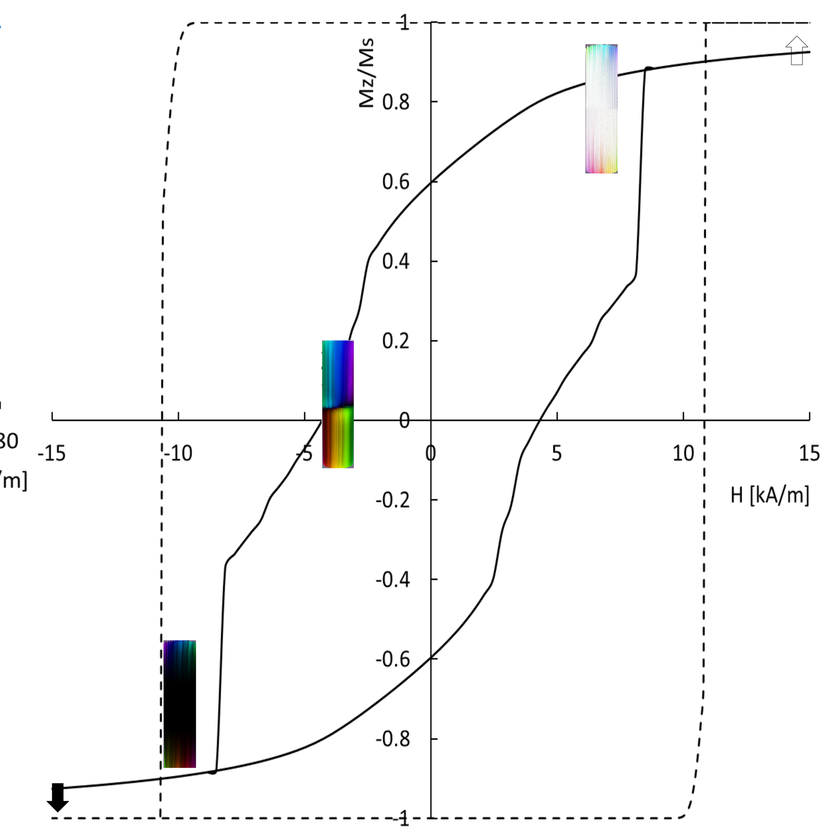
Results

Isolated MNWs with different sizes/shapes

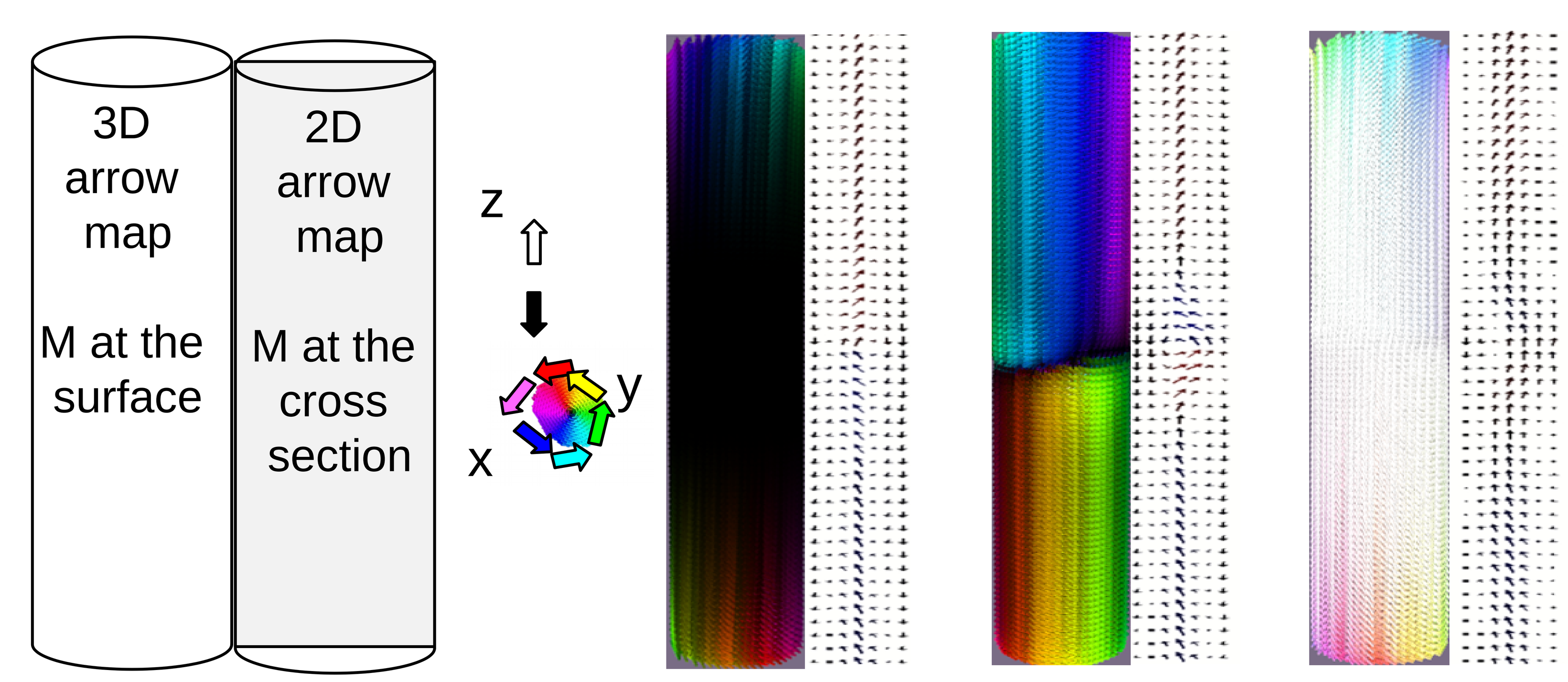


Hysteresis loops of 30 nm, 50 nm and 100 nm diameter cylindrical (solid) / ellipsoidal (dashed) nickel MNW

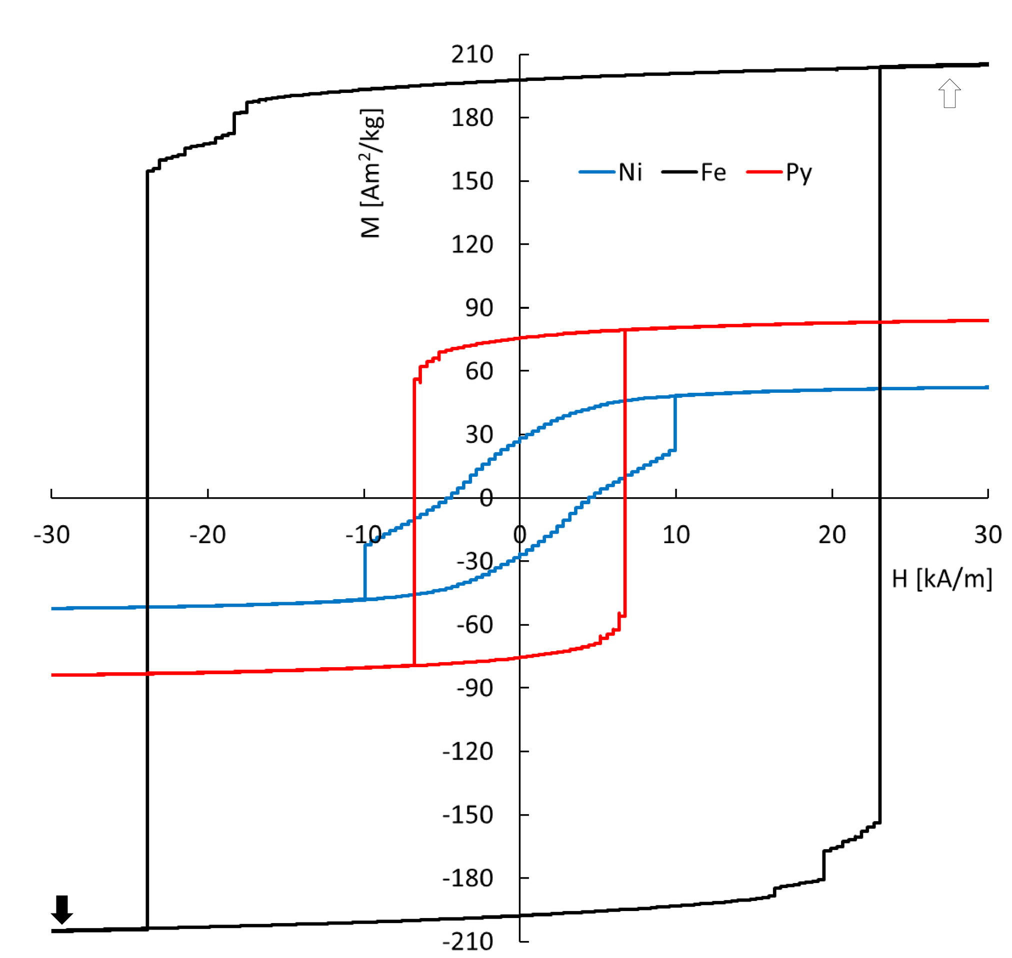


Hysteresis loops of 200 nm cylindrical (solid) / ellipsoidal (dashed) nickel MNW

Direction of magnetic moments during the reversal of 200 nm Ni cylindrical MNW causing a wasp-waisted M_z hysteresis loop



Isolated MNWs with different materials



Heating potential of isolated MNW made with different materials based on the area of hysteresis loops

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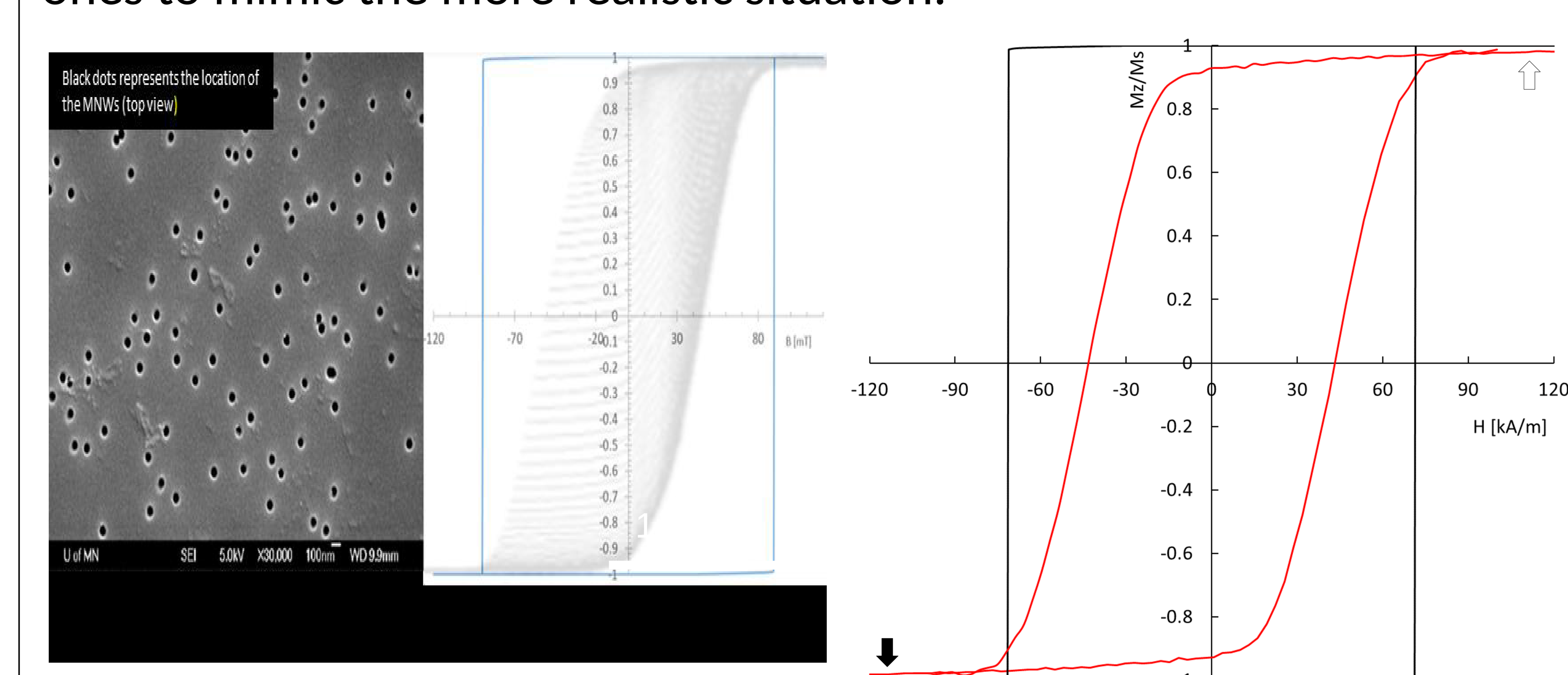
Discussion

- The coercivity (switching field) of isolated MNWs is negatively affected by the diameter of the MNW.
- Different reversal mechanisms were observed for isolated MNW with cylindrical and ellipsoidal shape. The switching of the magnetic moment started from the ends of the cylindrical MNWs and the center of the ellipsoidal MNWs.
- The wasp-waisted hysteresis of cylindrical MNWs (200 nm diameter):
  - explained by 3-step formation of the skyrmion lines during reversal;
  - 3D "hedgehog" is formed at the tip of the skyrmion lines at the center of the MNW. This appears to be a stable state at applied field H = ±5mT.
- Among the materials in this study, Fe MNW exhibited the most promising heating properties. It has the largest area hystersis loop and the required external field to fully switch each MNW is also within the range available in alternating magnetic field (AMF) coils (~±23 kA/m).

Future Directions

1. Different sizes of isolated MNW with different materials will be further simulated to complete the comparison.

2. Arrays of randomly distributed MNWs will be used instead of the isolated ones to mimic the more realistic situation.



The comparison on the right shows the discrepancy between the hysteresis loops of an isolated MNW (black) and a randomly distributed MNW array (red), SEM of which is shown on the left.[1]

Acknowledgements

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References

1. Kouhpanji, Mohammad Reza Zamani, et al. "Facile decoding of quantitative signatures from magnetic nanowire arrays." Scientific reports 10.1 (2020): 1-9.