NSF-NRI (#1637535): Design of nanorobotics based on FePd alloy nanohelices for a new diagnosis and treatment of cancer

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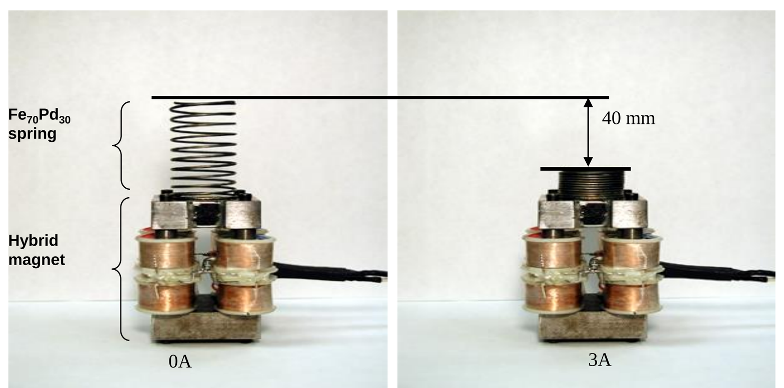
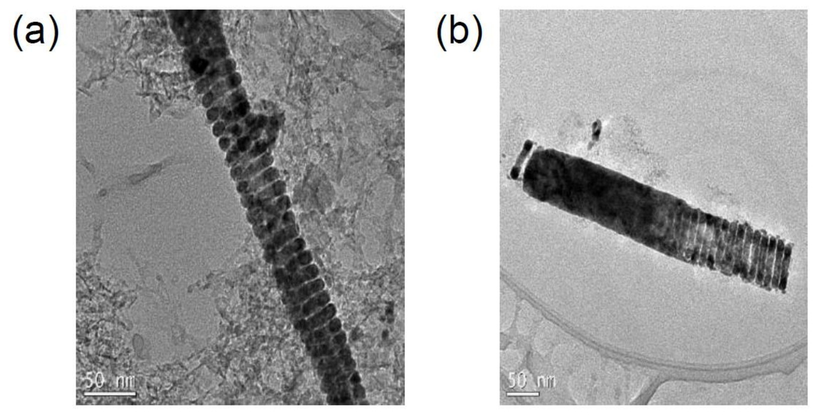
UW FePd Nanorobots
Downsizing the macroscopic FePd spring to FePd nanohelix



Wada, T. and Taya, M. (2002)

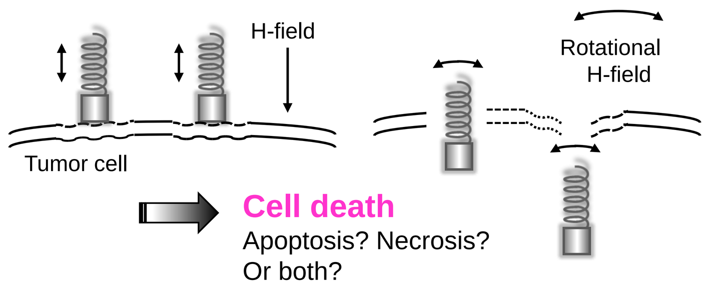


Xu, C. and Taya, M. (2015)

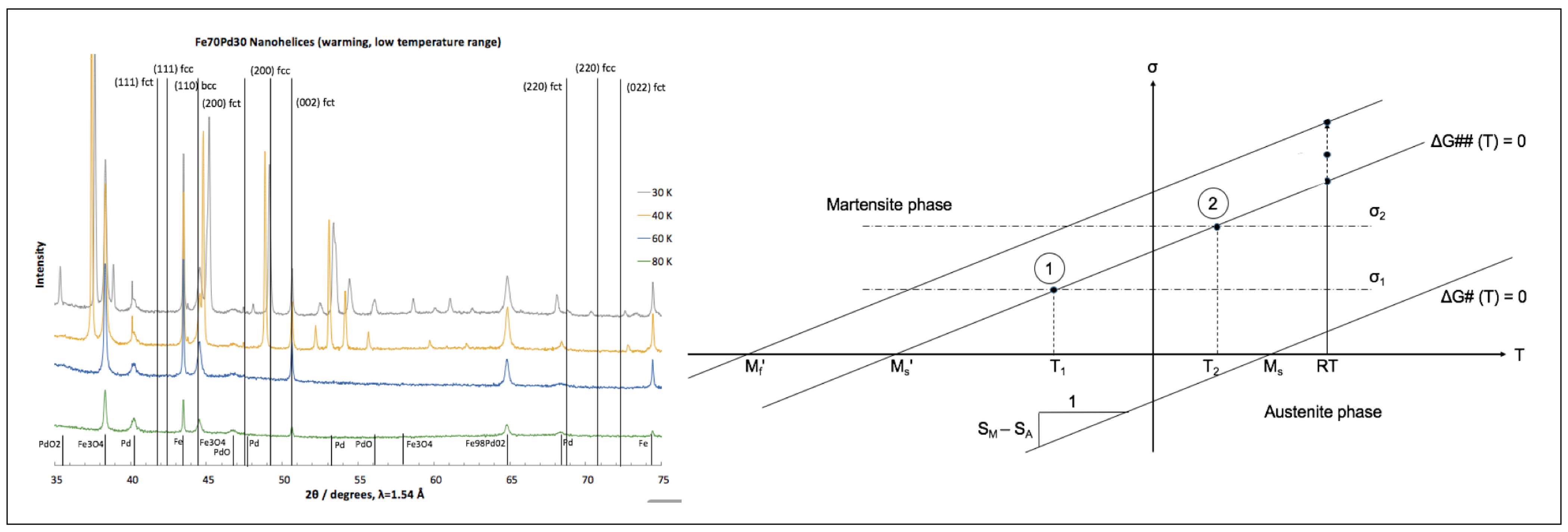
Advantages:
(1) Felxible helix, thus, can shrink and expand
(2) Swimming under rotational magnetic field thanks to the helical shape
(3) MRI enhancer due to large magnetization of FePd (120 emu/g)
(4) Biocompatible material

Two designs: (a) Helix only
(b) Head and helix (tail)

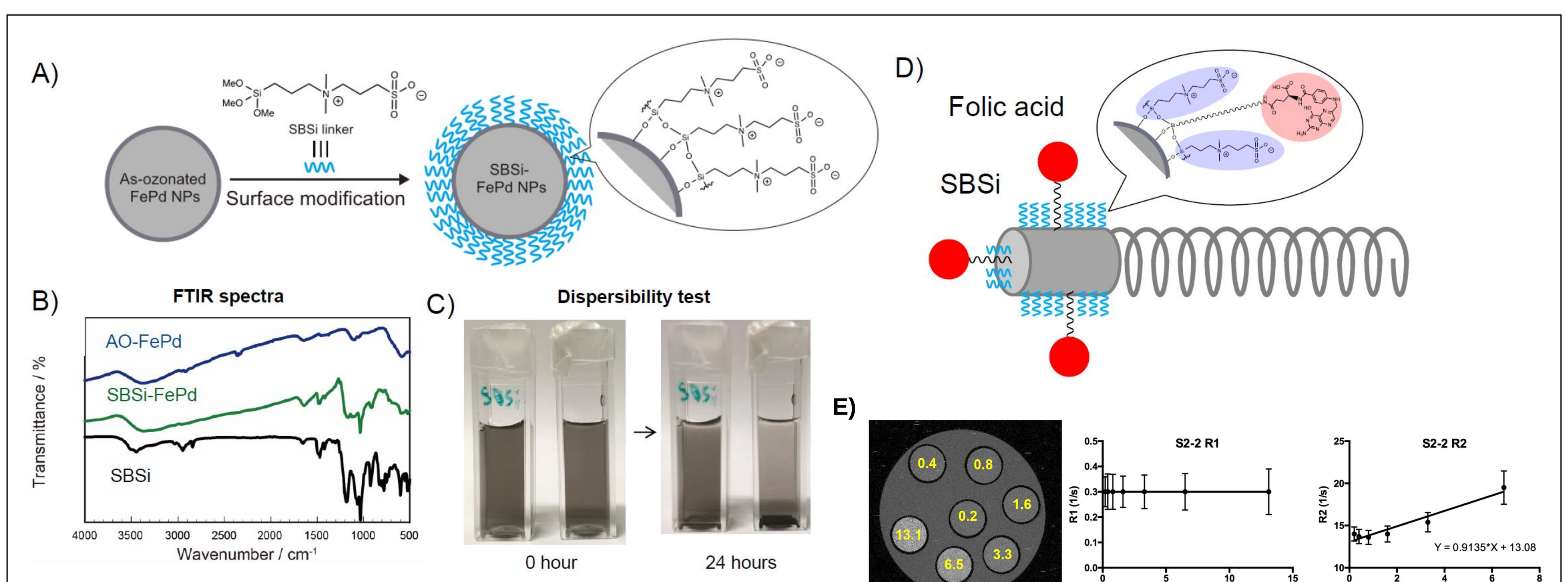
We aim to develop a new diagnostic method and treatment based on flexible nanohelix actuators made of FePd.



Austenite to martensite phase change of of FePd nanohelix under decreasing temperature and increasing stress

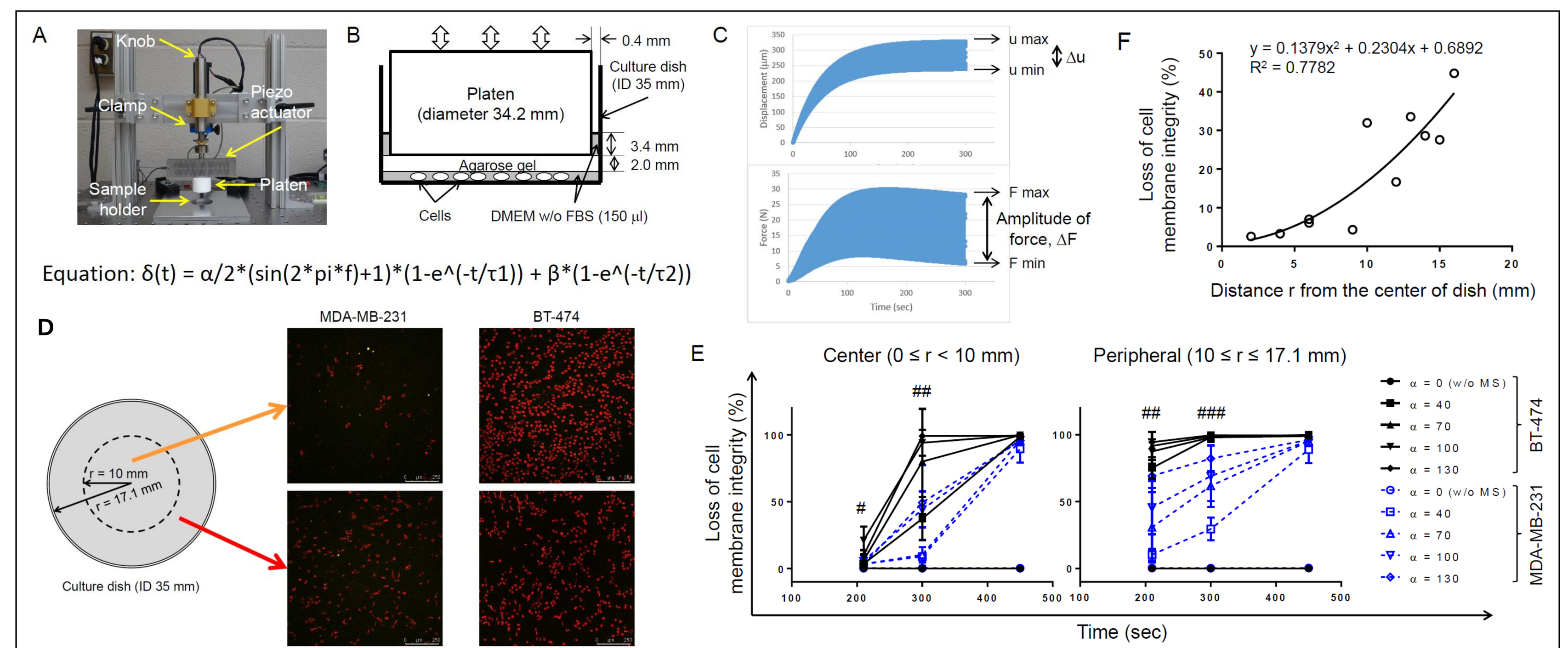


Evaluation of FePd naparticles and/or nanorobots



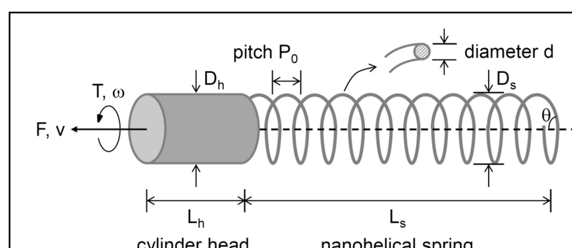
A) Illustration of the surface modification of FePd by Zwitterionic linker (SBSi) .
B) FT-IR indicated that SBSi linker can absorb on the surface of as-ozonated FePd NPs.
C) The dispersion test showed the dispersibility of FePd was improved by the surface modification with the SBSi linker.
D) Illustration of the surface modification of FePd by SBSi and Folic acid, which is targeting cancer cells without specific cancer marker, such as triple negative breast cancer.
E) T2-weighted images containing different iron concentrations in μg/ml (left) and R1 (middle) and R2 (right) as a function of iron concentration.

Mechanical stress-induced cell death (MSICD) in breast cancer cells



A, Mechanical stress loading device; **B**, Experimental setup for sample holder with cells; **C**, An equation integrated to the LabVIEW program, and a typical displacement loading-time curve (upper) and the resulted force-time curve (lower); **D**, MSICD in two regions; **E**, Necrosis-based MSICD in BT-474 cells (black) and MDA-MB-231 cells (blue), located in central (left) and peripheral (right) regions. Data shown in mean ± SD (n = 3). #, $p < 0.05$ for $\alpha = 40$; ##, $p < 0.01$ for $\alpha = 40, 70, 100, 130$; ###, $p < 0.01$ for $\alpha = 40, 70, 130$; **F**, Correlation between radius (r) of culture dish and the rate of necrosis in MDA-MB-231 treated for 300 sec with 40 μm displacement loading. DMEM, Dulbecco's modified Eagle's medium; FBS, fetal bovine serum.

FePd swimming model based on current 3D Helmholtz coil design



Dimension definition of a NR which is determined from TEM image.

$$\begin{pmatrix} F \\ T \end{pmatrix} = \begin{bmatrix} a + D_v & b \\ b & c + D_\omega \end{bmatrix} \begin{pmatrix} v \\ \omega \end{pmatrix}$$

In all cases, there are several physical properties and dimensions are kept similar such as:

1. Blood as Fluid viscosity, $\eta = 0.0035\ [Pa.s]$
2. Density of $Fe_{70}Pd_{30}$ as $\rho_{FePd} = 9.12 \frac{g}{cm^3}$
3. Helical Angle as defined in figure (1) $\theta = 82.6^\circ$
4. Since Helical Angle used is the same, the number of helical coil is dictated by Ls and Ds dimensions as shown in equation (a).
5. Comparison of swimming velocity of NRs and Swim time of NRs for different cases are done based on similar EM driving condition assumed for all cases which are:
   - $f = 50Hz$ rotational EM field, $l = 2cm$ swimming length,
   - $14mT$ rotational maximum magnetic field density and
   - $0.2\ T/m$ magnetic field density gradient.

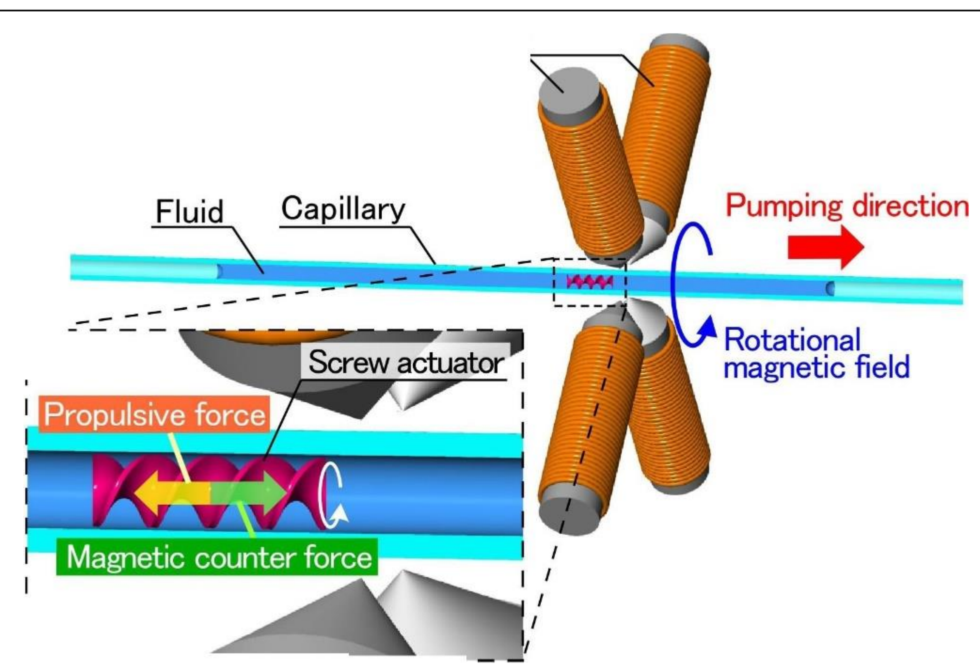
Table (1): Table of comparison for effects of different dimensions of the NRs on the velocity of swim time of NRs under the same electromagnet driving conditions.

Case	D_h (nm)	$L_h (nm)$	D_s (nm)	$d = 2r$(nm)	L_s (nm)	n	Velocity (mm/s)	Swim Time (Hours)	k_{mart} (N/m)	k_{aust} (N/m)
0	60	200	60	10	250	16	0.000525	12.7	0.00392	0.01305
1	60	200	200	20	1000	19	0.00161	3.46	0.00141	0.00470
2	60	200	1000	50	20000	76	0.0086	0.65	0.00011	0.000367
3	200	600	200	20	1000	19	0.00157	3.53	0.00141	0.00470
4	1000	3000	1000	50	20000	76	0.00854	0.65	0.00011	0.000367
5	1000	3000	2000	50	10000	19	0.018	0.32	0.000055	0.000184
6	1000	3000	1000	50	10000	38	0.0085	0.65	0.00022	0.000734

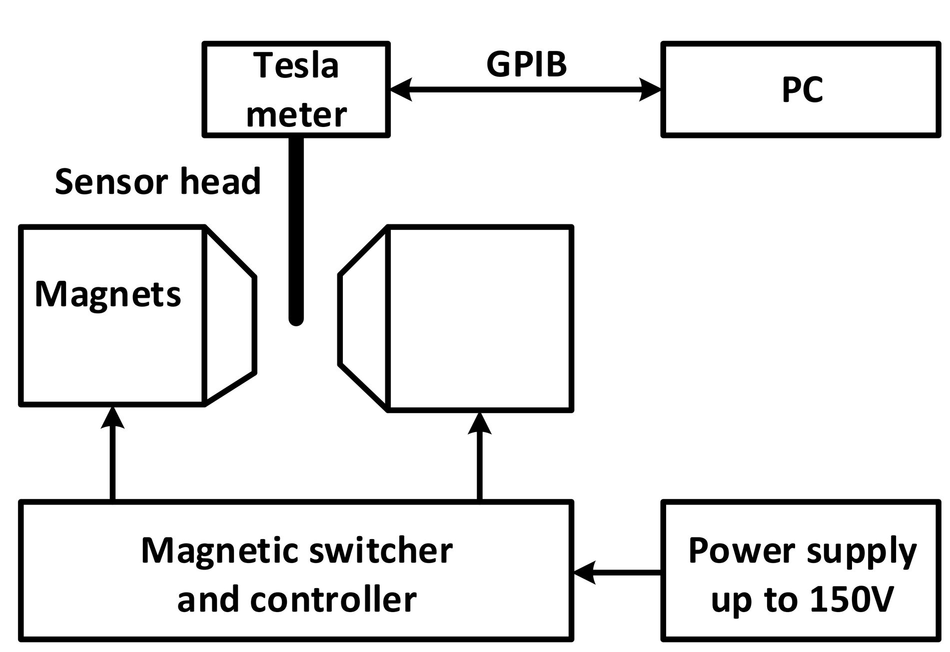
We used the following equation to predict the effective stiffness, k of the nanohelix along its symmetric axis.

$$k = \frac{d^4 G}{8 D_s^3 n}$$

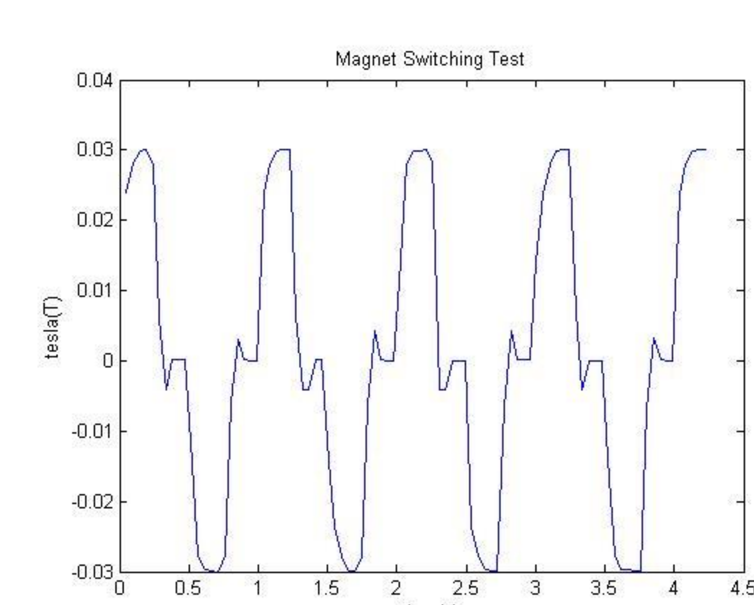
Design of bi-directional magnet switching circuit



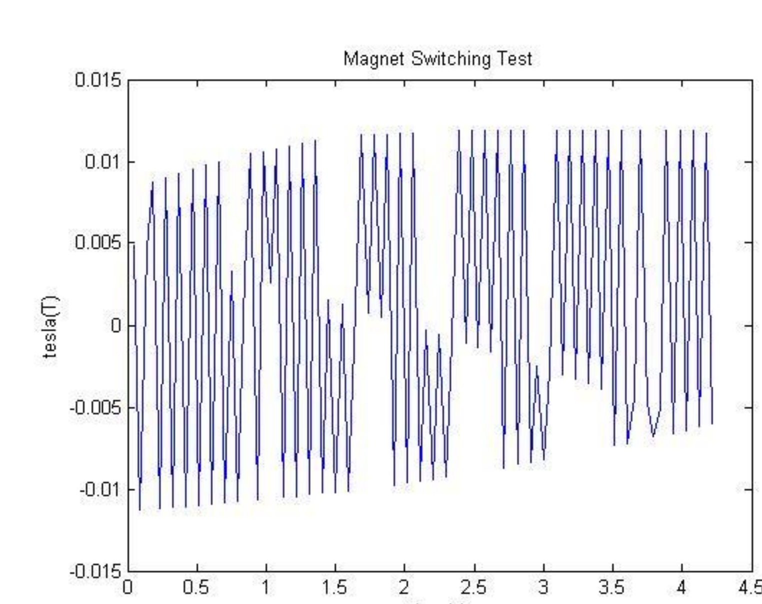
Conceptual diagram
Adapted from Kobayashi, K. and Ikuta, K. (2009)



Setup for testing



Response: 1 Hz



Response: 10 Hz

Acknowledgements

- NSF-NRI (Project #: 1637535)
- Nabtesco
- UW Center for Intelligent Materials and Systems (CIMS)
- UW Molecular Analysis Facility (MAF)
- UW Washington Nanofabrication Facility (WNF)

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