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

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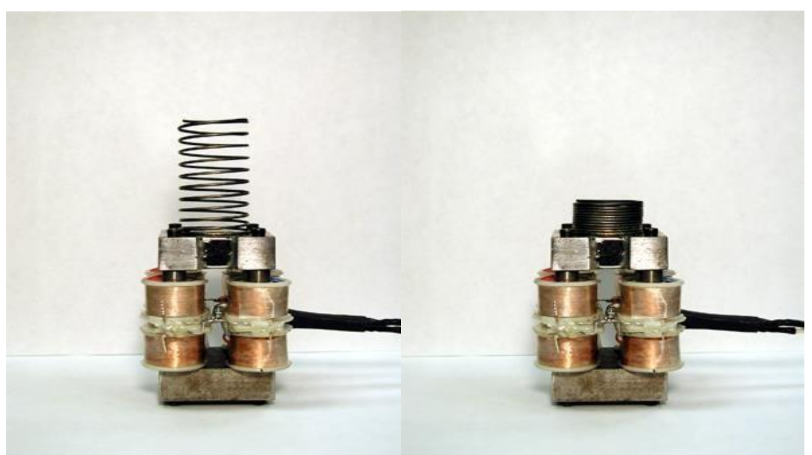
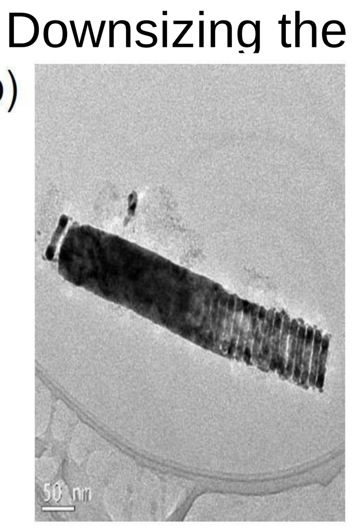
UW FePd Nanorobots: Downsizing the macroscopic FePd spring to FePd nanohelix



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

(a)

(b)



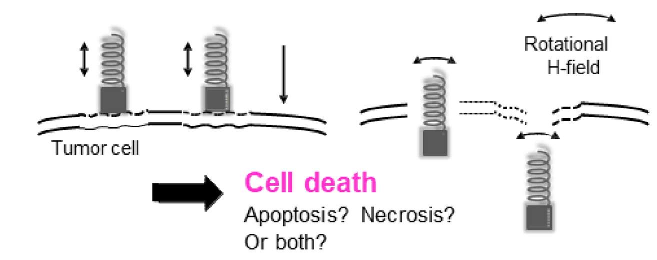
Xu, C. and Taya, M. (2015)

Advantages

(1) Flexible helix, thus, can shrink and expand to apply oscillating forces
(2) Swims under rotational magnetic field thanks to nanohelical propeller
(3) MRI enhancer due to large magnetization of FePd (120 emu/g)
(4) Biocompatible material

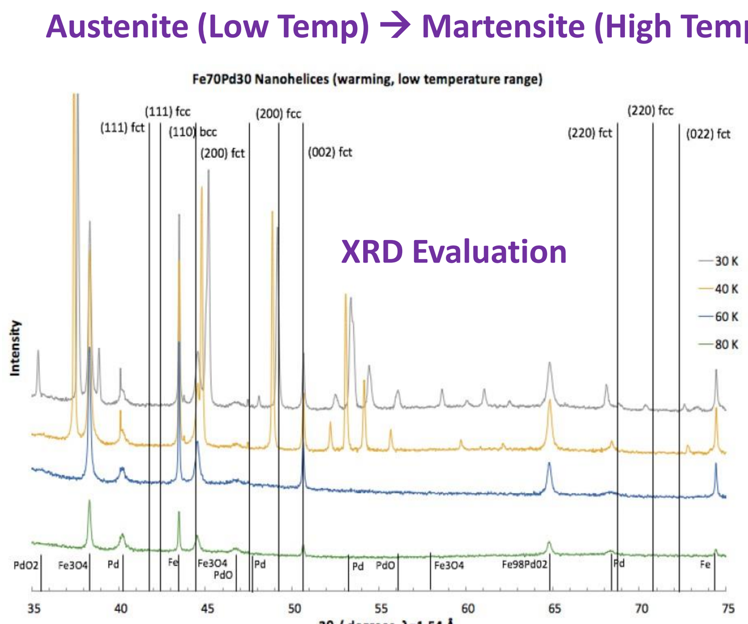
Two designs
(a) Helix only
(b) Head and helix (tail)

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

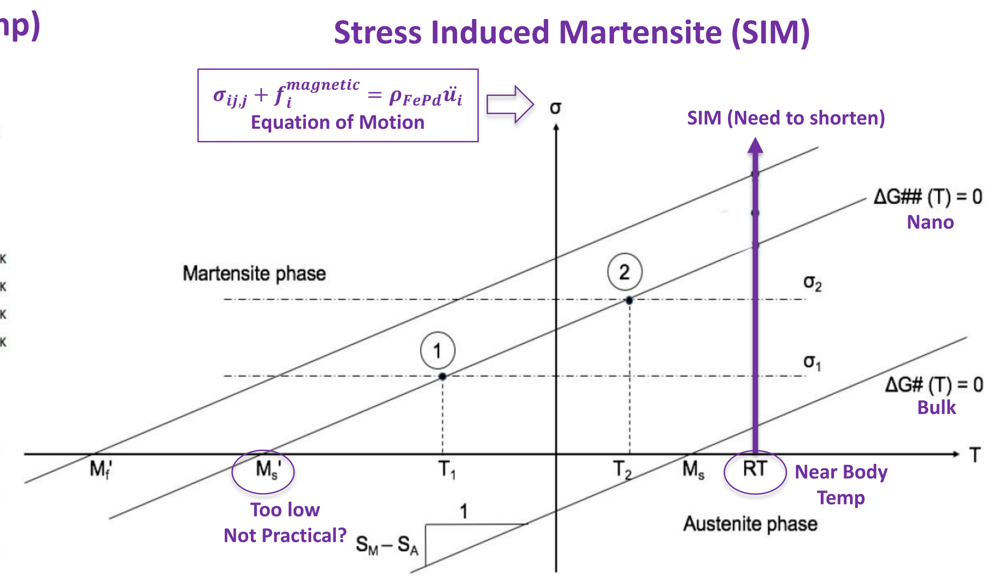


Actuation mechanism of FePd nanohelix and the optimization challenges

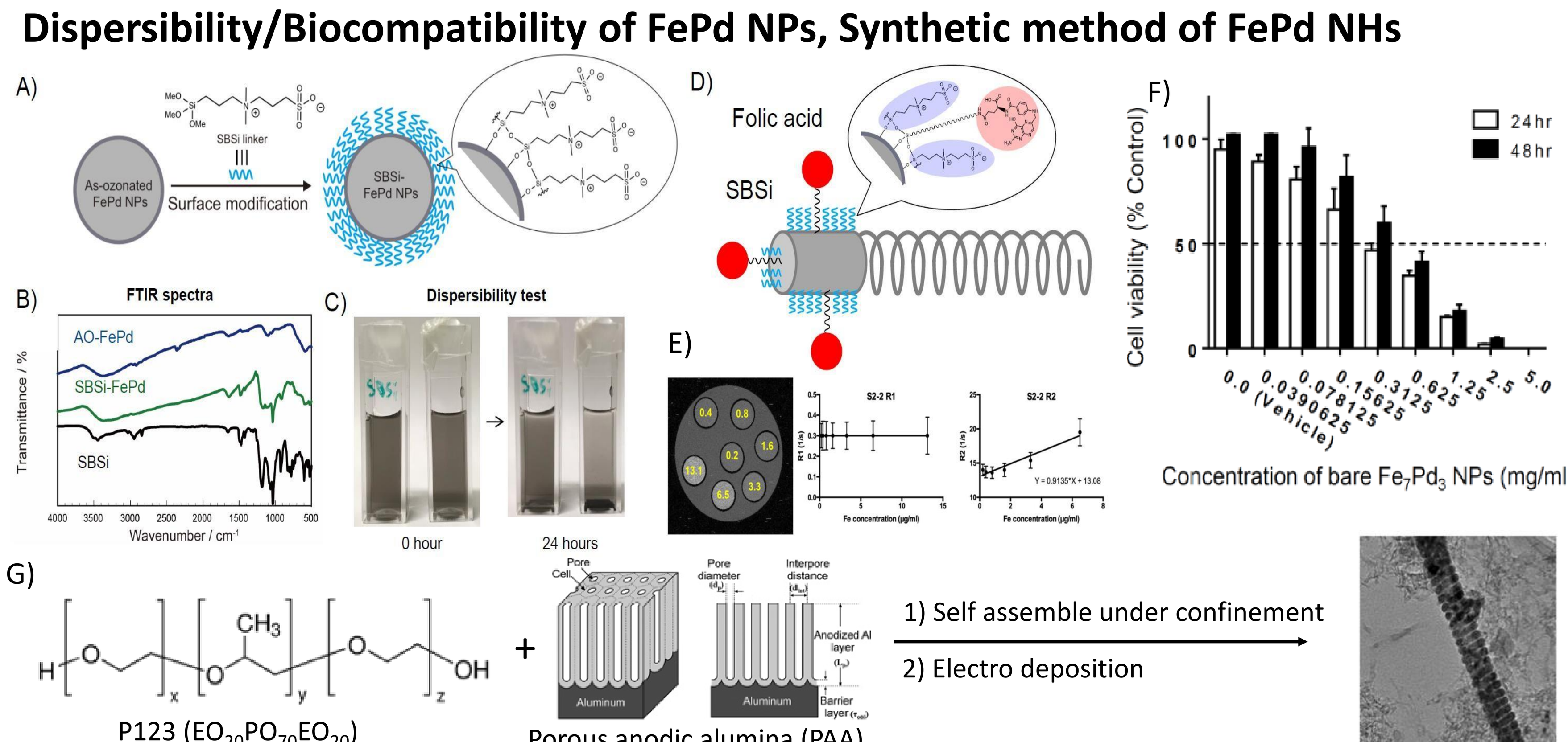
Austenite (Low Temp) → Martensite (High Temp)



Stress Induced Martensite (SIM)



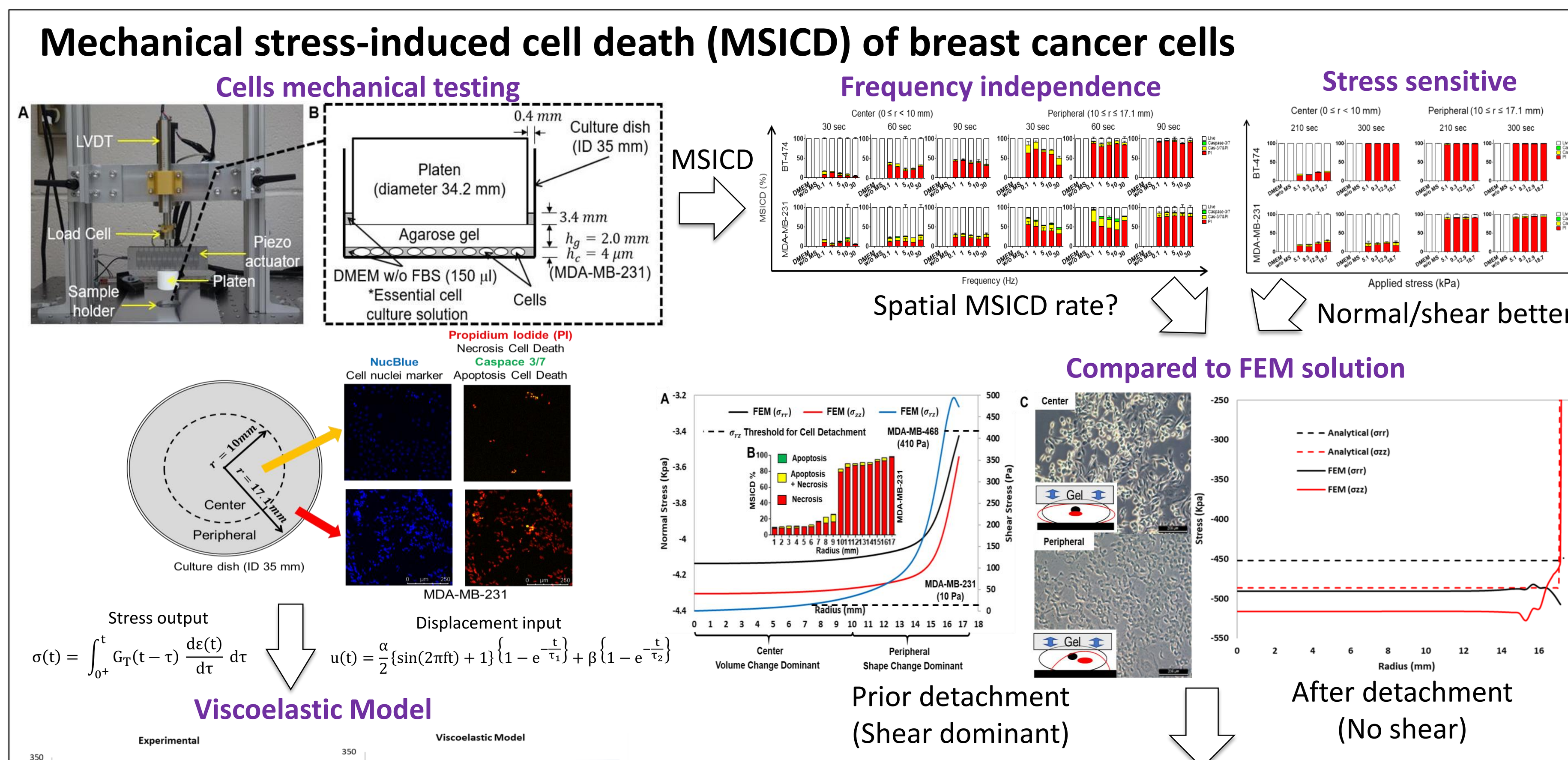
Dispersibility/Biocompatibility of FePd NPs, Synthetic method of FePd NHs

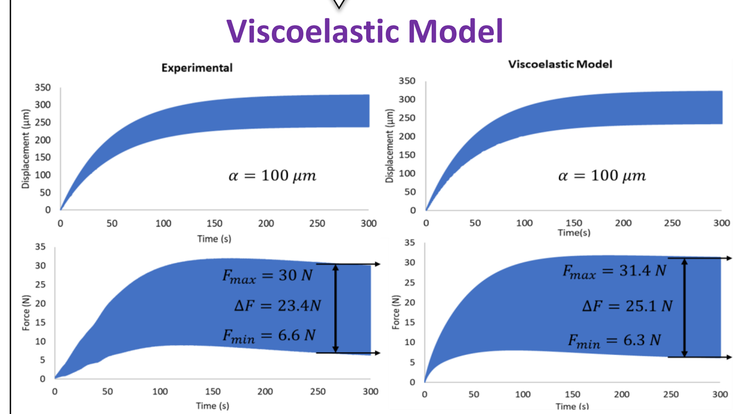


A)Illustration of the surface modification of FePd by Zwitterionic linker (SBSi) .
B)FT-IR indicated that SBSi linker can absorb on the surface of as-ozonated FePd NPs.
C)The dispersion test showed the dispersibility of FePd was improved by the surface modification with the SBSi linker.
D)Illustration 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 [illegible]g/ml (left) and R1 (middle) and R2 (right) as a function of iron concentration.
F) the Fe7Pd3 nanoparticles gave a lower biocompatibility in higher concentrations but this may be due to the bare state of nanoparticles that they could not maintain the dispersed condition during the culture and those "heavy" nanoparticles accumulated on cells
G) Synthetic method of FePd NHs using P123 and PAA template

References:
S. Yamamoto, S. Takao, S. Muraishi, C.Xu, M. Taya, "Synthesis of $Fe_{70}Pd_{30}$ Nanoparticle and its Surface Modification by Zwitterionic linker. *Materials Chemistry and Physics*, **2019**, 234, 237-244.

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





Control

Apoptosis/ Necrosis MSICD mode

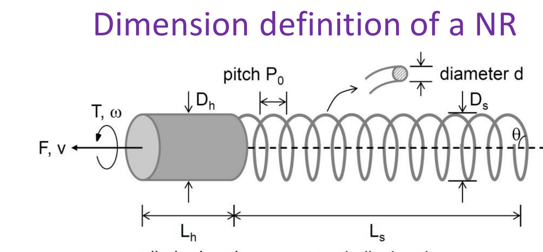
Dynamic > Quasi static stress

Study	MSICD Mode	MSICD% vs Equivalent Stress (σ_{eq})	
Viscoelastic Model	DS (Analytical)	$\sigma_{eq}(t) < \sigma^{ap}$ $(t < 100s)$	$\sigma_{eq}(t) > \sigma^{ap}$ $(210 < t < 300s)$
Takao et al., (2019)	DS (Experiment)	≅10% apoptosis, $< 75\%$ necrosis $(t < 100s)$	$< 1\%$ apoptosis, $< 90\%$ necrosis $(210 < t < 300s)$
Tse. J.M., (2011) σ^{ap} (0.773Kpa)	QS (Experiment)	No apoptosis reported (16Hrs)	Apoptosis reported (16Hrs)

References:
1. Takao, S., Taya. M., Chiew. C., (2019). Mechanical stress-induced cell death in breast cancer cells, Biology Open, bio043133 doi.10.1242/bio.043133
2. Chiew. C., Taya. M., Takao. S., (2020). Viscoelastic model to predict mechanical behavior of layered agarose gel and cancer cells under dynamic stress for the study of mechanical stress-induced cell death. (Drafted).
3. Tse, J.M., Cheng, G., Tyrrell, J.A., Wilcox-Adelman, S.A., Boucher, Y., Jain, R.K., Munn, L.L., 2011. Mechanical compression drives cancer cells toward invasive phenotype, PNAS, doi.10. 1073/pnas.1118910109/-/DCSupplemental.

Navigating and Propelling FePd NRs (Gradient vs Rotational)

Dimension definition of a NR



NR Dimension Definitions

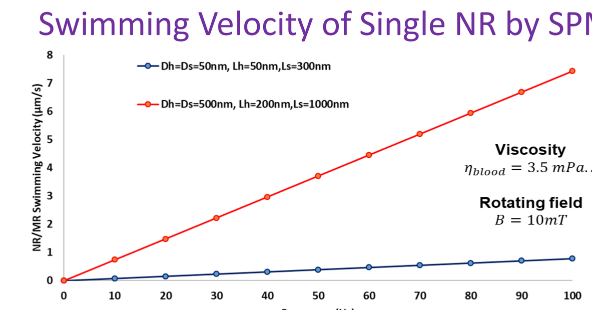
- D_h, FePd Head Diameter (50nm)
- D_s, FePd Helical Tail Diameter (50nm)
- L_h, FePd Head Length
- L_s, FePd Helix Tail Length(200~300 nm)
- θ, Chirality of Helix Tail (1.44rad)
- v, NR Translational Velocity
- V, Cylindrical Volume of FePd Head
- T, NR Torque
- ω, NR Angular Velocity
- α, β, γ; SPM Factors depend on Geometry and viscosity, η of environment (Abbott et al., 2009)

Symmetric Propulsion Matrix

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

Reference:
Abbott et al. (2009). How Should Microrobots Swim? *The International Journal of Robotics Research*, *28*(11–12), 1434–1447.

Swimming Velocity of Single NR by SPM



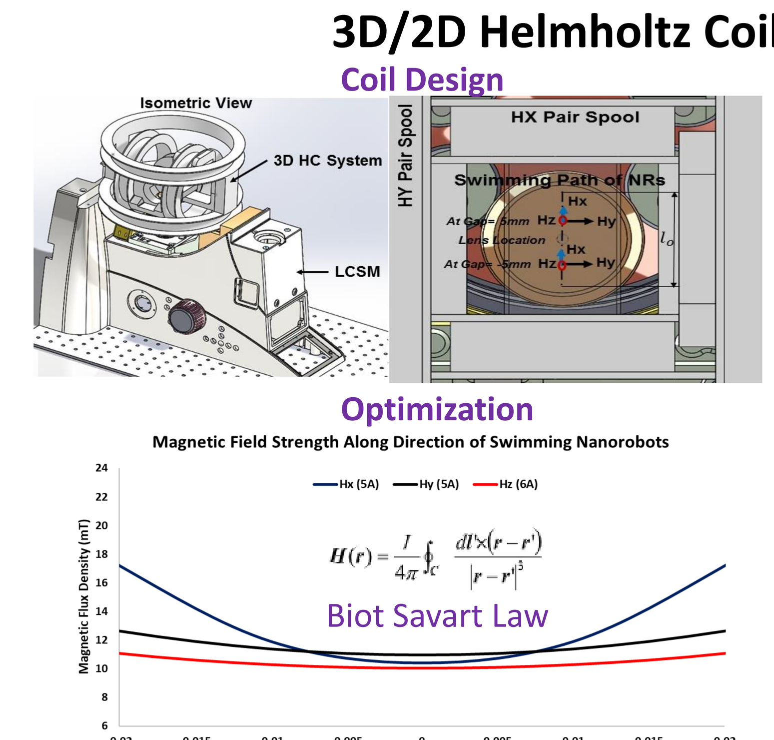
Swimming Velocity vs Rotational Field Frequency

Propulsion of single NR only by Gradient Field $\nabla B = 0.5\frac{T}{m}$

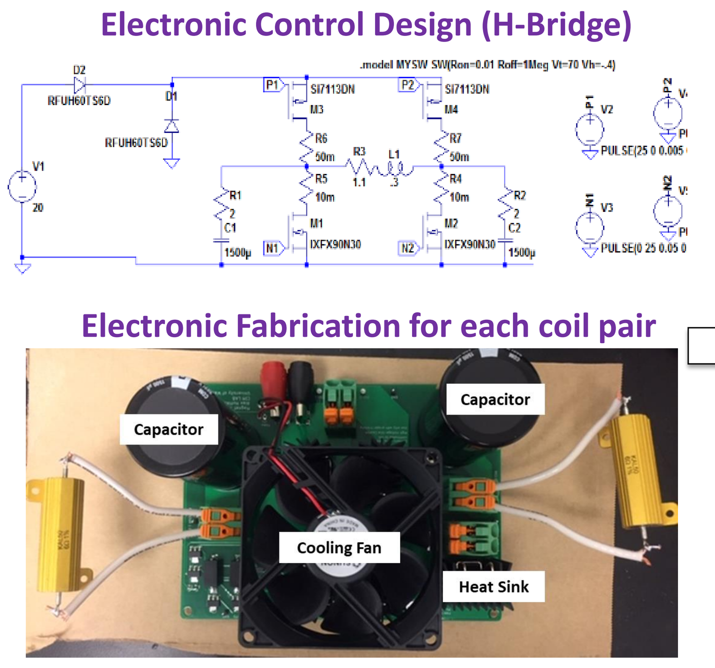
NR: $v = 0.0009\frac{\mu m}{s}$
MR: $v = 0.10\frac{\mu m}{s}$

3D/2D Helmholtz Coil for FePd NRs propulsion

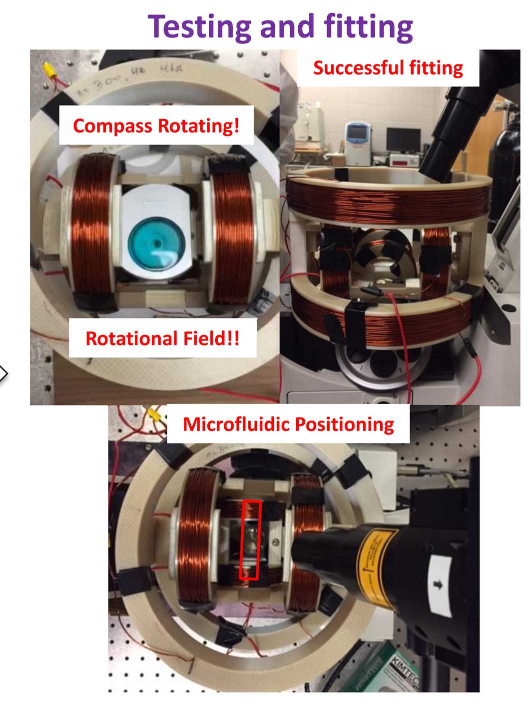
Coil Design



Electronic Control Design (H-Bridge)



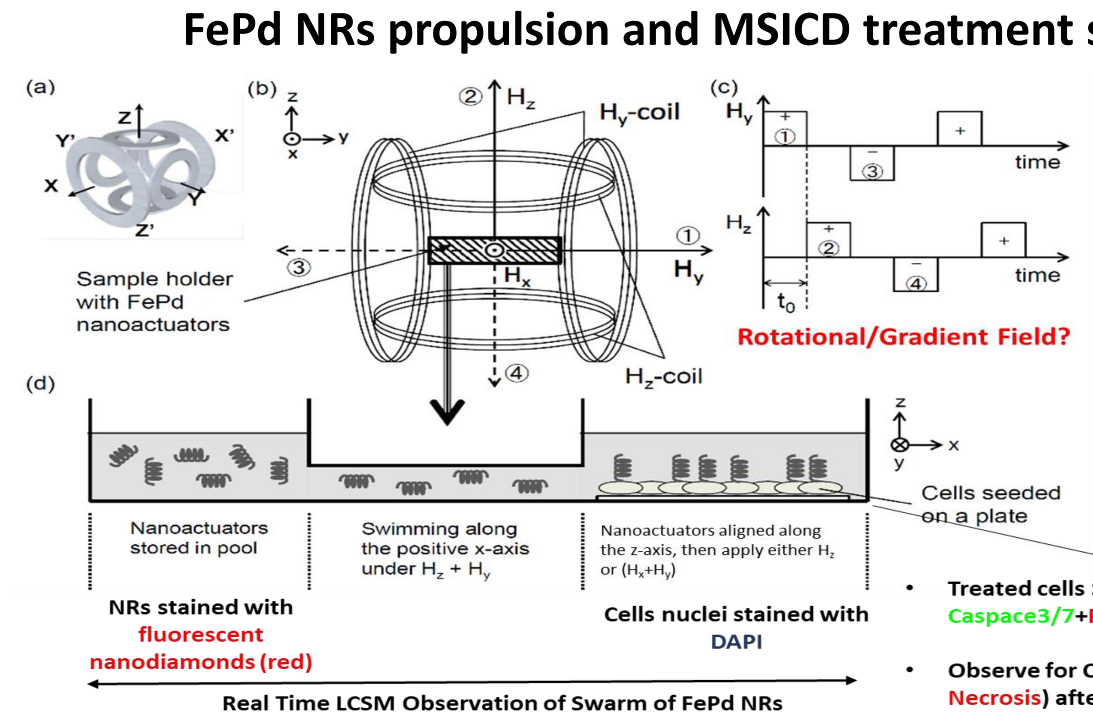
Testing and fitting



Near Future

In Vitro Testing

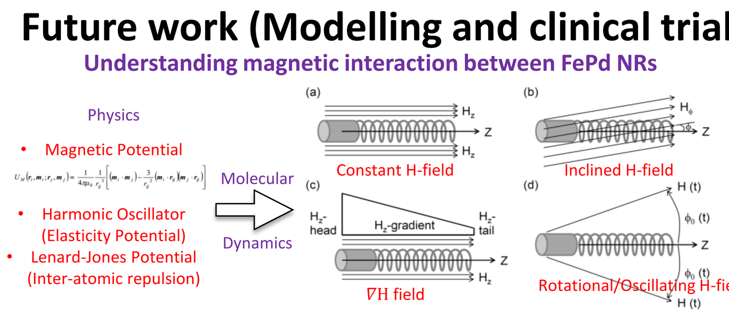
FePd NRs propulsion and MSICD treatment strategy



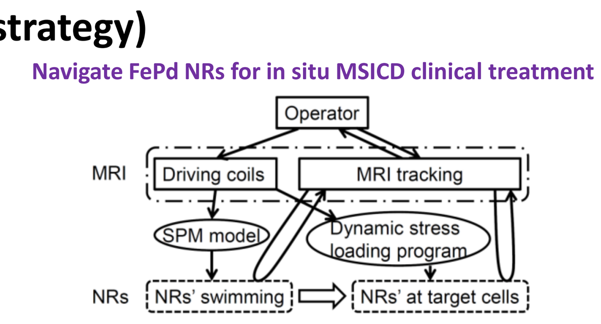
Propulsion Goal
Our 50~100 nm diameter FePd NRs are possibly small enough to navigate through narrow channel of Brain Blood Barrier (BBB)

Future work (Modelling and clinical trial strategy)

Understanding magnetic interaction between FePd NRs



Navigate FePd NRs for in situ MSICD clinical treatment



Potential Impact

New applications of FePd nano-herical structures.
Can be used for cancer treatment.

Acknowledgement

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