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

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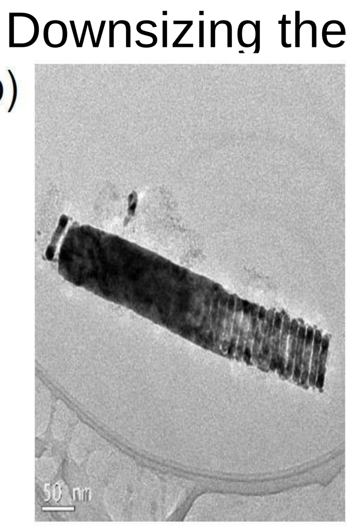
## UW FePd Nanorobots: Downsizing the macroscopic FePd spring to FePd nanohelix

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

(a)

(b)



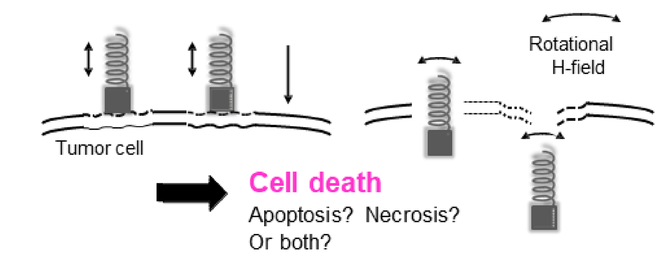
Xu, C. and Taya, M. (2015)

**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

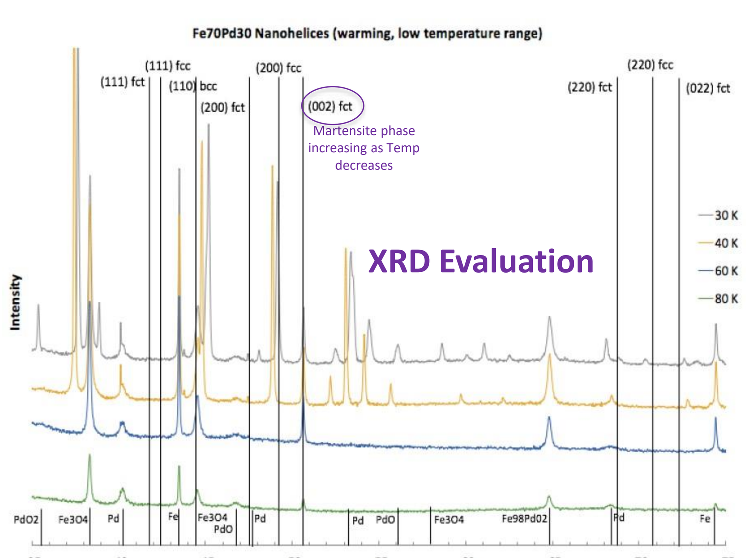
**Two designs**
(a) Helix only
(b) Head and helix (tail)

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

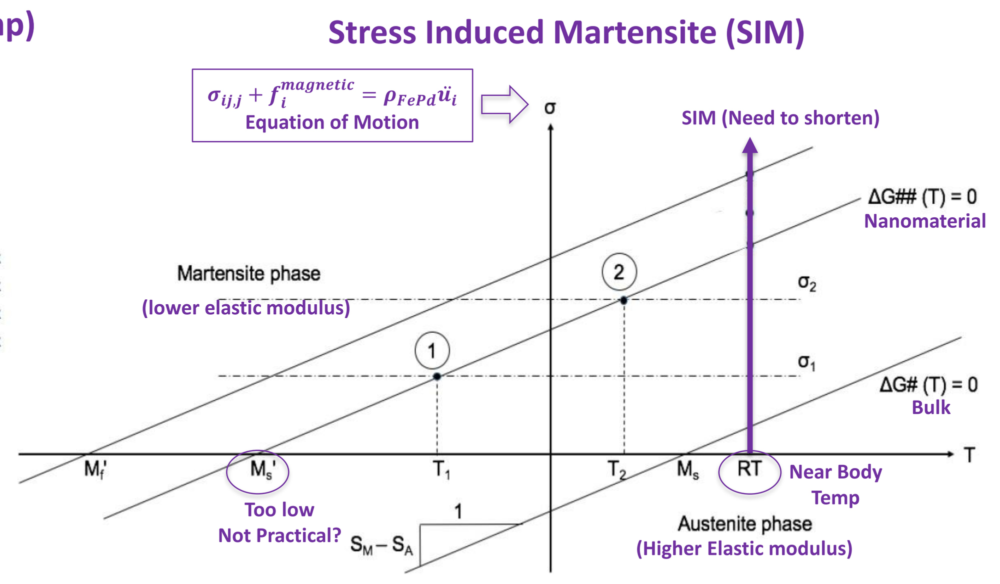



## Actuation mechanism of FePd nanohelix and the optimization challenges

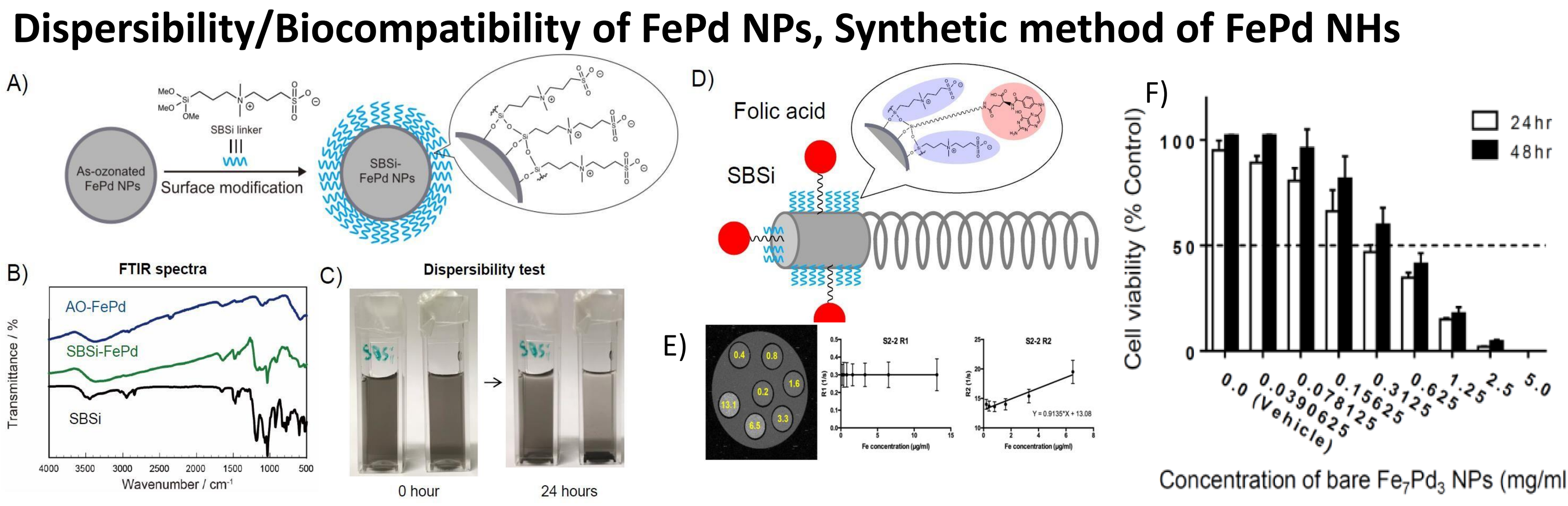
Austenite (Low Temp) → Martensite (High Temp)



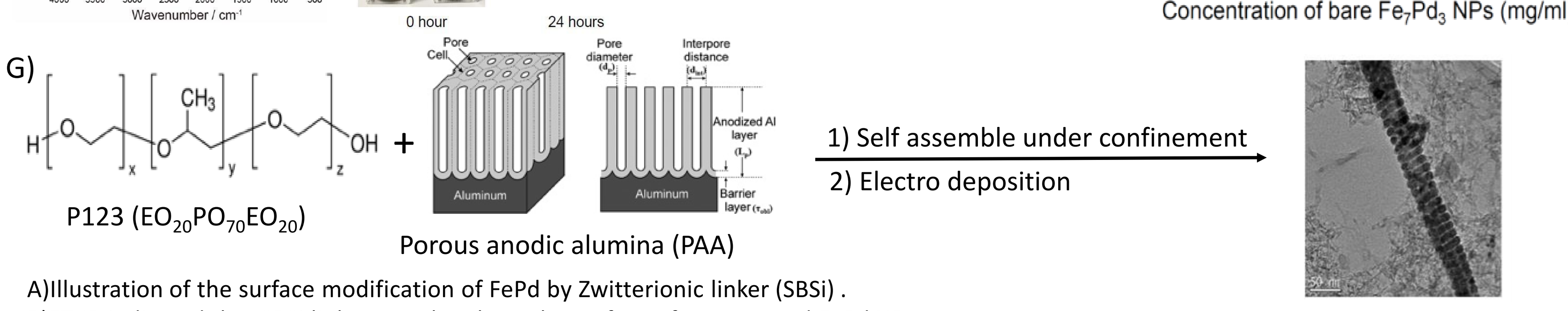

Stress Induced Martensite (SIM)




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



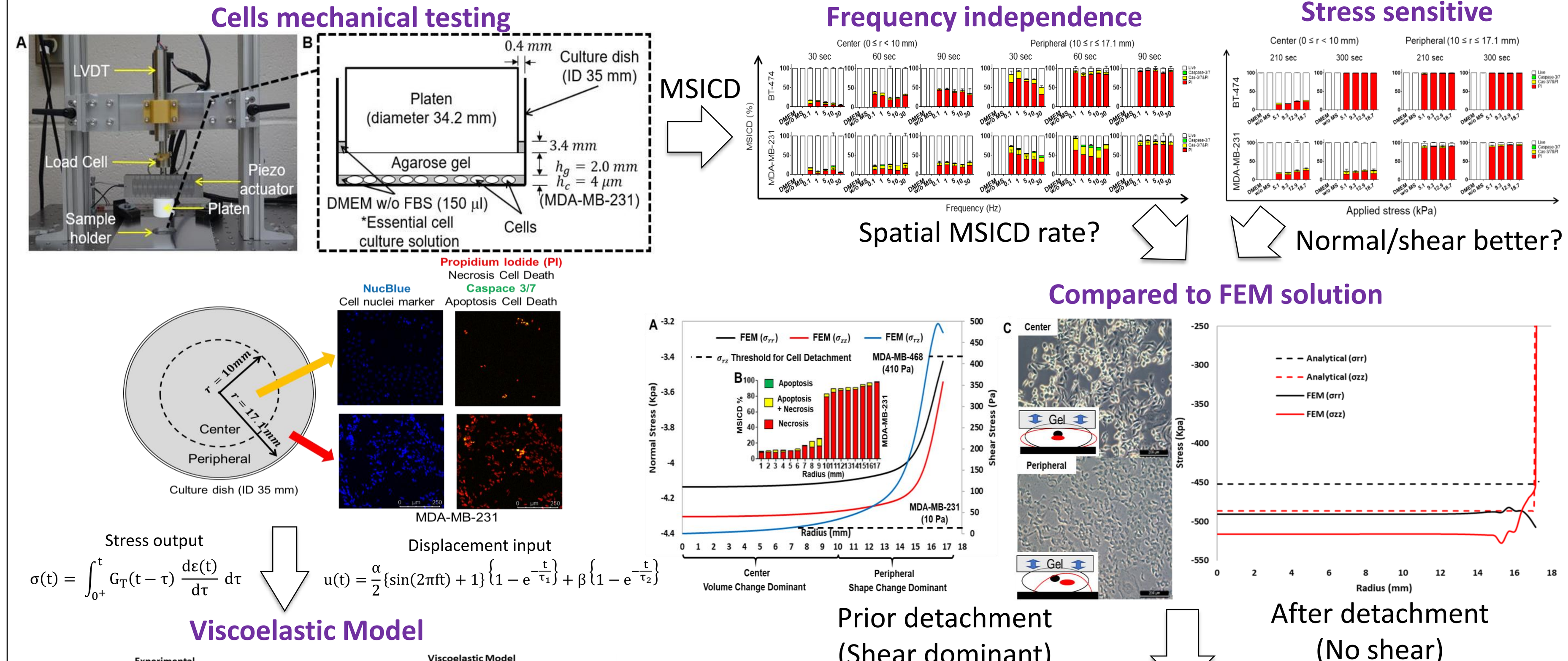

G)

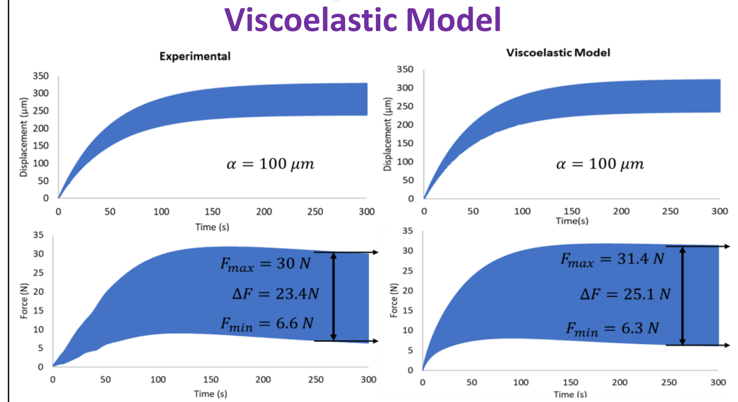



A)Illustration of the surface modification of FePd by Zwitterionic linker (SBSi) .
B)FT-IR indicated that SBSi linker can absorb on the surface of as-ozonated FePd NPs.
C)The dispersion test showed the dispersibility of FePd was improved by the surface modification with the SBSi linker.
D)Illustration 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 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

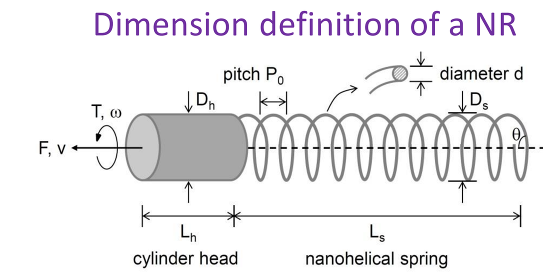
**Dynamic > Quasi static stress**

| Study | MSICD Mode | MSICD% vs Equivalent Stress ($\sigma_{eq}$) | |
|---|---|---|---|
| **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) $\sigma^{ap}$ (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/-/DCSupplementall.

## Navigating and Propelling FePd NRs (Gradient vs Rotational)

Dimension definition of a NR




Symmetric Propulsion Matrix

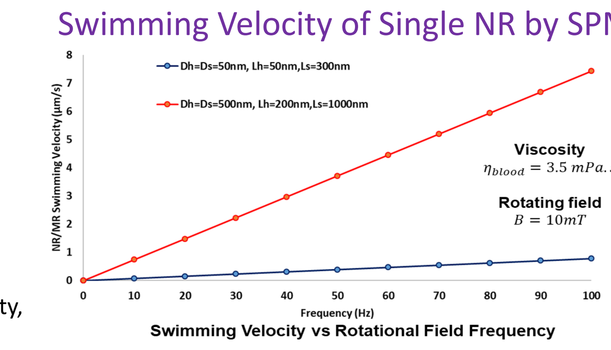
$$\begin{pmatrix} F \\ T \end{pmatrix} = \begin{bmatrix} \alpha + D_v & b \\ b & c + D_\omega \end{bmatrix} \begin{pmatrix} v \\ \omega \end{pmatrix}$$

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)
- $\theta$, Chirality of Helix Tail (1.44rad)
- $v$, NR Translational Velocity
- $V$, Cylindrical Volume of FePd Head
- $T$, NR Torque
- $\omega$, NR Angular Velocity
- $\alpha, \beta, \gamma$; SPM Factors depend on Geometry and viscosity, $\eta$ of environment (Abbott et al., 2009)

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

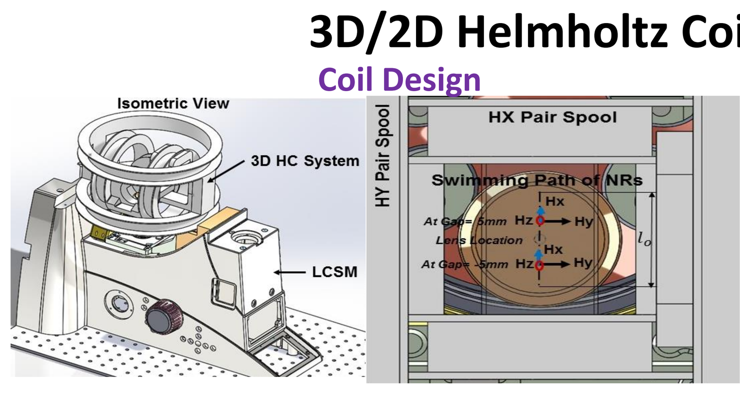
Propulsion of single NR only by Gradient Field $\nabla B = 0.5\frac{T}{m}$

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

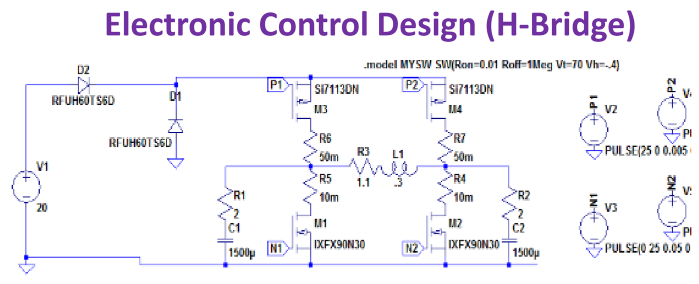
MR: $v = 0.10\frac{\mu m}{s}$

## 3D/2D Helmholtz Coil for FePd NRs propulsion

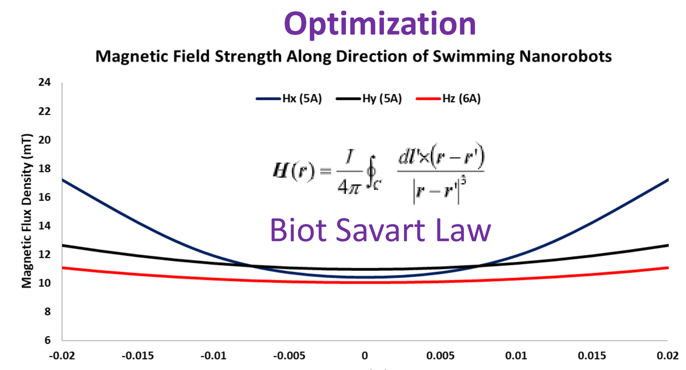
Coil Design



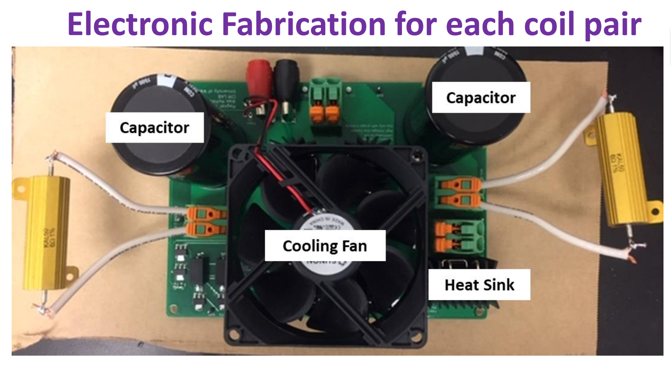

Electronic Control Design (H-Bridge)



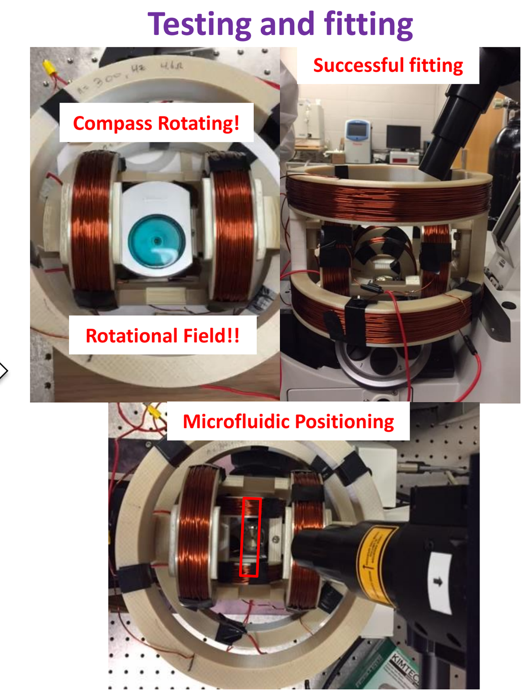
Optimization




Electronic Fabrication for each coil pair

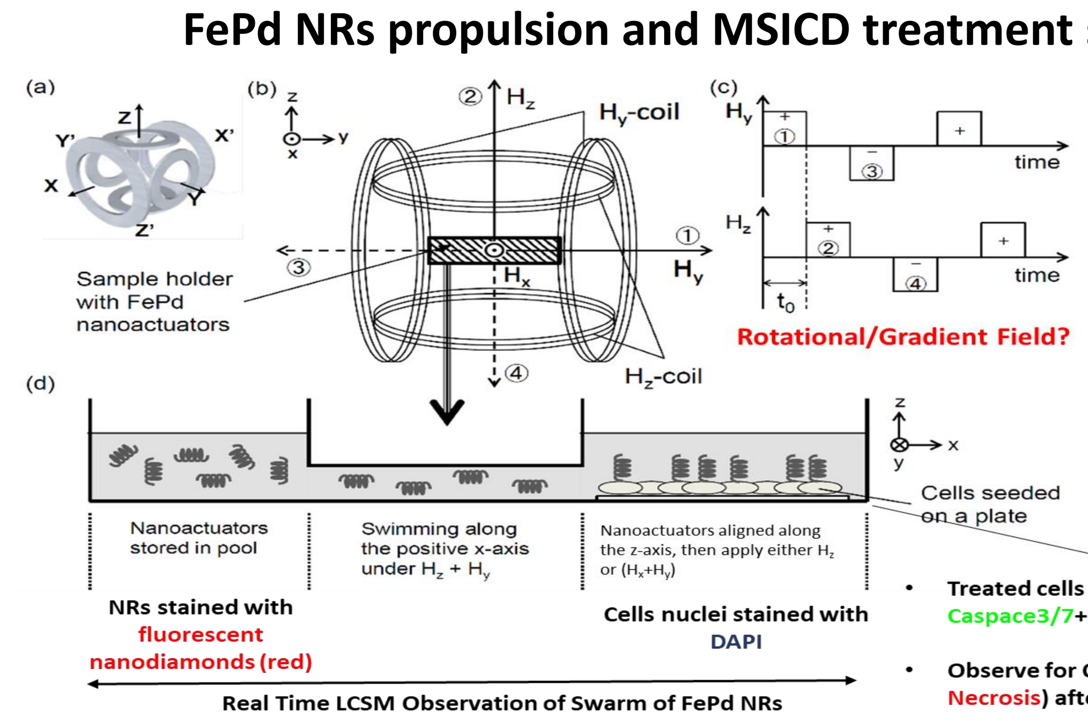



Testing and fitting



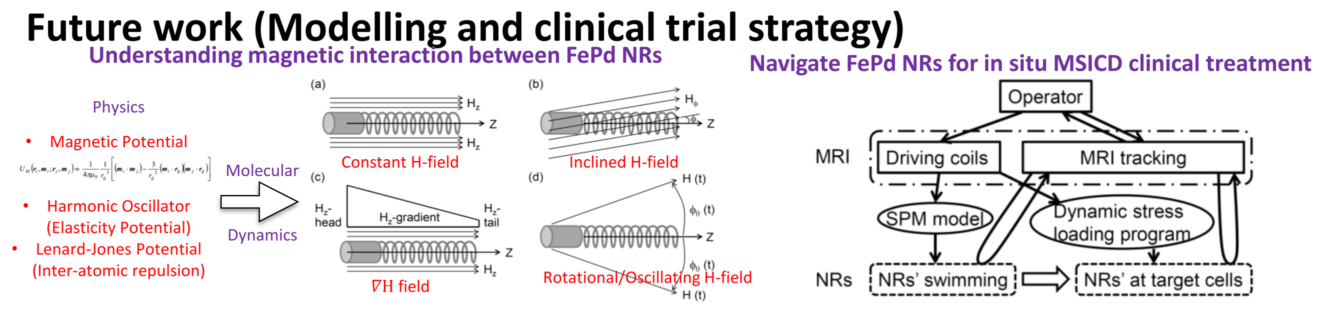

Near Future → In Vitro Testing

## 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)




## Potential impact and intellectual merits

- Cancer Marker+ Nanohelix propulsion of FePd NRs = High arrival rate→ Higher cancer treatment success by MSICD.
- Chemical free cancer treatment with minimum side effects.
- Can potentially pass the Blood Brain Barrier (BBB) with ease allowing access to hard to reach tumor in patient body.

## Acknowledgement

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