# Modeling, Design, and Fabrication of an Array of Planar Electromagnets to Actuate Micro-rafts

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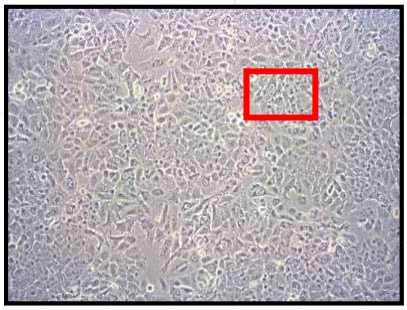
# MOTIVATION

## Taking a small step towards:

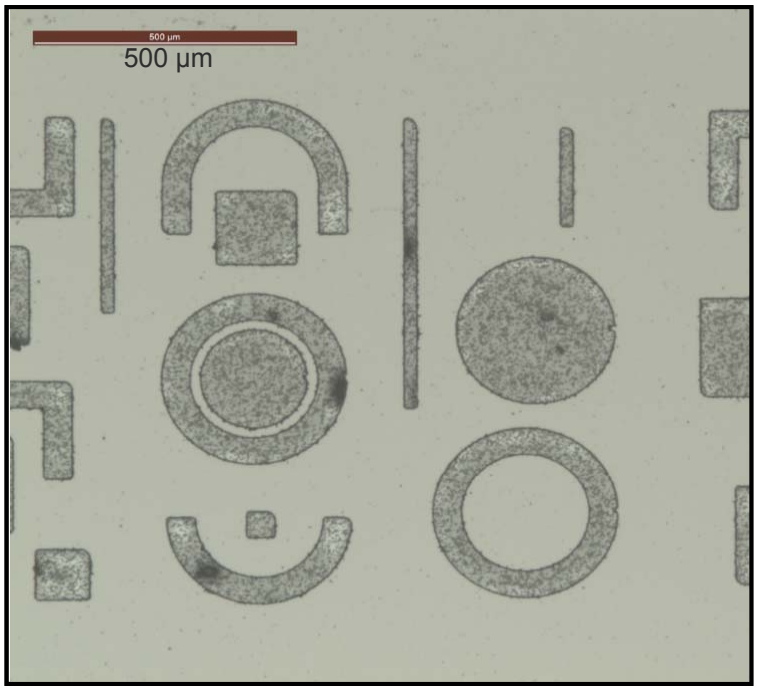
- Another way of cell isolation and sorting.
- Effective Cell Mechano-Biology experimentations.
- Cell surgery.



MCF-7 Cell Line

Image Taken from https://www.mybiosource.com/images/tds/

# INTRODUCTION




Fabricated by Mr. Sudhanshu Shekhar, M2D2 Lab.

## MICRO-RAFTS

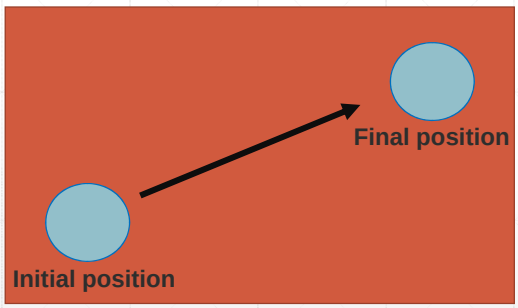
A microscopic image of fabricated Micro-Rafts

They are attached to the glass wafer

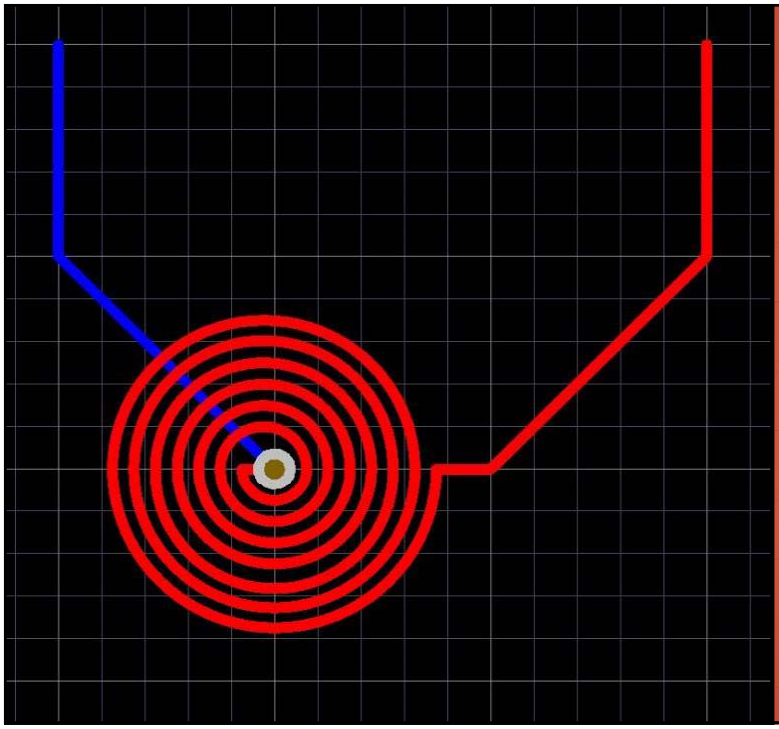
They are finally released when immersed in DI water

## Objective

- To design a mechanism to guide/navigate these fabricated micro-rafts in a controlled and useful way.



# METHOD



**Planar, current carrying micro-coil array**

Specifications:

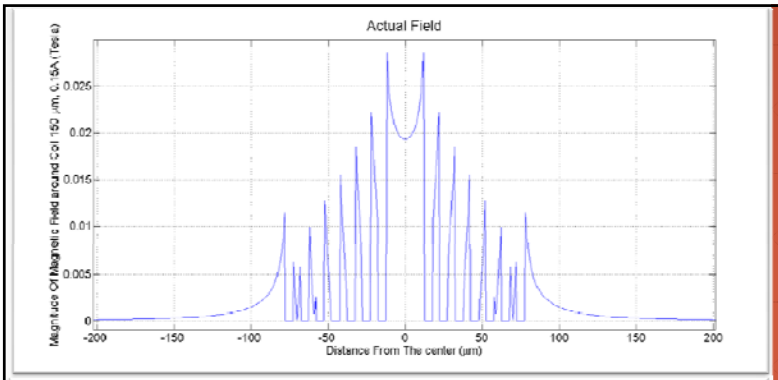
Outer Diameter:150 µm

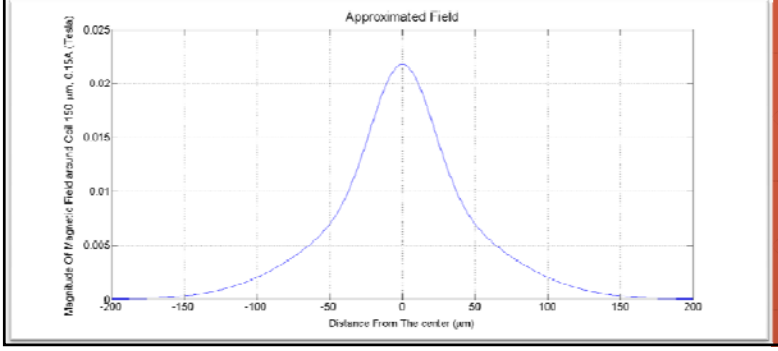
Width of the lines: 5 µm

Via hole diameter: 10 µm

Via outer diameter: 20 µm

Line spacing: 5 µm



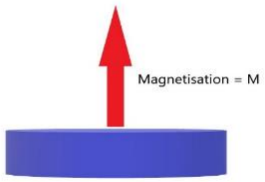

## Magnetic Field Around The coil

Current Supplied: 0.15A

Magnetic Field at Center: 19.26 mT

Field drop to 1mT at: 108.6 μm

## Forces acting on a "disk" shaped raft




**Electromagnetic Force produced by the coil.**

- $Magnetic\ Moment(\vec{m}) = \iiint Mdxdydz$
- $\vec{m} = MV_{iron\ content} = \frac{1}{\mu_0} B_r V_{iron\ content}$
- $\vec{F_b} = \nabla(\vec{m} \cdot \vec{B}(x,y,z)) = \nabla\left(\frac{B_r}{\mu_0} V_{iron\ content} \cdot \vec{B}\right)$

## Drag Force resisting the electromagnetic force.

- $\vec{F}_d = C_d A \rho \frac{v^2}{2}$
- $C_D = \frac{13.6}{Re}$
- $Re = \frac{\rho v L}{\mu}$

Now, L(Characteristic Length) is:

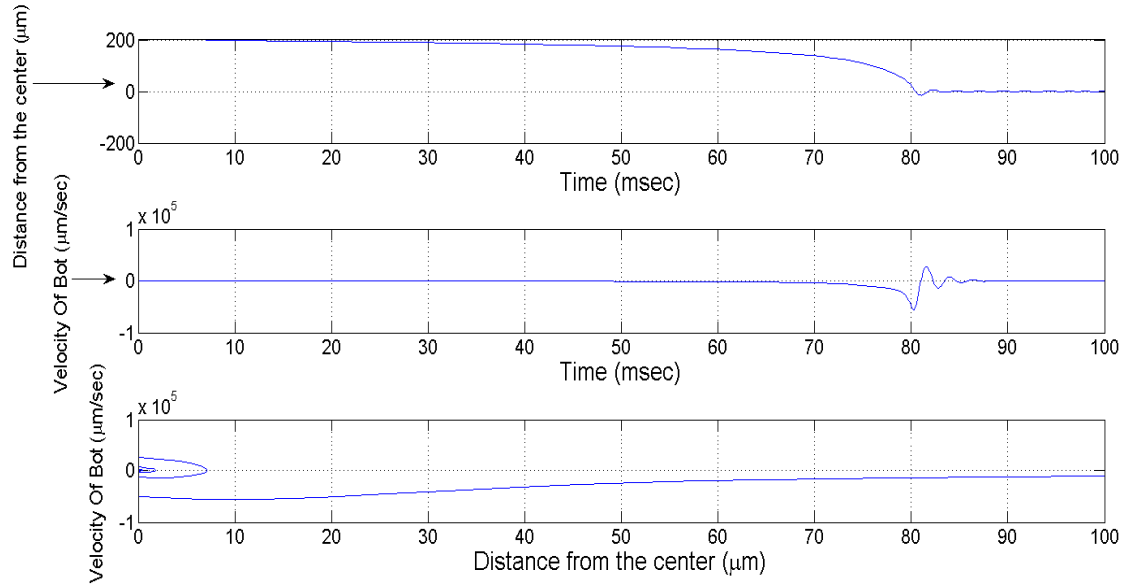
- $L = \frac{4 \times Area}{Perimeter} = \frac{4 \times Dt}{2 \times (D+t)} = \frac{2Dt}{D+t}$

Hence, $F_d$ can be written as,

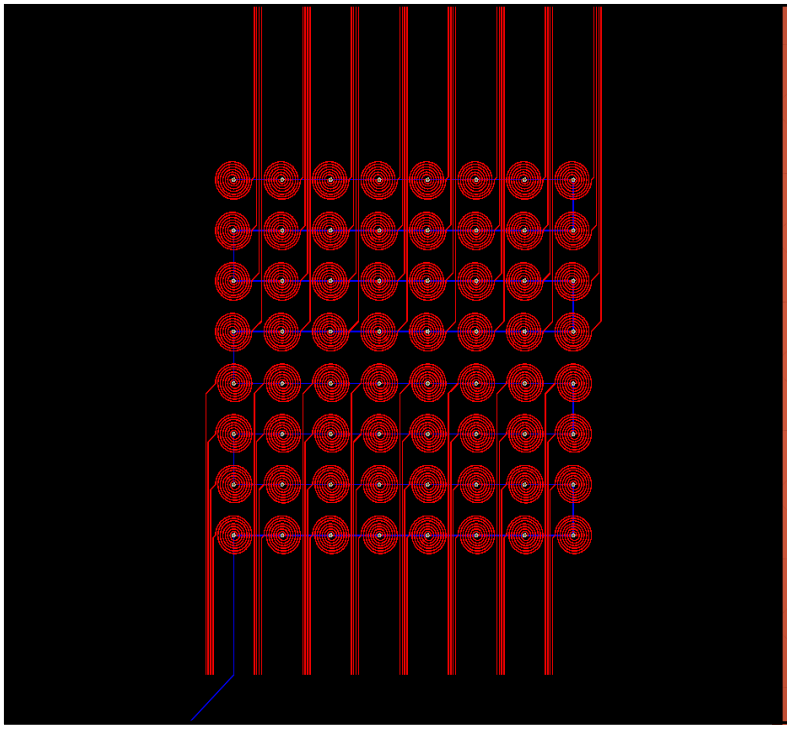
- $\vec{F}_d = \frac{13.6 \times D \times t(\rho v^2)}{\frac{2 \times \rho v (2Dt)}{\mu(D+t)}} = 3.4\mu(D+t)v$

## Solution,

- $m\ddot{x} + b\dot{x} = F(x)$
- For "stick and slip" motion of the raft, it needs to be in the same plane as that of the coil. Hence, the magnetic moment and magnetic field is always taken in the same direction.
- $m\ddot{x} = \frac{B_r}{\mu_0} V_d (\nabla \vec{B}) - 3.4\mu(D+t)v$
- Putting in all the variables,
- Liquid taken is water ($\mu = 8.9 \times 10^{-4} Pa$)
- $(8.4 \times 10^{-10})\ddot{x} = (1.95 \times 10^{-10})(\nabla \vec{B}) - (9.38 \times 10^{-7})\dot{x}$
- $\ddot{x} = (0.119 \times 10^{10}) \left( (1.95 \times 10^{-10}) \frac{d}{dx} \left( a1\, e^{-\left(\frac{x-b1}{c1}\right)^2} + a2\, e^{-\left(\frac{x-b2}{c2}\right)^2} \right) - (9.38 \times 10^{-7})\dot{x} \right)$




**Motion characteristics of the raft in a liquid**

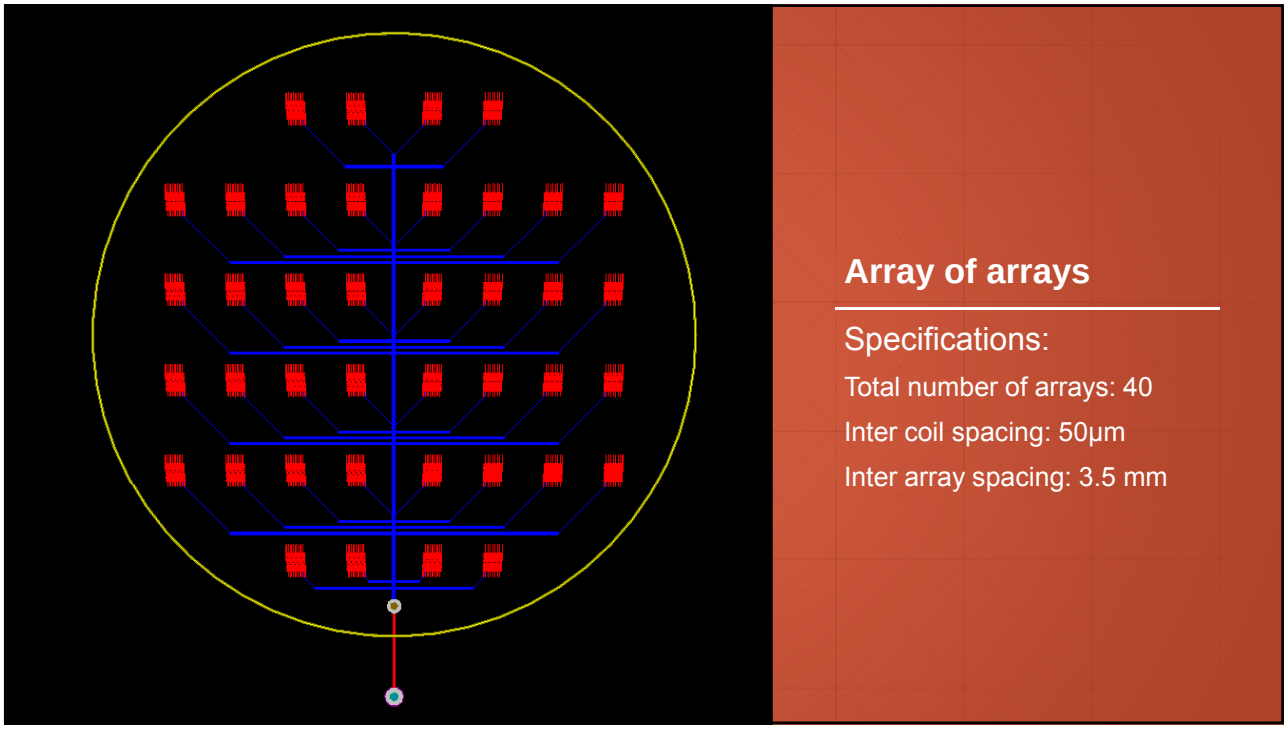


## Micro-Coil array

Specifications:

Total number of coils: 64

Inter coil spacing: 50μm



## Array of arrays

Specifications:

Total number of arrays: 40

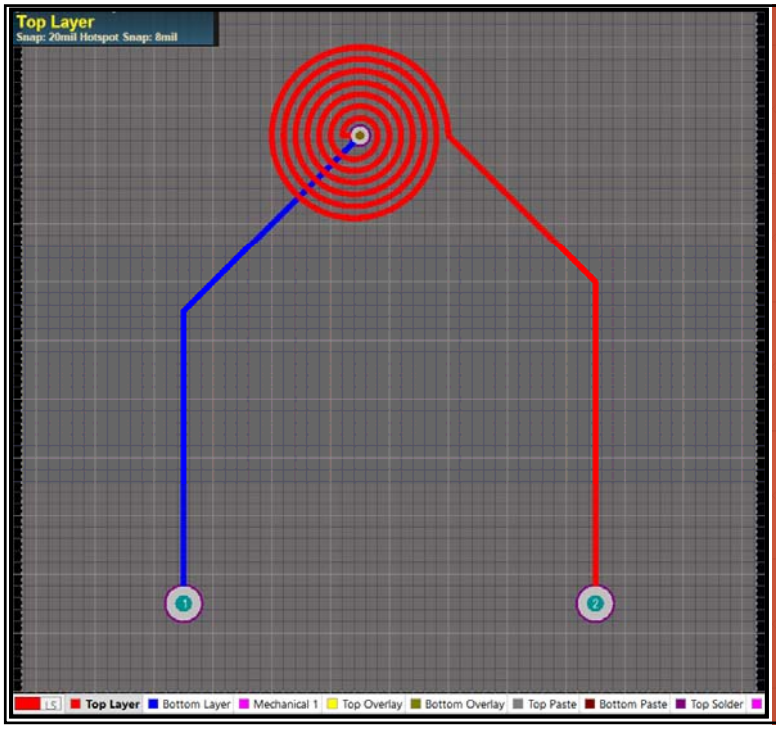
Inter coil spacing: 50µm

Inter array spacing: 3.5 mm

## Fabricating the prototype

### WHY?

- To indirectly see if the micro-coil can handle the current required for producing 20 mT.
- To be sure that the rafts can be attracted to the micro-coils.
- To do some experimentations with the rafts.




## PROTOTYPE-1 (Milli-Coil)

Specifications:

Outer Diameter: 300 mil

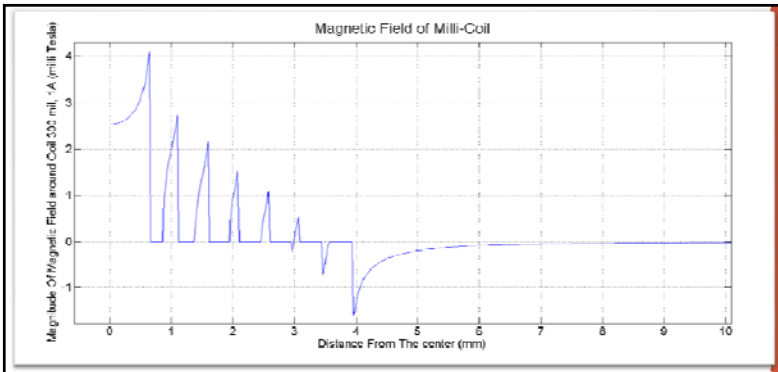
Number of turns: 7

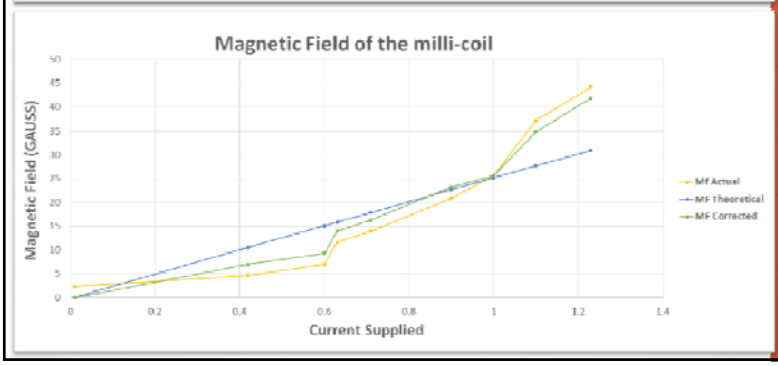
Track Size: 10mils

Via hole size: 0.4 mm

Pad hole size: 0.75 mm

**1 mil = 25.4 µm**



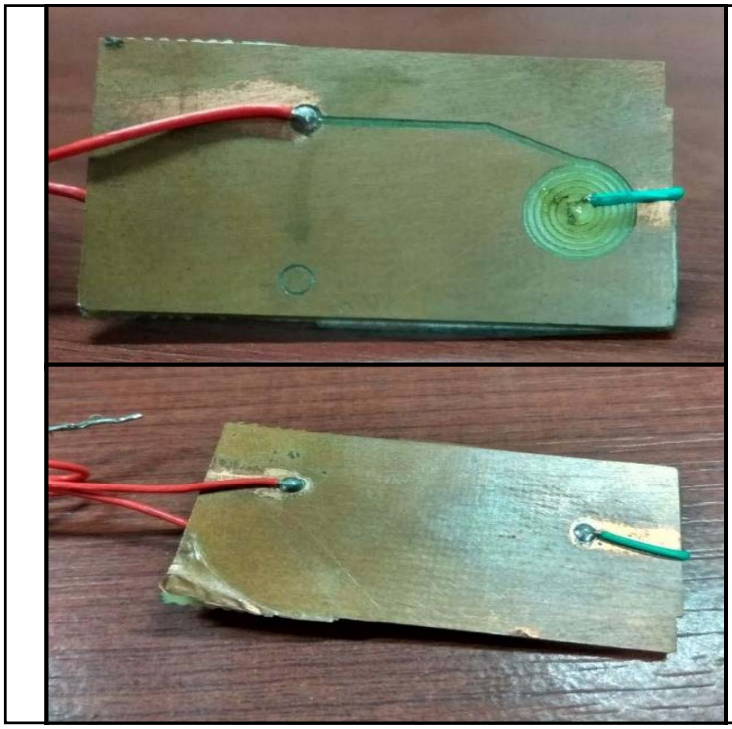




## Magnetic Field Around The Milli-Coil

Current Supplied: 1A

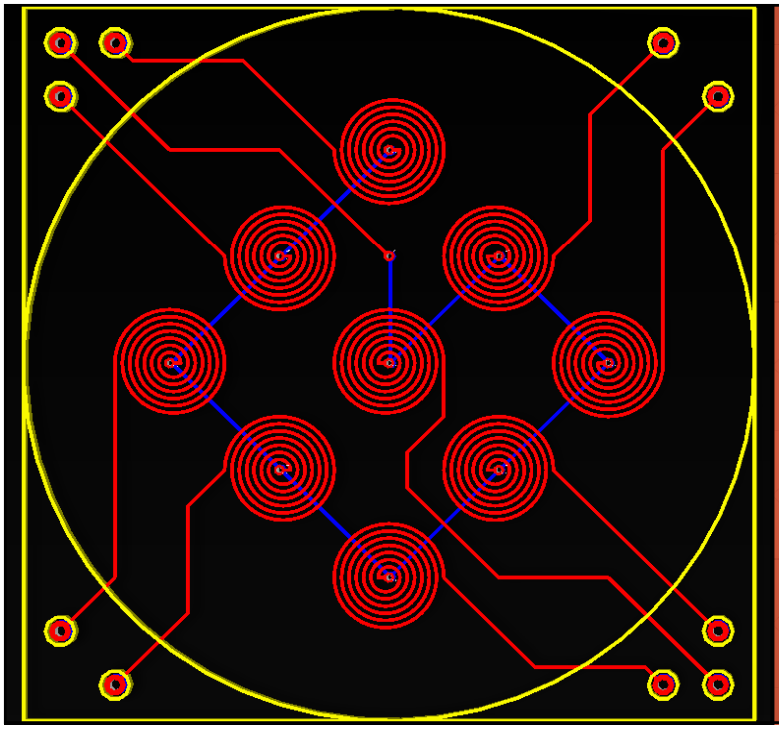
Magnetic Field at Center: 2.56 mT

**Heat Loss of milli coil at 1A**
**=**
**Heat loss of micro-coil at 0.15A**



## FABRICATED PROTOTYPE-1

Fabricated in CENSe department



## PROTOTYPE-2 (Array of Milli-Coils)

Specifications:

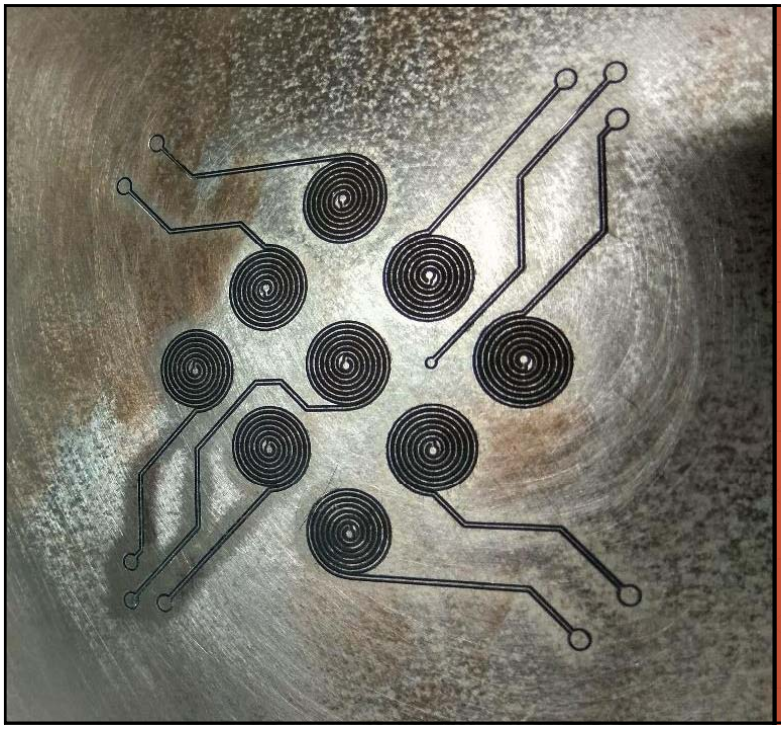
Inter coil spacing: 127 mils

Via hole size: 0.4 mm

Via diameter: 0.8 mm

Pad hole size: 0.75 mm

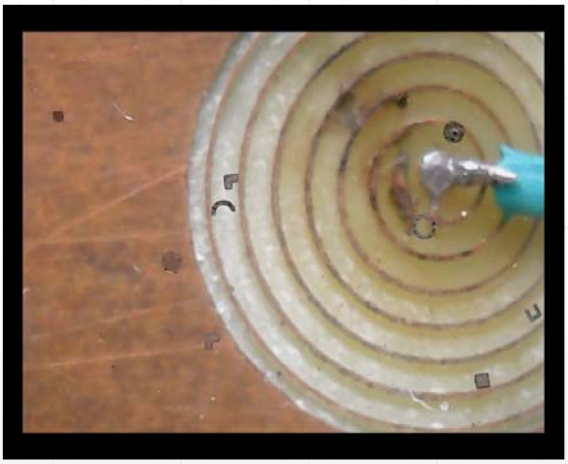
Pad Size: 1.5 mm

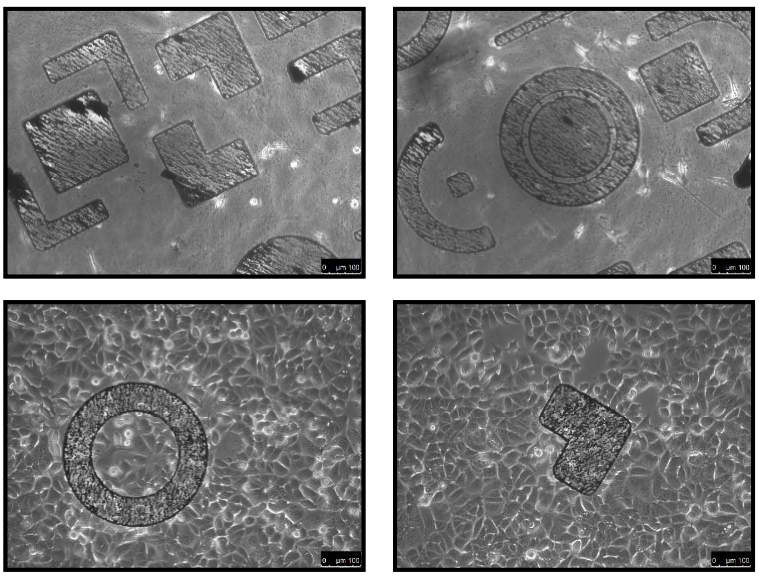


## FABRICATED PROTOTYPE-2

Fabricated in CENSe department

## Experiment on Prototype-1





Two of these images are taken from the work of Mr. Harsh Chhajer and Mr. Sudhanshu Shekhar

## Cell Culture on Micro-Rafts

Done under Bright-Field Inverted microscope

# Results and Conclusions

**Results,**

- The prototype could easily handle the current of 1A. The maximum current that it can handle is 1.4A.
- The Micro-Rafts are easily attracted by the Milli-Coil which has a field of 2.56 mT.
- The Micro-Coil will be able to attract rafts in the range of 200 μm from its center.
- Cells attached to the rafts are not visible directly.

**Conclusions,**

- The micro-coil should be able to handle the current of 0.15A and produce the desired magnetic field.
- If 2.56 mT can attract the rafts, 19.26 mT is more than enough.
- The micro-coil array should properly be able to guide the rafts.

# Summary and Future Work

**To Summarize,**

- The project was to provide a way to move cell carrying Micro-Rafts with precision.
- Provided a framework which can now be used to fabricate the micro-coil array.

**In Future,**

- Prototype-2 needs to be completed.
- Experimentations are needed to be done on Prototype-2.
- The imaging procedure needs to be done with an upright microscope to see the cells properly moving on the array.

**Finally,**

- Microfabrication procedure must be used to make the micro-coil array and achieve the goal.

# Acknowledgements

This work would not have been possible without the huge guidance that I got from people around me during these two months.

- First of all I would like to express my love to my **family**, my parents who allowed me to join such a nice programme away from my home in these two months.
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- I want to thank **Mr. Sudhanshu Shekhar** and **Ms. Shilpa**. Without them I couldn't have done what little I have done here.
- I would also like mention **Mr. Praveen** of the Instrumentation Department and **Mr. Venkataramana Avabhrath** of the CENSe department who helped me during experimentations and fabrications.
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- I am also thankful to my friends who are here with me as they helped me with my problems related to the subject.

# THANK YOU !