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MEMS REPS Overview

Objective
- To electroplate soft magnetic material (nickel-iron) into silicon mold of magnetic poles for the integrated generator design.

Requirements
- Thick deposit, 900 microns
- High saturation magnetization
- Good mechanical properties
  - Obtain low residual stress

Research Overview

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- Thick deposit, 900 microns
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  - Obtain low residual stress
The fabrication process is similar to LIGA but the mold is silicon (Si) and the electroformed structures are not released.

- A temporary seed layer is used for electrical connectivity.
- An advanced electroplating cell is used to deposit NiFe into the Si mold.
- The fabrication of the engine rotor will follow the chemical mechanical polishing (CMP) of the over-plated NiFe.

SEM photographs of (a) the silicon mold and (b) a silicon rotor fabricated with DRIE.

**Fabrication Process**

- Deep reactive ion etching (DRIE) of silicon mold
- Deposition of chrome-copper (Cr-Cu) seed layer onto photoresist
- Bond Si mold to seed layer handle wafer
- Electroform nickel-iron (NiFe) into Si mold
- Chemically release mold from seed layer with acetone
- Chemical mechanical polish (CMP) both sides of wafer
Nickel-Iron (NiFe)

- Highly used in the read-write head industry
- Soft magnetic material (high permeability)
- Electrodeposited material
- High saturation magnetization and low coefficient of thermal expansion (CTE) at various compositions

Magnified picture (300X) of initial NiFe deposit (left) onto copper seed layer (right).

Design Issues

Variation of Saturation Magnetization and Curie Temperature with Composition of Nickel-Iron

Based on R. Buzarde, Ferromagnetism
Electroplating

**Citrate-Complexed Nickel-Iron Electrolyte**

(H.V. Venkatassetty)

- Cell conditions (temperature, pH, bath concentration, duty cycle & current density) affect the deposition rate, composition, and grain size.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Amount</th>
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<tr>
<td>FeSO$_4$ – 7H$_2$O</td>
<td>5 g/L</td>
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<tr>
<td>NiSO$_4$ – 6H$_2$O</td>
<td>112 g/L</td>
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<tr>
<td>NaC$_6$H$_5$O$_7$ – 2H$_2$O</td>
<td>75 g/L</td>
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<tr>
<td>K$_2$SO$_4$</td>
<td>1.5 g/L</td>
</tr>
<tr>
<td>Saccharin</td>
<td>1 g/L</td>
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<tr>
<td>Sodium n-dodecyl sulfate (SDS)</td>
<td>0.2 g/L</td>
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**10L Experimental Cell**

- **Anode (+)**: Ni S-Rounds in Anode Basket
- **Cathode (-)**: Wafer holder with insulating top plate
- **Pump for Mass Transfer**

**T=45°C**

**pH=6**

**Results: Composition**

**Target composition attained**

<table>
<thead>
<tr>
<th>wt % Iron in Nickel</th>
<th>Current Density (mA/cm$^2$)</th>
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<td>100</td>
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</table>
**Results: Magnetic Properties**

Magnetic Properties

Magnetization Curve for Electroplated NiFe Film

Current Density = 20 mA/cm²

Saturation magnetization of ~1.5 Tesla attained

**Electroforming Issues**

Current density distribution inside the mold without top plate during electroforming.

Magnified photograph of initial electroforming results displaying thick NiFe deposits at the perimeter.
**Electroforming Modeling**

Current density distribution inside the mold with an insulating top plate during electroforming.

Schematic of the silicon molds used for investigation of feature proximity.

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**Results: Electroforming**

- Through-mold deposition was observed underneath the insulating parts of the top plate.

Magnified photographs of electroformed NiFe in silicon mold.

- NiFe Pole
- 600um
- 3mm spacing
Conclusions

- A process for electroforming soft magnetic poles into a silicon mold has been completed.
- The design of an advanced electroplating cell that can deposit films with good magnetic properties has been completed.
- FEM modeling of the electric field lines between the anode and cathode shows that an insulating top plate can be implemented to attain through-mold deposits.

Future Work

- Further investigate the effect of the insulating top plate and the proximity of the wafer features on the topography of the deposit
- CMP the electroformed deposit to create a planar surface
- Complete the DRIE of the silicon rotor features around the magnetic poles