Electroforming of Low-Stress Iron Group Alloys

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Motivation

The objective of this work is to develop electrodeposition processes to produce low-stress iron group metal and alloy films, which can be later integrated to MEMS including LIGA as structural materials and magnetic-MEMS as magnetic sensing materials.

Challenges

- Producing high performance soft magnetic materials (Magnetic saturation upto 2.4 T) with minimum film stress (< 100 MPa).
- Integrating these materials to other MEMS processes.

NASA Needs

•Size, mass and power consumption for devices and instruments are severely constrained on space missions.

•Given the prohibitive costs of launching any payload into space (between $10,000 - $1000,000 per kg, depending on the type of mission), the trend during the past decade has been towards "smaller, faster and cheaper" space missions. Such missions are necessarily of the "micro-spacecraft" class (under 100 kg mass).

Some Important Considerations for In situ Instruments Used in NASA Applications

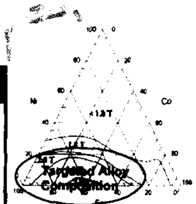
- Low Power
- Low mass
- Low volume (for space applications)
- High reliability
- Long lifetime (sometimes as long as a decade)
- Manageable data rate
- Easily calibrated
- Must have compatible sample handling mechanisms
- Able to withstand extreme environments
- Able to withstand launch loads

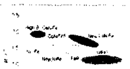
Soft Magnetic Materials

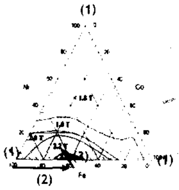
Requirements:
- High Magnetic Saturation (M_s)
- Low coercivity (H_c)
- Optimal anisotropy field (H_k) for high permeability
- Good corrosion resistance
- High electrical resistivity (r)

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	1	[illegible]	-0+
[illegible]	1.6	[illegible]	+
NiFeCo	0.8-2.4	1	-0+
[illegible]	1.5	[illegible]	
[illegible]	1.7	1	+
CoFe	1.9	3	-0+
CoFeB	1	[illegible]	-0+
[illegible]	1.7	[illegible]	-
[illegible]	1.7	[illegible]	+
[illegible]	1.5	1	-0+
[illegible]	1.7-2.2	1	-0+
CoFeB (electroless)	1.2	1	
[illegible]	1.2	1	

(1)







(2)

Approach:

1. Investigated single iron group metals (i.e. Ni, Co, Fe)
   - Determine optimal solution composition and deposition conditions to minimize film stress
2. Investigated CoFe binary alloys
   - Determine Optimum Deposition Conditions to yield low stress magnetic saturation materials
3. Addition of ... to CoFe binary alloys to improve ... of films while maintaining high magnetic saturation ...

Experimental Conditions

Electrolyte Composition:
- Typical Single Iron Group Metal Solutions:
  - 1.5 M IG (i.e. Ni, Fe, Co) Cl_2 + 1.0 M $CaCl_2$
- FeCo Binary Alloy Plating Solutions
  - 1.5-X M $FeCl_2$ + X M $CoCl_2$ + 1.0 M $CaCl_2$

pH = 0.34; No agitation

Temperature = room temperature to 90 °C

Anode: Iron Group Metals (i.e. Ni, Fe, Co)

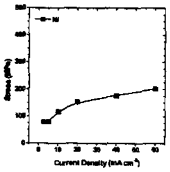
Substrate: Copper-Be...

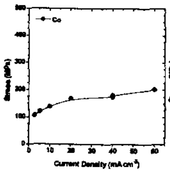
Stress: Strip Method

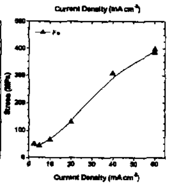
Single Iron Group Metal Depositions

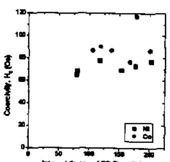
Effect of Applied Current Density:

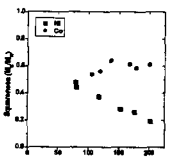
Temp: 66-72 °C





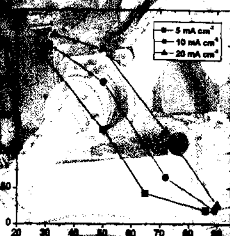


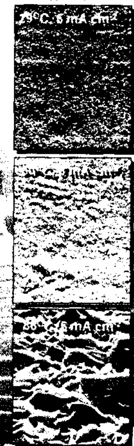


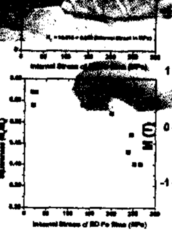


Effect of $CaCl_2$ Concentration on Fe Electrodeposition:

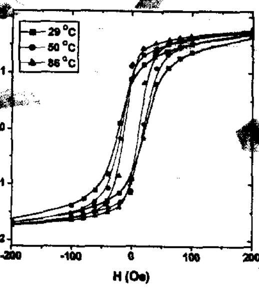
Effect of Temperature on ... ED:





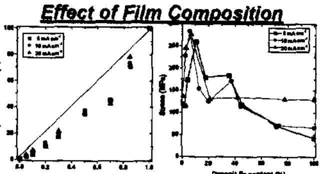


B-H Loop

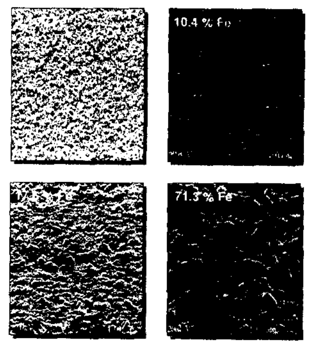


CoFe Binary Alloy Electrodeposition

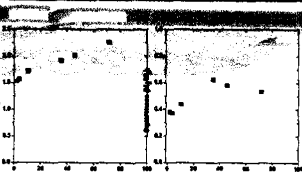
Effect of Film Composition



Surface Morphology of CoFe Films



Magnetic Properties of CoFe Films



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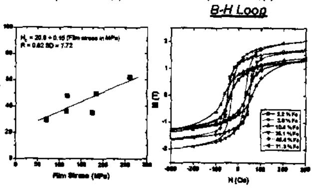
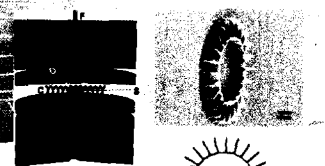
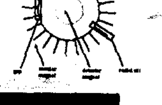


JPL's Force-Detected NMR Spectrometer





Quadrupole Mass Filter for Miniature GC/MS

Summary

Iron Group Single Metals
- Film stress were strongly influenced by applied current density and operating temperature.
- Low current density and high operating temperature promote grain growth and reduce film stress.
- Coercivity (H_c) of Fe electrodeposits linearly increases with increase in film stress.

FeCo Alloys
- Film stress were strongly influenced by applied current density and operating temperature as single iron group metal.
- Low current density, high operating temperature, and high deposit Fe content promote grain growth and reduce film stress.
- Maximum film stress were observed at 10 % Fe.
- Magnetic Saturation of 2.26 T were obtained with film stress of 50 MPa.

Acknowledgment

This project was supported by NASA Code R