Electrodeposition of Magnetic Materials

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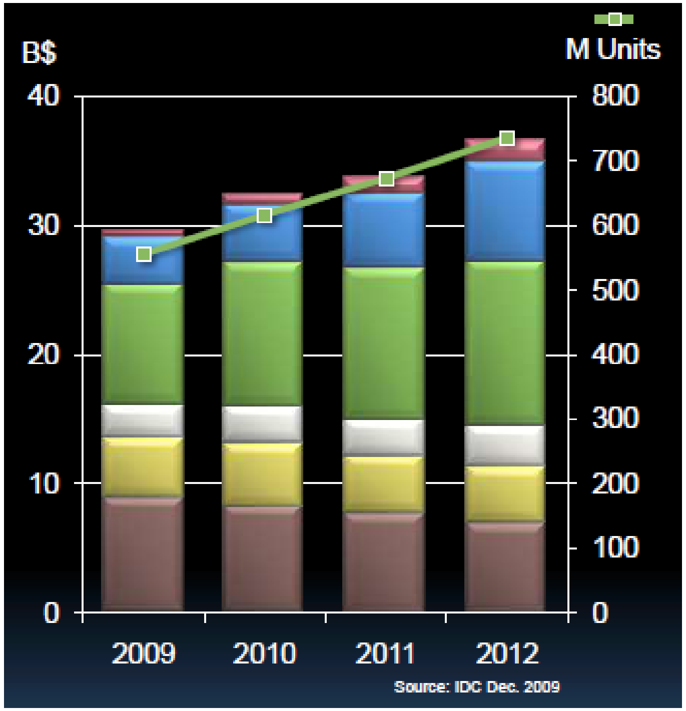
Electrodeposition and the HDD Business

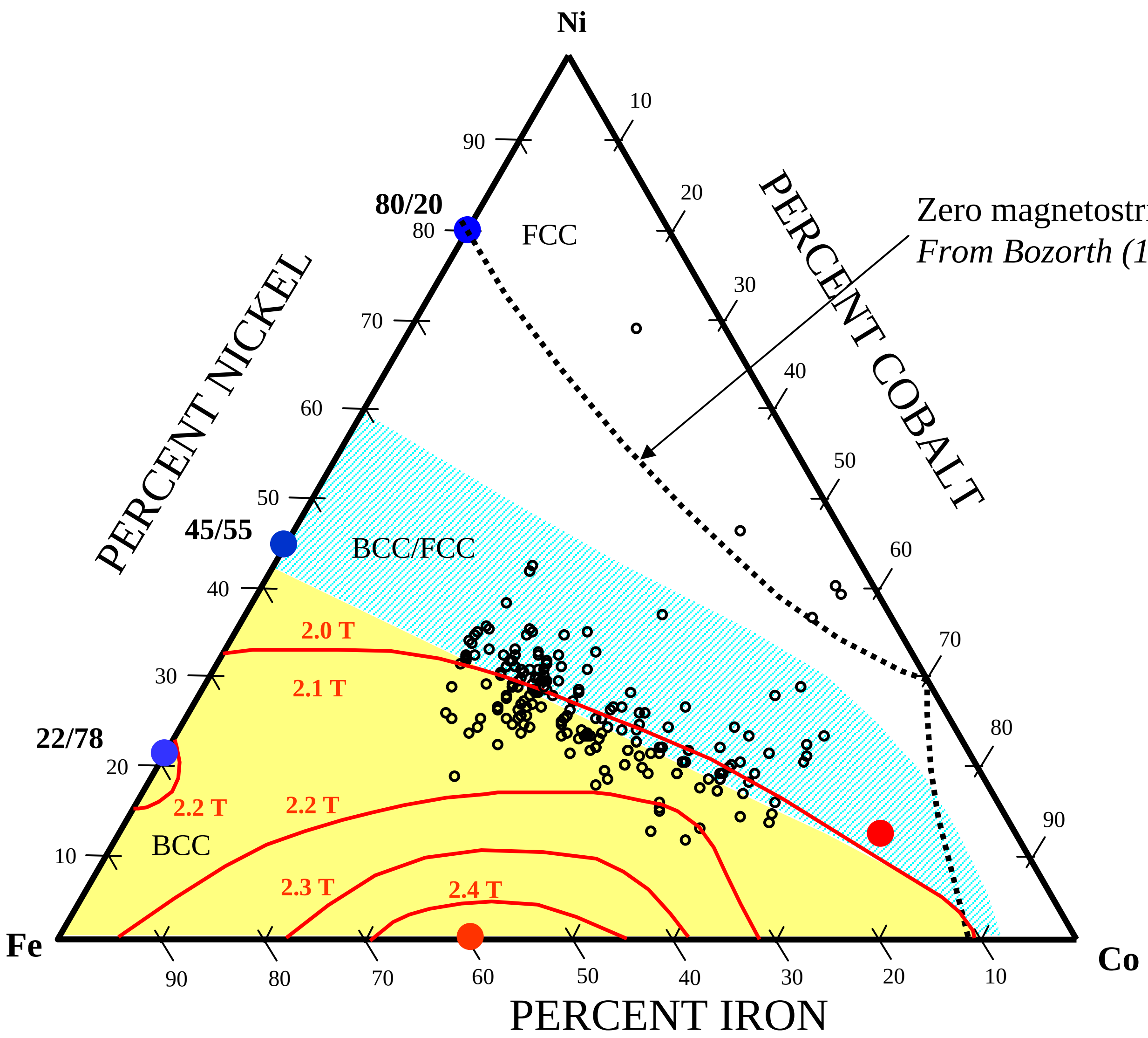
- **HDD's are a very high volume business**
- **HDD units translates to on the order of 2 Billion magnetic recording heads per year.**
- **Each head has 5-6 plated magnetic layers with feature sizes ranging from ~50nm to 10 um with a variety of different alloy compositions.**
- **Other layers use plated Cu and Au.**
- **Plating is done on either 6" or 8" wafers in fully automated tooling.**
- **Electroplating is**
  - High rate
  - Low cost equipment
  - Can produce thick films with good magnetic properties
- **Industry has developed both materials and robust manufacturing procedures to make magnetic plating successful.**



Outline

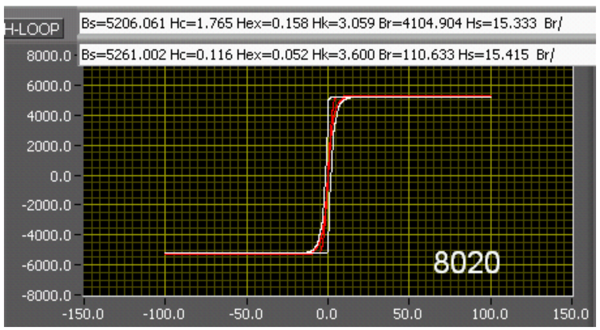
- **Electroplated Magnetic Materials**
- **Wafer Integration**
- **Electrodeposition Tools**
- **Process Control**
- **References**

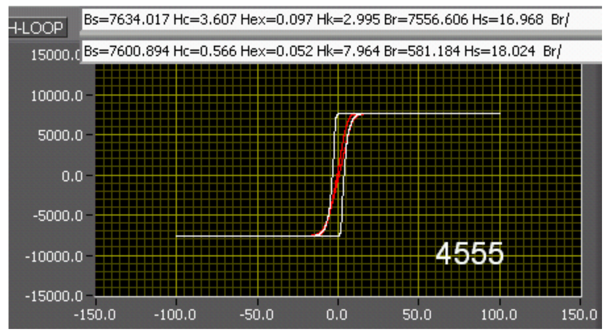
Electroplated magnetic materials

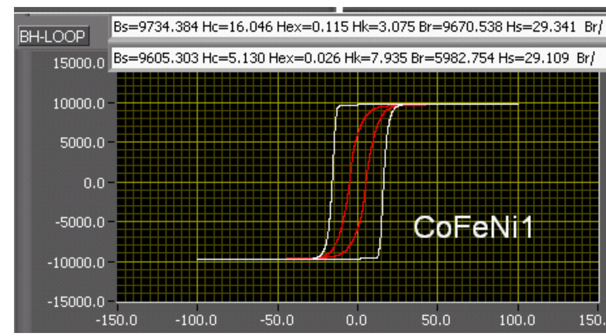


Magnetic Materials

			Magnetics			
Alloy	Stress (Mpa)	Resistivity (uOhm-cm)	Hc	Hk	Bs	Lamdda (ppm)
Ni(80)Fe(20)	150	20	1.5	3	1	Negative
Ni(45)Fe(55)	130	50	3.5	8	1.65	11
Co(60)Fe(39)Ni(1)	450	20	15	8	2.4	24







- **Examples of typical magnetic materials used in recording heads**
- **Need to choose material based upon application need and consider tradeoffs (Ms, softness, resistivity, magnetostriction, corrosion ….). Lots of choices.**
- **A key missing ability has been to get high resistivity materials to suppress eddy currents that have the rest of the appropriate properties.**
- **Very large literature of material options including adding 3 or 4^{th} element.**

Magnetic Alloy Plating

- **NiFe plating is an example of anomalous codeposition where the less noble alloy (Fe) deposits much faster then the more noble species (Ni). Bath can be very sensitive to Fe ion concentration.**

- **4 simultaneous reactions happening at the cathode that complicate the control of thickness and composition.**

- **$Ni^{+2} + 2e^{-}$ >>> Ni** — **Kinetics limited**

- **$Fe^{+2} + 2e^{-}$ >>> Fe** — **Mixed kinetics and diffusion limited**

- **$2H^{+} + 2e^{-}$ >>> $H_{2(g)}$** — **Diffusion limited**

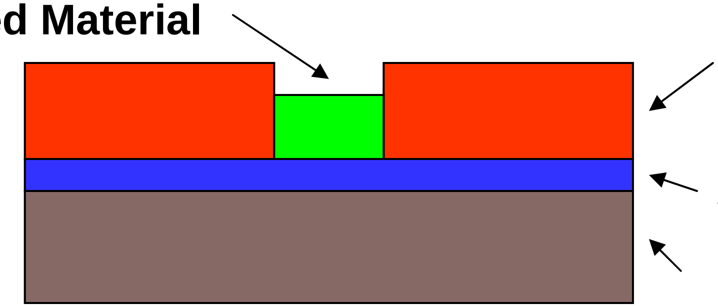
- **$2H_2O + 2e^{-}$ >>> $H_{2(g)} + 2OH^{-}$** — **Kinetics limited**

- **To get good magnetic properties it is key to have some sort of additive in the bath to get small grains and low stress. Sulfur containing additives like Saccharin are popular but others are in use in the industry.**

- **Ferric from a homogenous reaction and therefore $Fe(OH)_3$ which is insoluble needs to be controlled. Either a low pH bath or the use of complexing agents is needed to prevent rapid accumulation. Filtration is one method to remove the hydroxide.**

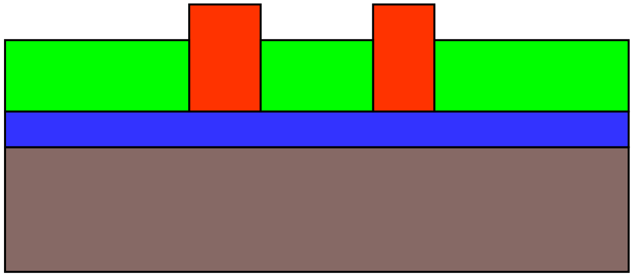
Wafer

- **Wafer Layout is key factor**
  - Need to consider interactive effects of wafer process integration needs versus those that will impact success in plating process
  - Usually plating is done in additive process since one of the overall advantages is the ability to plate directly into a resist pattern and get exact replication.



Patterned Plating

- **Simpler integration scheme**
- **More issues with micro uniformity due to mass transfer and current distribution**



Frame Plating

- **More complex integration since requires an additional lithography and etch step to get final pattern**
- **Better micro uniformity due to mass transfer and current distribution**
- **Less magnetic field needed to saturate the final pattern**

Wafer

Integration choices

- The macro scale uniformity contribution from the wafer itself are usually dominated by the terminal effect, which is how well does the current distribute itself across the wafer. Cell design can help overcome some of these issue as we will see.
  - Is substrate conductive or not. Can it be used as a path for current
  - How thick can the seedlayer be and what is its conductivity.
- Seedlayer
  - Same material as plated or need to be different due to design ?
  - Resist adhesion and compatibility with resist developer.
  - How to remove seedlayer in the field. Chemical or dry process ?
  - Impact of any pre-plating process on seedlayer. Ashing oxidation ?
- Photoresist
  - Adhesion to seedlayer
  - Is a pre-plate ash process needed ?
  - Adhesion during the plating process
  - How to strip resist with method compatible with plated material. Aqueous clean allowed ?

Wafer

- **Integration choices**
  - Microscale uniformity issues
    - Are dependent on details of pattern layout combined with cell design, bath design, and plating current conditions. Generally significant variation in sizes of features across the wafer cause issues.
    - Very high aspect ratio features can lead to composition gradients within the pattern. Bath design and plating current conditions can be used to help this problem.

Tools

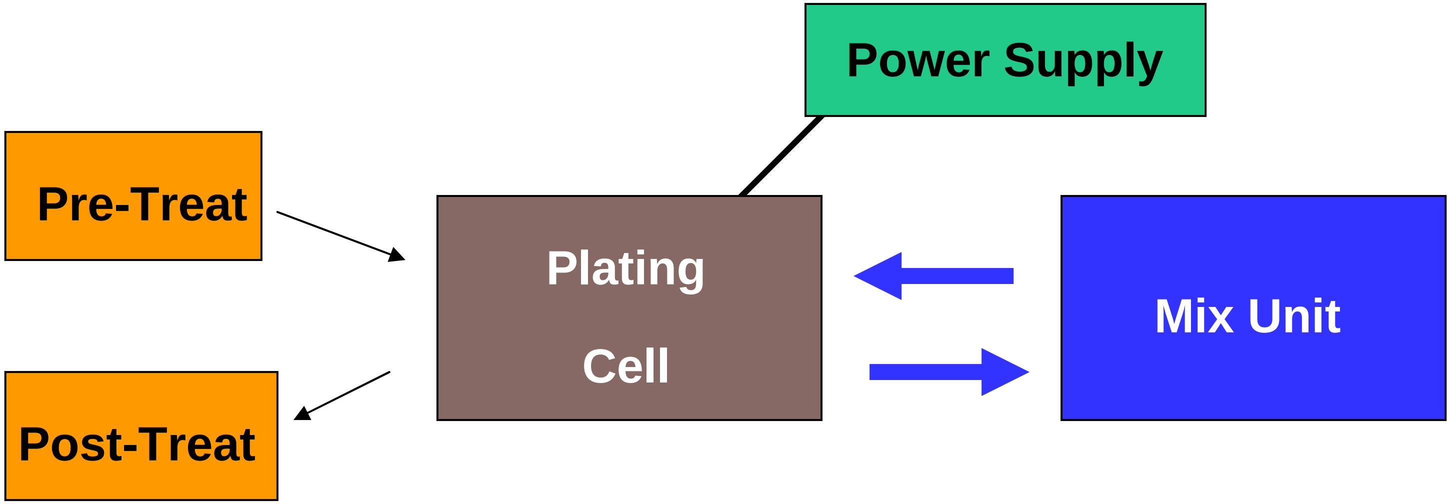
AMERIMADE TECHNOLOGY

Tosetz
Safety & Relief

APPLIED MATERIALS

Tools

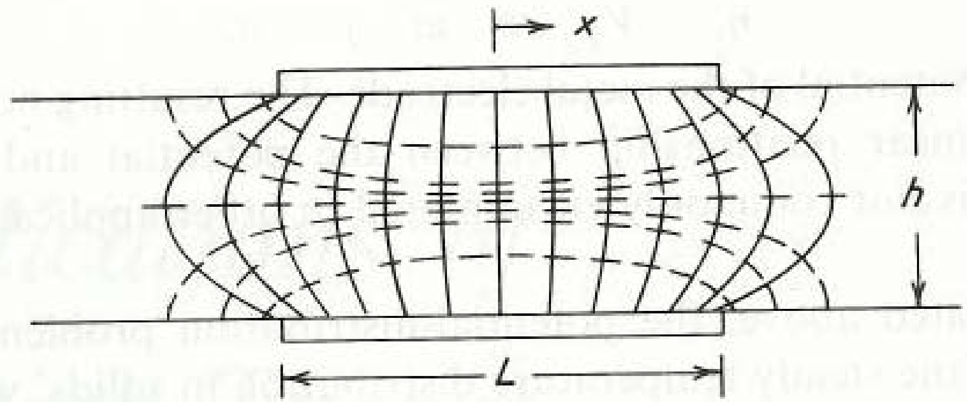
- **A variety of vendors make tools for magnetic plating**
  - They have strong experience in this area
  - Choice depends on a number of business and technical factors
  - Will discuss a few key points

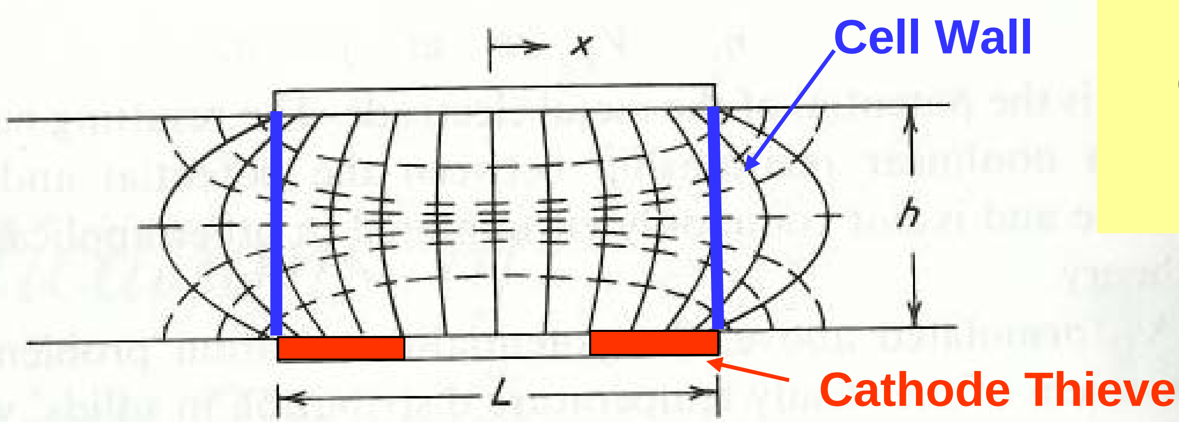


Tools

- **Mix unit**
  - Large volume for better bath stability
  - Temperature control (+/- 0.1C)
  - Agitation
  - N2 bubble/blanket
  - Filtering system (can be important part of bath control for Ferric hydroxide removal)
  - pH control, density control, plating chemical addition scheme
- **Power supply**
  - Need to have enough power overhead for peak needs
  - Need to be able to drive multiple cathode points and anode points
  - Ability to program complex pulse and ramp sequences
    - To influence macro uniformity as plating proceeds and terminal effect changes
    - For alloys to allow grading/laminating of composition in single bath
    - Pulse plating to improve diffusion issue in small features and to influence grain size of materials

- **Cell design**
  - Uniformity
    - Function of cell design which impacts diffusion and primary current distribution of the system
    - Function of bath and plating conditions which influence Wagner number





Wa = K/L dE/di   Larger value yields better uniformity

K- solution conductivity

L= critical dimension

dE/di = slope of plating polarization in region of plating

- **Cell design**
  - Anode
    - -single piece or multi-part to allow current shaping to improve macro-uniformity
  - Cathode
    - Design of electrical contacts depends on wafer details. Edge or back-side contact.
    - Thieves to improve macro-uniformity
      - » Layout
      - » Material choice to prevent peeling and to allow ease of cleaning.
  - Open or membrane between cathode and anode side of cell
  - Agitation
    - Paddle or Jet have been popular.
  - Magnetic field. Choice depends on strength of natural anisotropy of material and shape anisotropy of pattern on wafer whether needed or not.

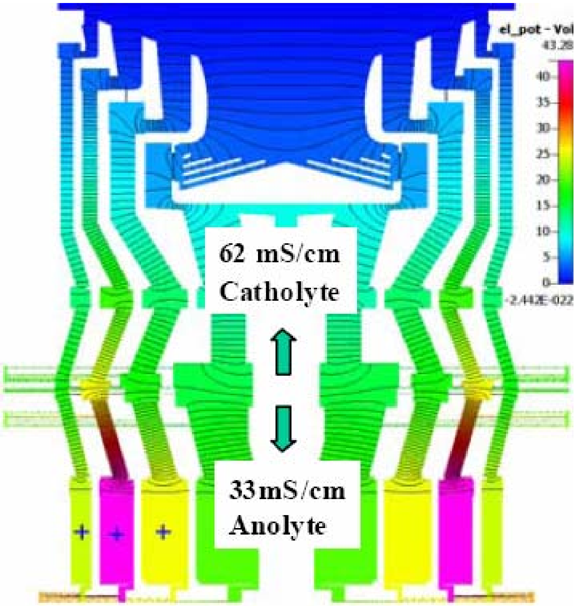


Figure 1. Axisymmetric electric-field model of the 4-anode CFD reactor including a membrane cartridge. The anolyte and catholyte have different conductivities. *Semitool modeling*

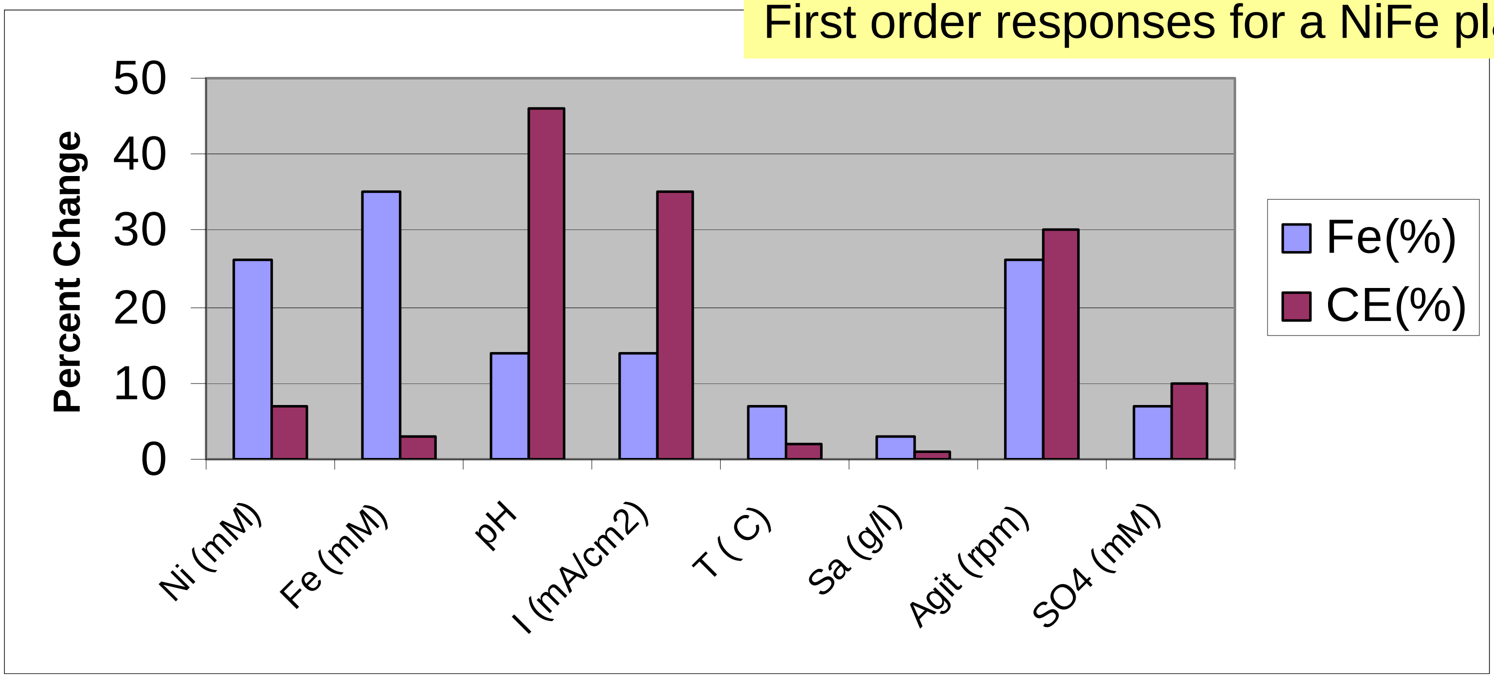
- **Post wafer plating clean**
  - How to prevent in tool corrosion for Co-alloys between end of plating and final rinse/dry is a key design requirement.
  - DI water is not the issue. It is the combination of residual electrolyte, air, and water in a thin film that can cause damage.
  - Other key point to watch is overall cleanroom contamination that can cause corrosion outbreaks.

Bath Control

- **Need to understand specifications for device. Then need to control:**
  - Composition
  - Thickness via plating rate. Mainly in alloy baths issue is current efficiency
  - Film magnetics. Mainly controlled by composition
  - Bath stability. Want to prevent bath from crashing

- **Need to understand bath sensitivity to inputs. DOE is useful. Optimize system to best control specifications for your application needs. The DOE will point to factors to focus control system on.**

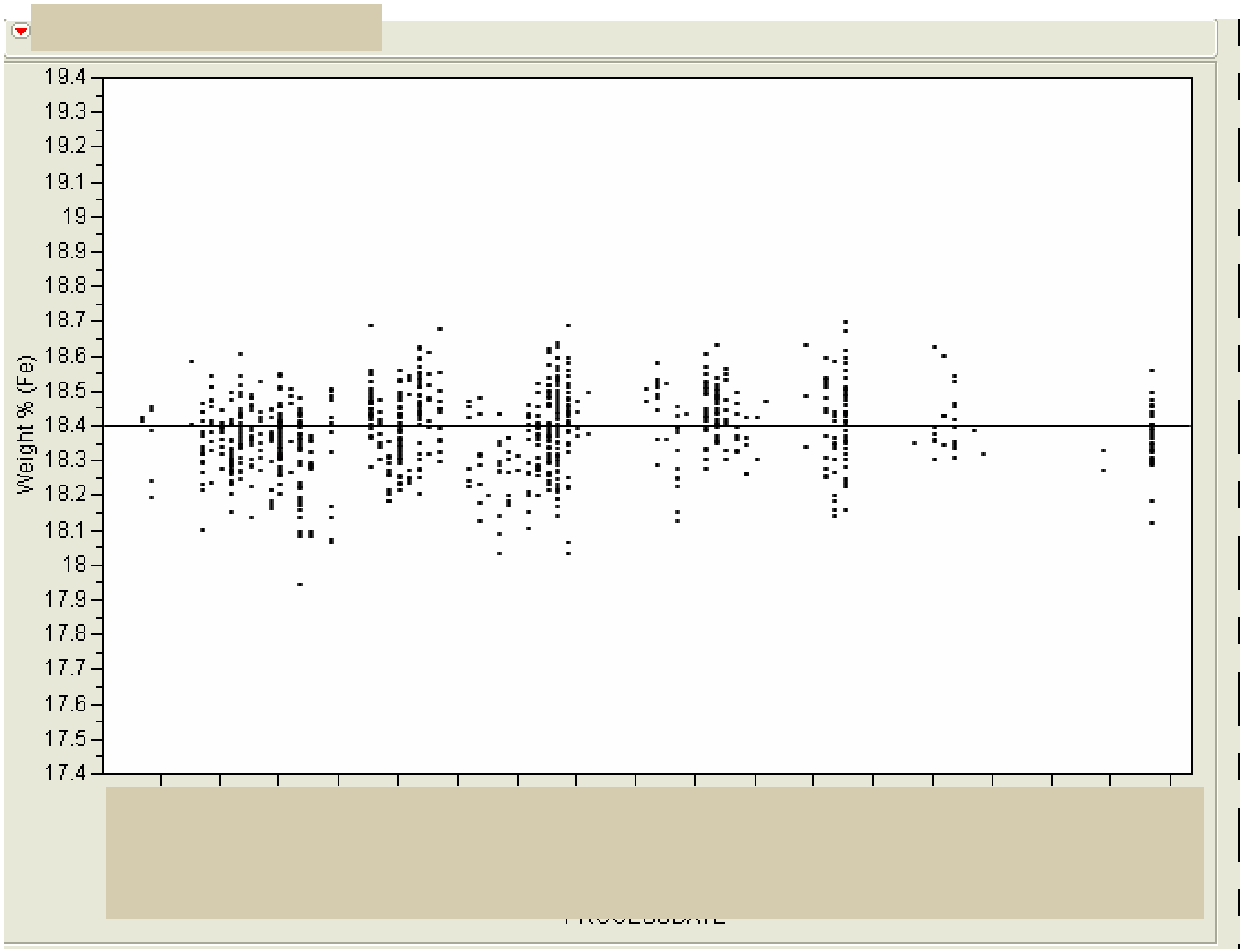
First order responses for a NiFe plating bath



Bath Control

- **Metrology**
  - Online
    - pH
    - Temperature
    - Density
  - Offline
    - Film composition (XRF)
    - Thickness (XRF, profilometery)
    - Magnetics (mainly dependent on composition)
    - Bath composition of all species (XRF, titration, ICP)
- **Control**
  - Online
    - pH
    - Density
    - Temperature
    - Critical consumed bath species are replaced via a mass balance of the system linked to a bath makeup mix. Need to input to mass balance: plating coulombs, anode replacement rate, and dragout.
  - Offline (via control charts and additions based on control limits)
    - Consumed species that online bath makeup allows to slowly drift
    - Less critical non consumed species. ($SO4^-$, Cl^- ......)

- **Control example**
  - Long term control works well.
  - Composition control over 3months within +/- 0.3%

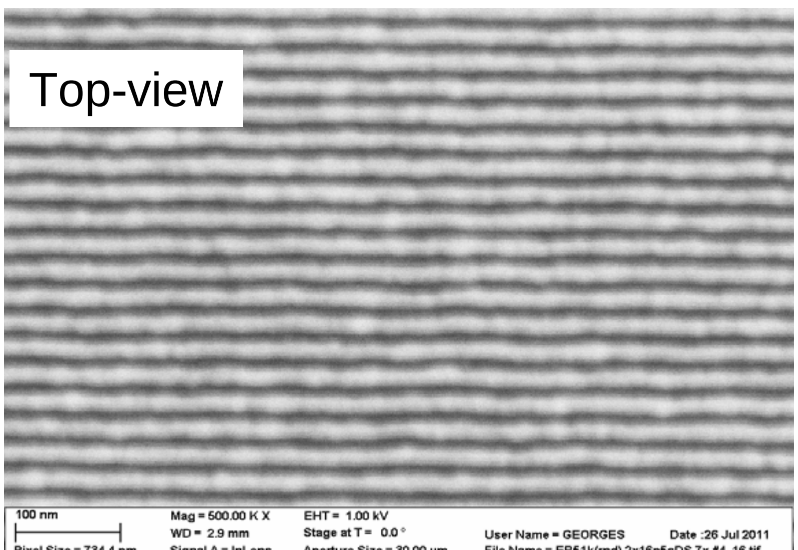


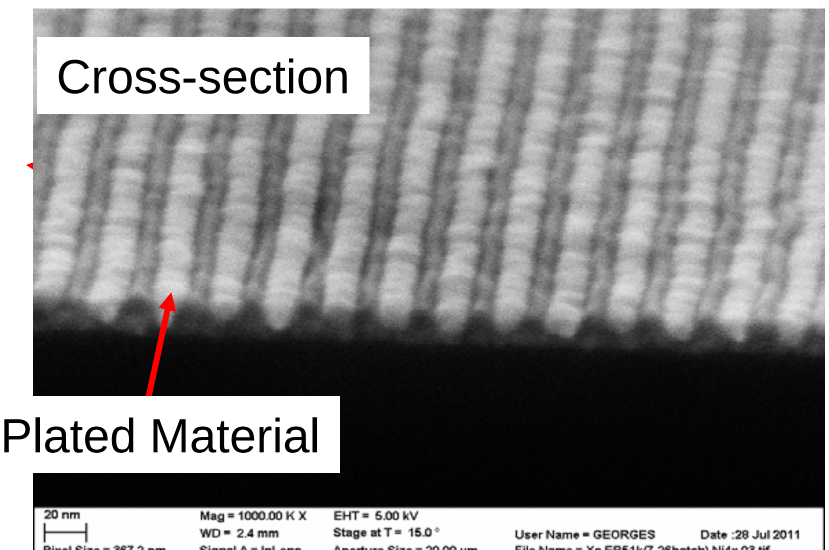
Summary

- **Electrodeposition of magnetic materials is a high volume and well controlled process in thin film head manufacturing**
- **A wide variety of magnetic materials are available**
- **Device integration via plating can enable devices to be built that would otherwise not be feasible.**

Electroplating of 13nm features created by Block-CoPolymers

1:2 Directed Self Assembly (DSA) by e-beam with PMMA resist and 27nm pitch PS-b-PMMA BCP





Bonhote et. al, Fall 2012 ECS Conference