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The Electrodeposition of the Magnetic Shape Memory Alloy Ni-Mn-Ga

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Abstract

Shape memory alloy (SMA): Material capable of overcoming large strains to return to a pre-deformed shape via a thermally induced martensitic phase transformation. In magnetic SMA, the shape change can be induced with a magnetic field.

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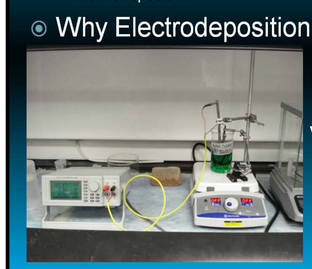
Introduction

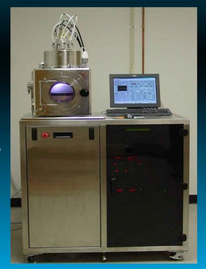
Shape memory alloy (SMA): Material capable of overcoming large strains to return to a pre-deformed shape via a thermally induced martensitic phase transformation. In magnetic SMA, the shape change can be induced with a magnetic field.

Research Purpose

- **Purpose:**
  - To determine the feasibility of producing thin films of the magnetic shape memory alloy Ni-Mn-Ga through electrodeposition
- **Why Electrodeposition?**



Vs.

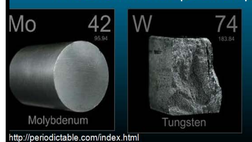


Electrodeposition Vs. Sputter Deposition

- Less expensive Equipment
- More Energy Efficient
- Less Metal Waste

Goals

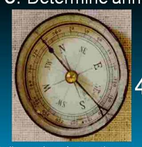
1. Determine deposition parameters



http://periodictable.com/index.html

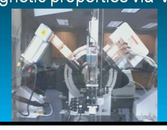
2. Deposit metals onto refractory metals in the ratio $Ni_{50}Mn_{29}Ga_{21}$

3. Determine annealing parameters



http://www.solarnavigator.net/compass.htm

4. Obtain proof of magnetic properties via VSM



5. Verify presence of Ni-Mn-Ga alloy

Deposition Parameters

Metal	Bath Composition	Current Density	pH Range	Avg. cathode efficiency
Nickel	0.3M H_3BO_3 0.5M $NiCl_2$	50mA/cm^2	3.8-4.2	99%
Manganese	1M $(NH_4)_2SO_4$ 0.59M $MnSO_4$	65mA/cm^2	3.0-4.7	65%
Gallium	0.3M Ga_2Cl_3 0.5M $NaH_2C_6H_5O_7$	40mA/cm^2	10.5-11.7	60%

Ga/Mn/Ni

Annealing Parameters

Table below depicts diffusion length of Nickel in Ni-Mn-Ga in micrometers at corresponding temperature and time.

T Celsius/ t-min	700	750	800	900
10	1.38μm	2.15μm	3.21μm	6.45μm
30	2.40μm	3.73μm	5.56μm	11.2μm
60	3.39μm	5.27μm	7.86μm	15.8μm
180	5.88μm	9.13μm	13.6μm	27.4μm
600	10.7μm	16.7μm	24.9μm	49.9μm

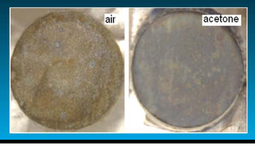
Ga/Mn/Ni layer order produced little alloying due to high oxide deposition when plating Mn onto Ga thus Ga/Ni/Mn order was used.

Ga/Ni/Mn

Layer Order: GaNiMn

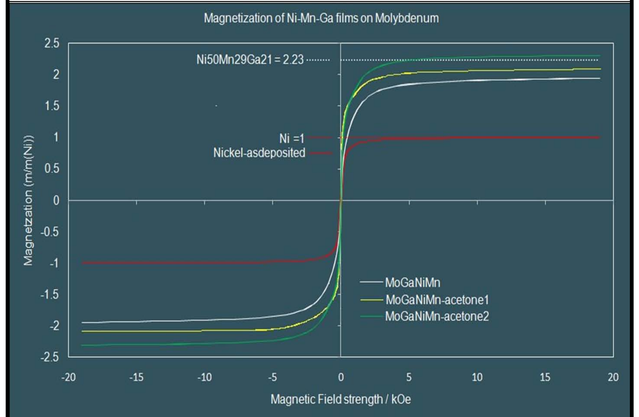
- **GaNiMn**
  - Metallic Manganese deposits onto Gallium
  - Manganese oxidation prevention needed
- **Oxalic Acid**
  - Removes Manganese Oxide
  - Forms bi-layer barrier
  - Cannot plate after treatment

Oxalic Acid Treatment



- **Acetone**
  - Prevents oxidation
    - Bi-layer or induced phase transformation to α-Mn
  - Can plate after treatment

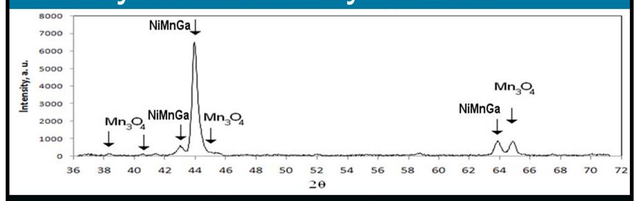
VSM Results



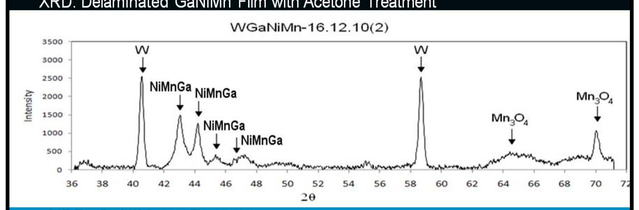
Layer order Ga/Ni/Mn VSM results showed much improvement over previous Ga/Mn/Ni results. Samples with and without acetone treatment were used, with best results coming from acetone treated samples. NiMnGa is a Heusler alloy, meaning it should show more magnetization than all of its magnetic components (which in NiMnGa is Nickel). Results show a film (depicted by green line) emulating same magnetization as the NiMnGa experimental value (and much higher than Nickel value), providing evidence of Heusler alloy formation.

X-Ray Diffraction

Verify Heusler Alloy via XRD



XRD: Delaminated GaNiMn Film with Acetone Treatment



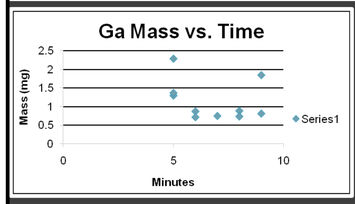
XRD: GaNiMn on Tungsten

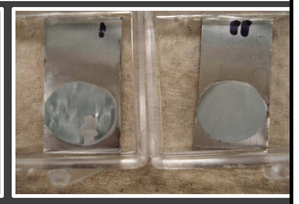
Future Research

Standing Hurdles

- **Delamination after annealing process**
  - Causes
    - Lattice mismatch
    - Gallium melting

- **Oxidation**
  - Manganese or Ni-Mn-Ga oxides form during annealing process
  - Solutions
    - Reduce oxygen incorporation during plating
    - Organic Solvents





Conclusion

Results of VSM and XRD experiments support the conclusion that the NiMnGa Heusler alloy can be formed using an electrodeposition method. Samples with the lowest oxygen content have the same magnetization as bulk material with the same composition, and future work will be directed at lowering oxide formation.

Thanks

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  - Dr. Peter Mullner
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