



# Galfenol Nanowires for Touch Sensors and Electroplated Thin Films

Katherine A. Kuehn, University of Wisconsin Eau Claire  
Mentors: Dr. Bethanie J.H. Stadler, K.S. Madhukar Reddy

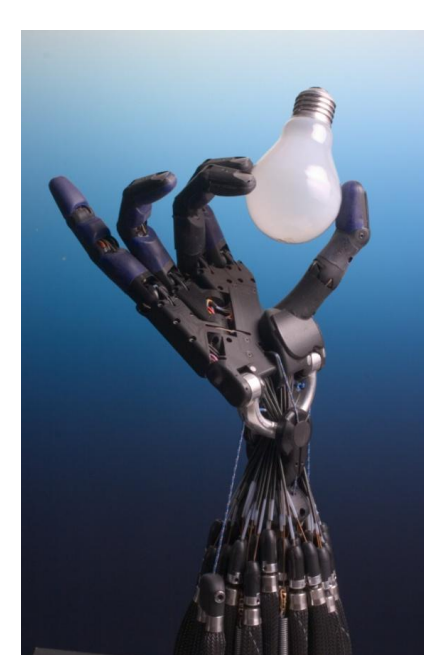
University of Minnesota – Materials Research Science and Engineering Center



## Introduction

Galfenol ( $\text{Fe}_{1-x}\text{Ga}_x$   $x = 10-40\%$ ) is a relatively new Gallium-Iron material that shows magnetostriction or a change in its magnetization direction in response to compression and deformation. Other materials show this, but Galfenol is 230 times more responsive than most. Most highly magnetostrictive materials tend to be very brittle whereas Galfenol is more mechanically stable.

If the Galfenol could be grown as wires and its magnetostriction detected, new uses could be envisioned. For example, touch sensors could be developed to be used for sensitivity equipment such as robotic finger tips.



## Abstract

The goal of this project was to electroplate and characterize thin films of metal alloys that have not been previously studied. Galfenol ( $\text{Fe}_{1-x}\text{Ga}_x$ ) was found to be highly magnetostrictive, so other materials also containing Gallium may show similar characteristics. All of the desired thin films were able to be electroplated, but the compositions of the films were not ideal. The biggest obstacle encountered was high levels of oxides found in the films. To minimize this, the molarities of the initial electro synthesis solution must be optimized. Once perfected, these alloys will be used to grow nanowires to develop touch sensors.

## Project Outlook

Synthesize Additional Thin Film Materials

- $\text{Ni}_{1-x}\text{Ga}_x$
- $\text{Ni}_2\text{CoGa}$
- $\text{Co}_2\text{MnGa}$

Characterize similar materials made into thin films

Grow nanowires of those materials

- Same process as electroplating thin films only using templates instead of substrates
- Two types of templates
  - Bilayer Gold and Anodized Aluminum Oxide (AAO)
    - stiff, brittle
  - Polycarbonate Material
    - flexible, durable, ideal for compression testing
- Alternate deposition between Galfenol and Copper to form layered nanowires

Grow Galfenol and Copper layered nanowires in different templates

- Three different sizes of holes: 0.05  $\mu\text{m}$ , 0.1  $\mu\text{m}$ , 0.2  $\mu\text{m}$
- Chemically etch away AAO leaving Nanowires exposed and attached to Gold layer
  - Used for characterization

Compression Testing

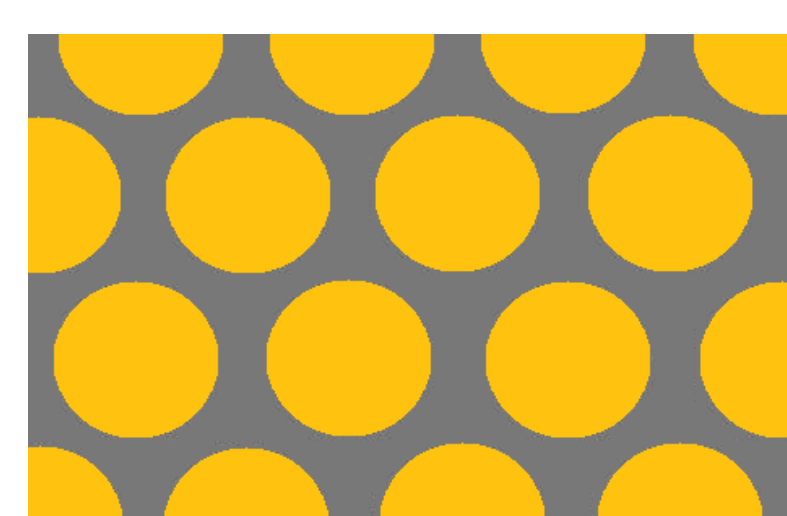
- Use un-etched polycarbonate template

Touch Sensors

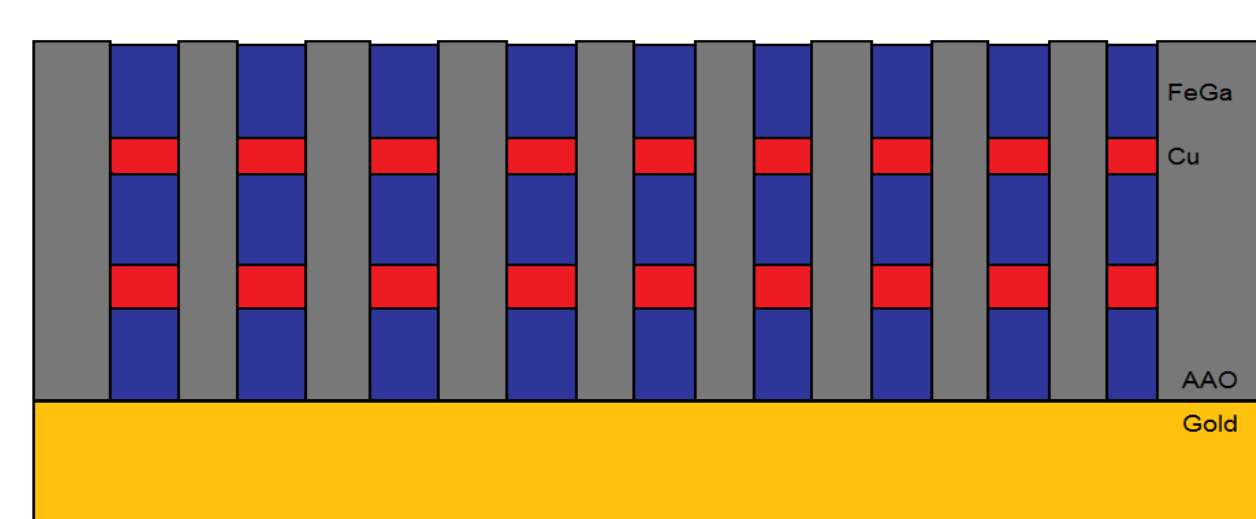
- Ideal for robotic arms especially while working with delicate equipment and materials

Other Applications yet undiscovered

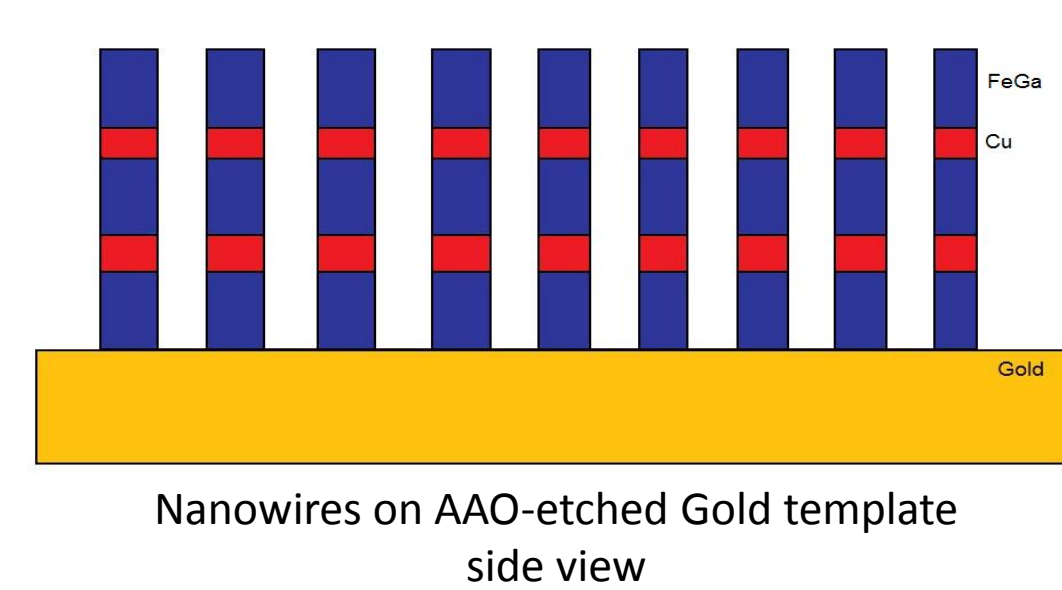
- New characteristics will lead to new applications



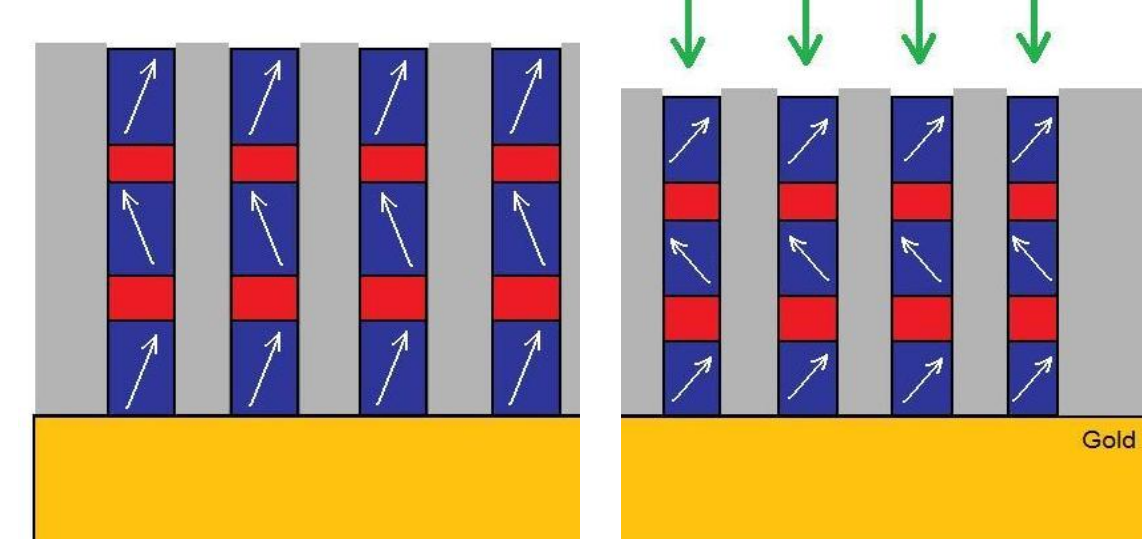
AAO as viewed from above with Gold layer below



AAO and Gold Template with Nanowires, side view



Nanowires on AAO-etched Gold template side view



Compression Testing - Polycarbonate

## Electro Synthesis and Electroplated Thin Films

Galfenol and similar materials also containing Gallium were simultaneously electro synthesized and electroplated onto brass substrates using the experimental setup shown. A test called chronoamperometry is run using a computer program. There are three electrodes; the working, reference, and counter electrodes. The working electrode is the brass substrate that has a negative charge to attract the positively charged ions in the solution to be electroplated. The reference electrode checks that the potential between the working electrode and the electrolyte is of the desired value. The counter electrode is made of Platinum and has a positive charge, but does not experience any electroplating.

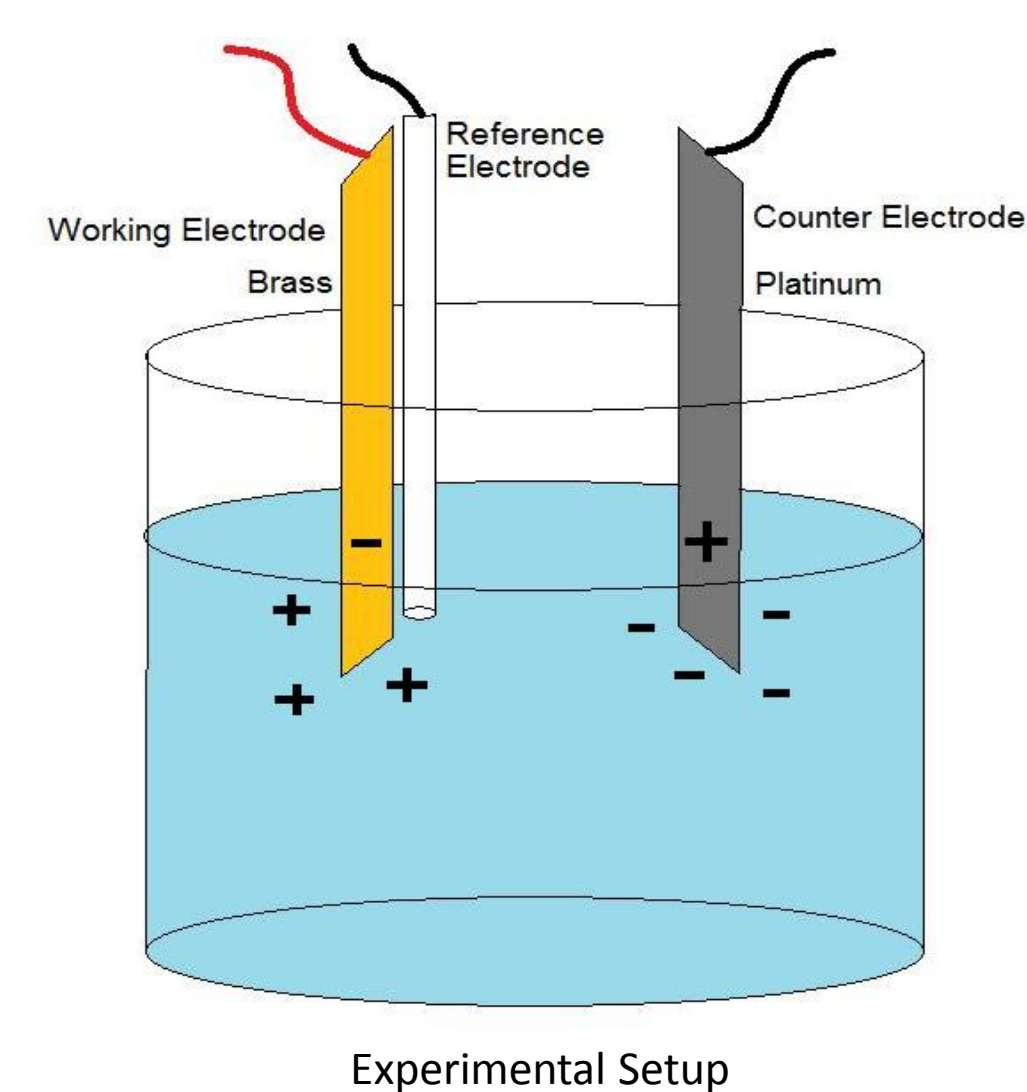
For each solution, twenty samples were made. The pH was increased in increments of 0.5 usually starting around 3.5 and adjusted 4 times ending around 5.0. For each pH, the voltage was also increased from -800 mV to -1200 mV in increments of 100 mV, so there were five different potentials. Each sample had only one pH value and one potential, resulting in 20 samples. Once the test was run, the samples with metallic deposition were examined and photographed on a tabletop Scanning Electron Microscope (SEM). From that group, the best samples were taken to the SEM in the Characterization Facility and were analyzed using Energy Dispersive X-Ray Spectroscopy (EDS) to show the composition of the thin film. Pictures of the samples and thin films as well as graphs of their composition are shown below.

List of Thin Film Materials Studied (chemicals made with in parenthesis)

- $\text{FeGa}$  (2, 3, 6)
- $\text{Co}_{1-x}\text{Ga}_x$  (1, 2, 6)
- $\text{Ni}_2\text{MnGa}$  (2, 4, 5, 6)
- $\text{Fe}_2\text{MnGa}$  (2, 3, 4, 6)

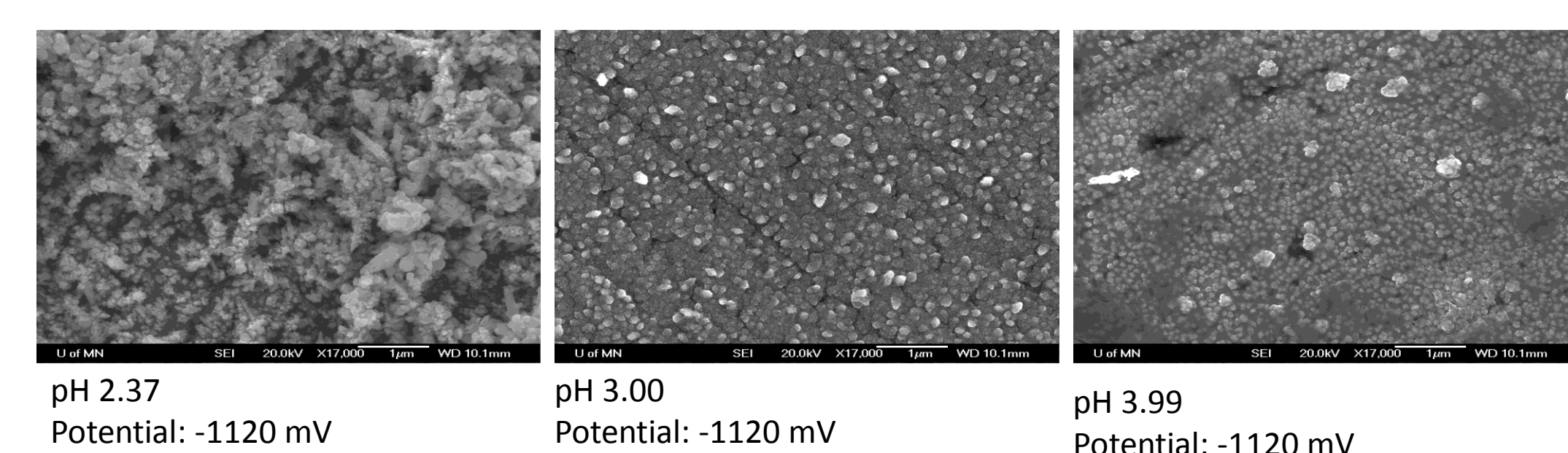
To Electro Synthesize the desired thin films, the following chemicals were used, respectively.

- Cobalt (II) Sulfate Heptahydrate  $\text{CoSO}_4 \cdot 7\text{H}_2\text{O}$
- Gallium (III) Sulfate Hydrate  $\text{Ga}_2(\text{SO}_4)_3 \cdot x\text{H}_2\text{O}$  ( $x \sim 18$ )
- Iron (II) Sulfate Heptahydrate  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$
- Manganese (II) Sulfate Monohydrate  $\text{MnSO}_4$
- Nickel (II) Sulfate Hexahydrate  $\text{NiSO}_4 \cdot 6\text{H}_2\text{O}$
- Sodium Citrate Dihydrate  $\text{HOC}(\text{COONa})(\text{CH}_2\text{COONa})_2 \cdot 2\text{H}_2\text{O}$



Experimental Setup

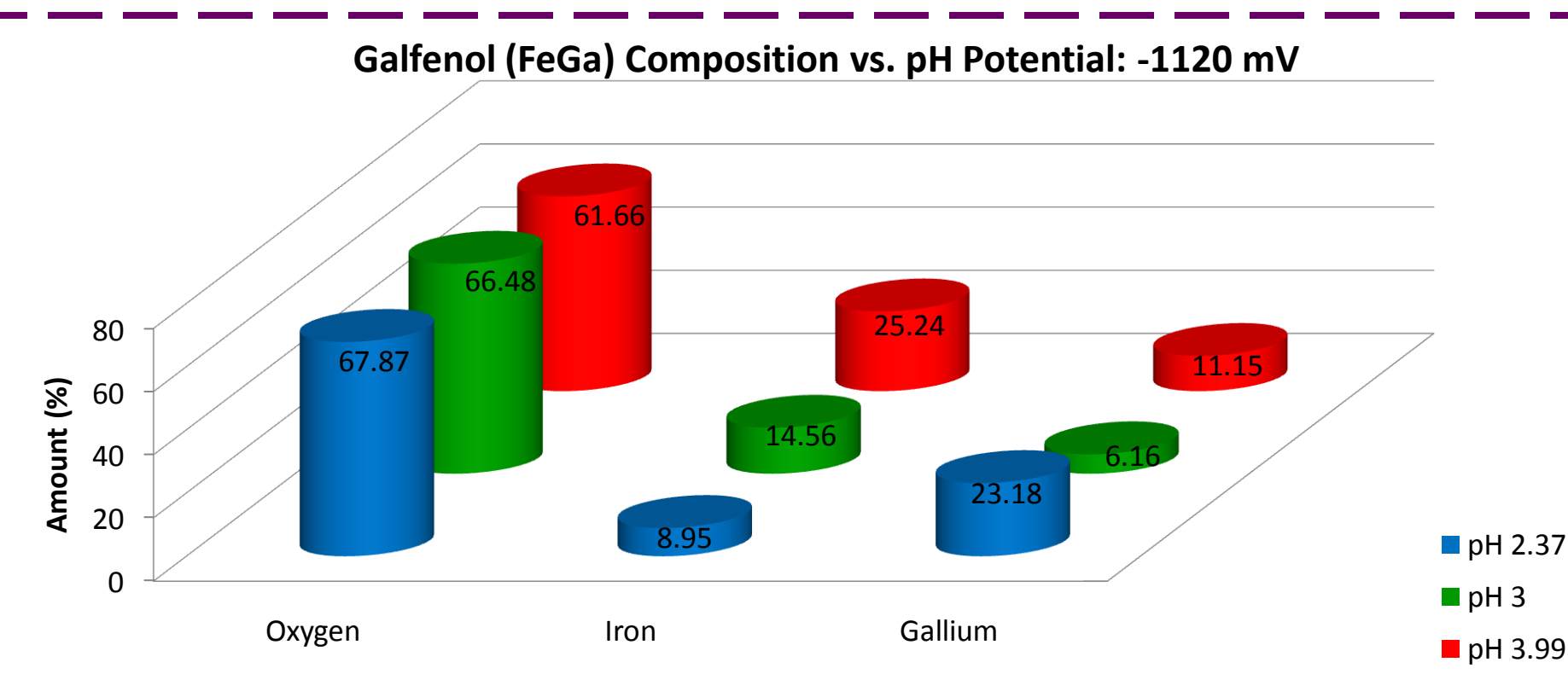
Galfenol (test run with aged electrolyte)



pH 2.37 Potential: -1120 mV

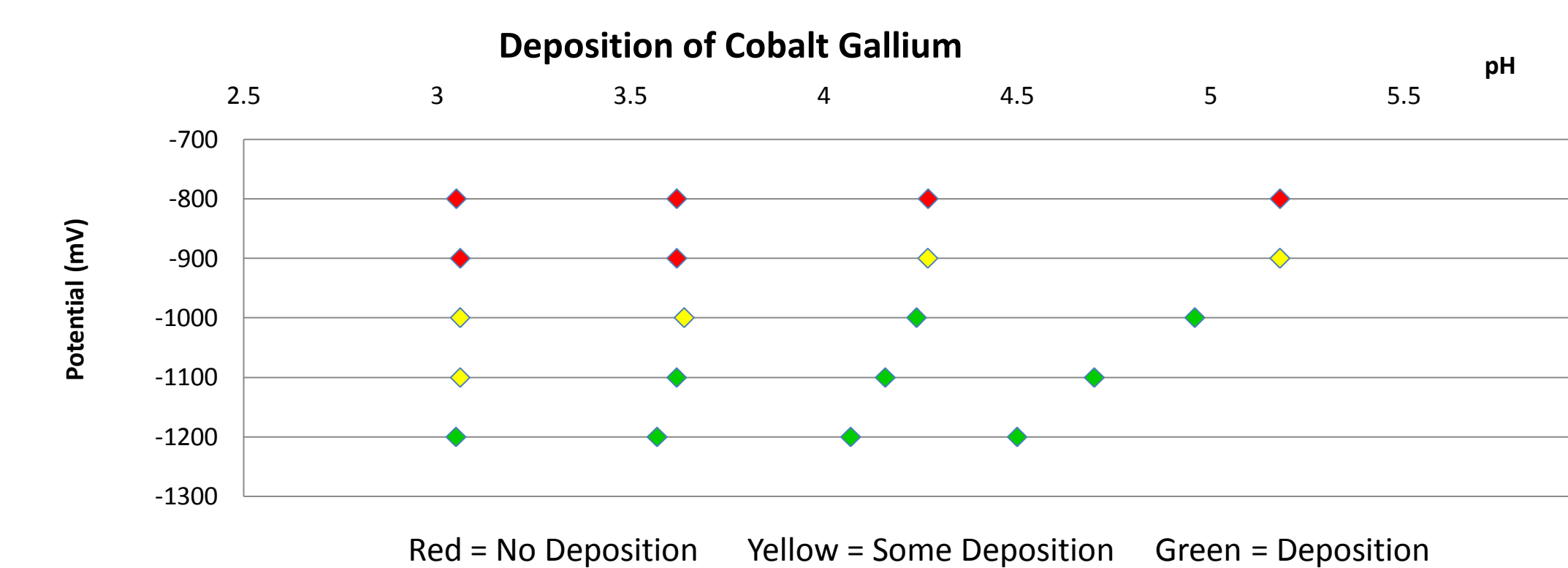
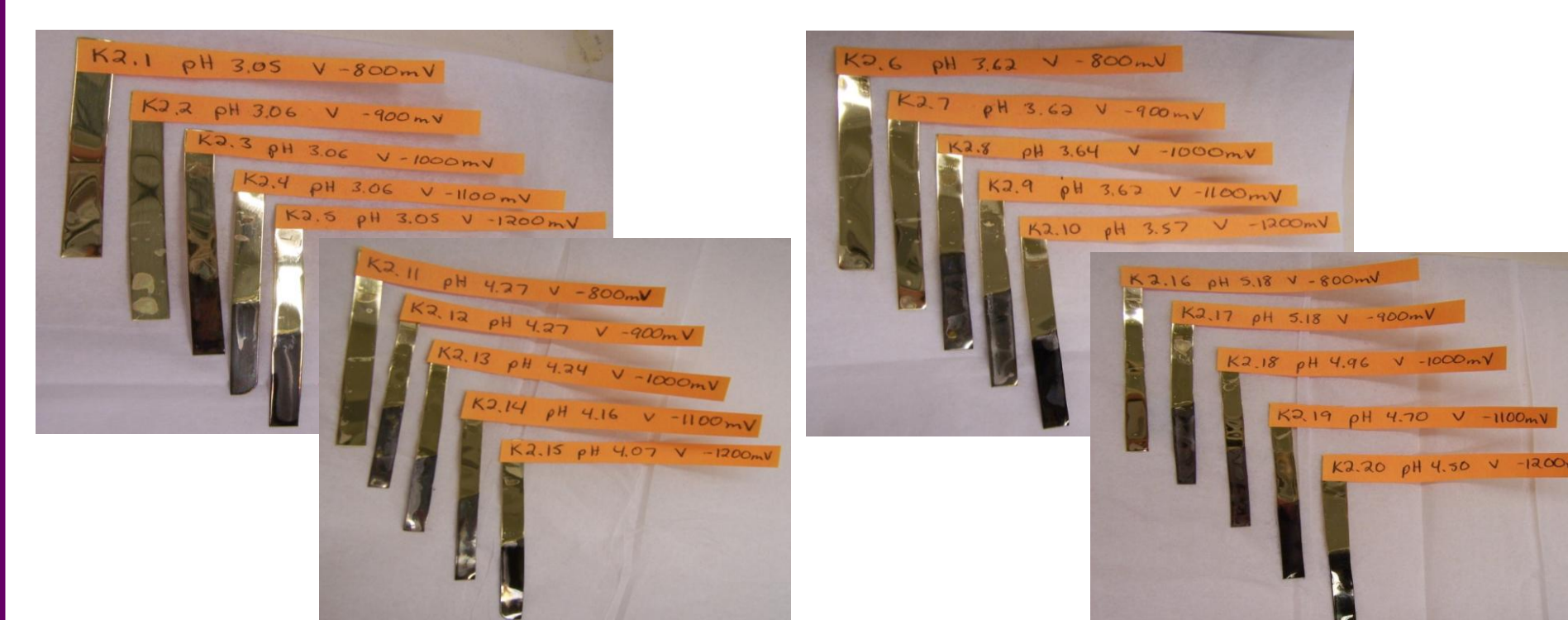
pH 3.00 Potential: -1120 mV

pH 3.99 Potential: -1120 mV

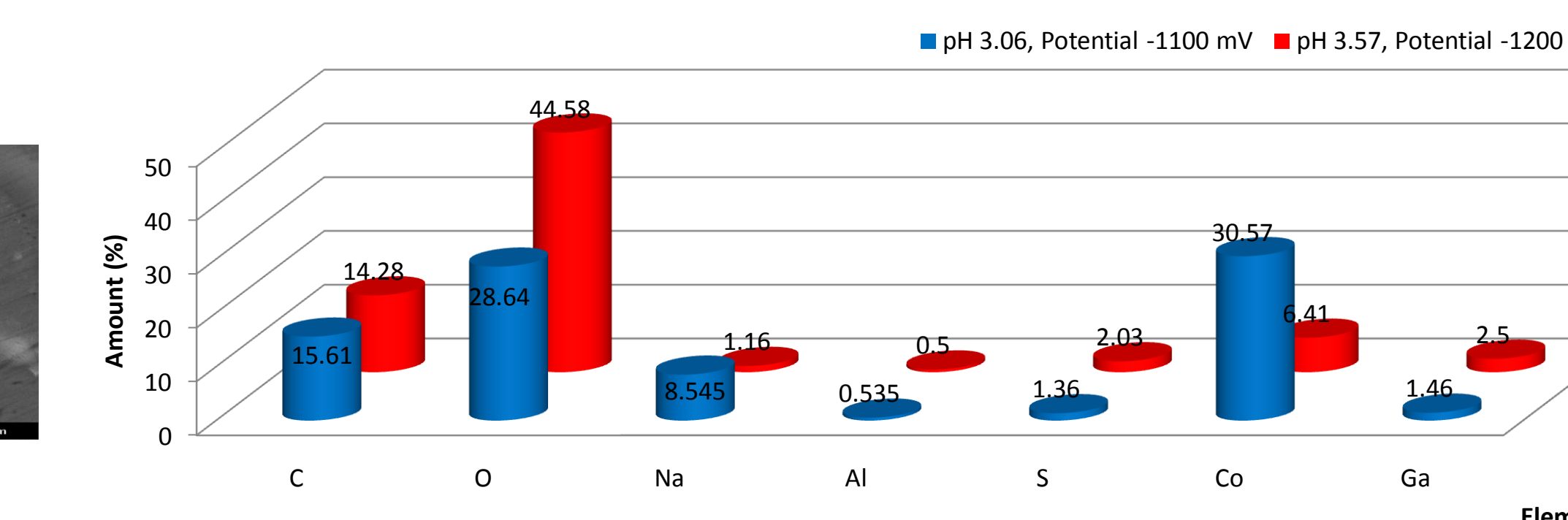


## Electro Synthesis and Electroplated Thin Films (continued)

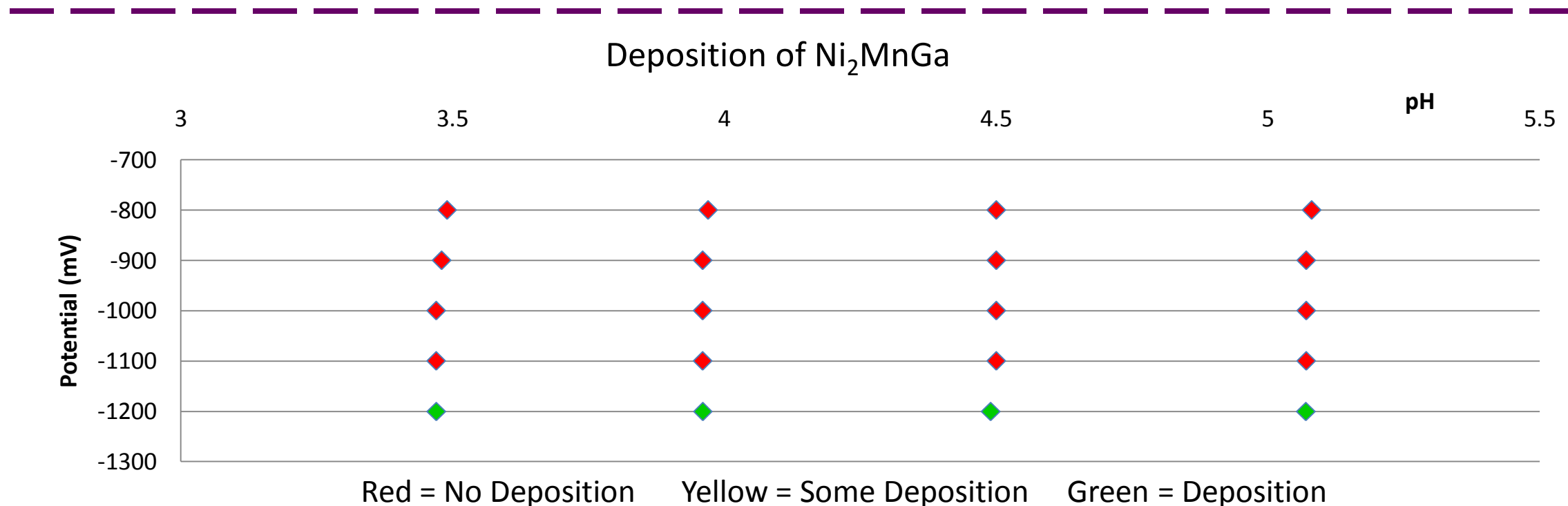
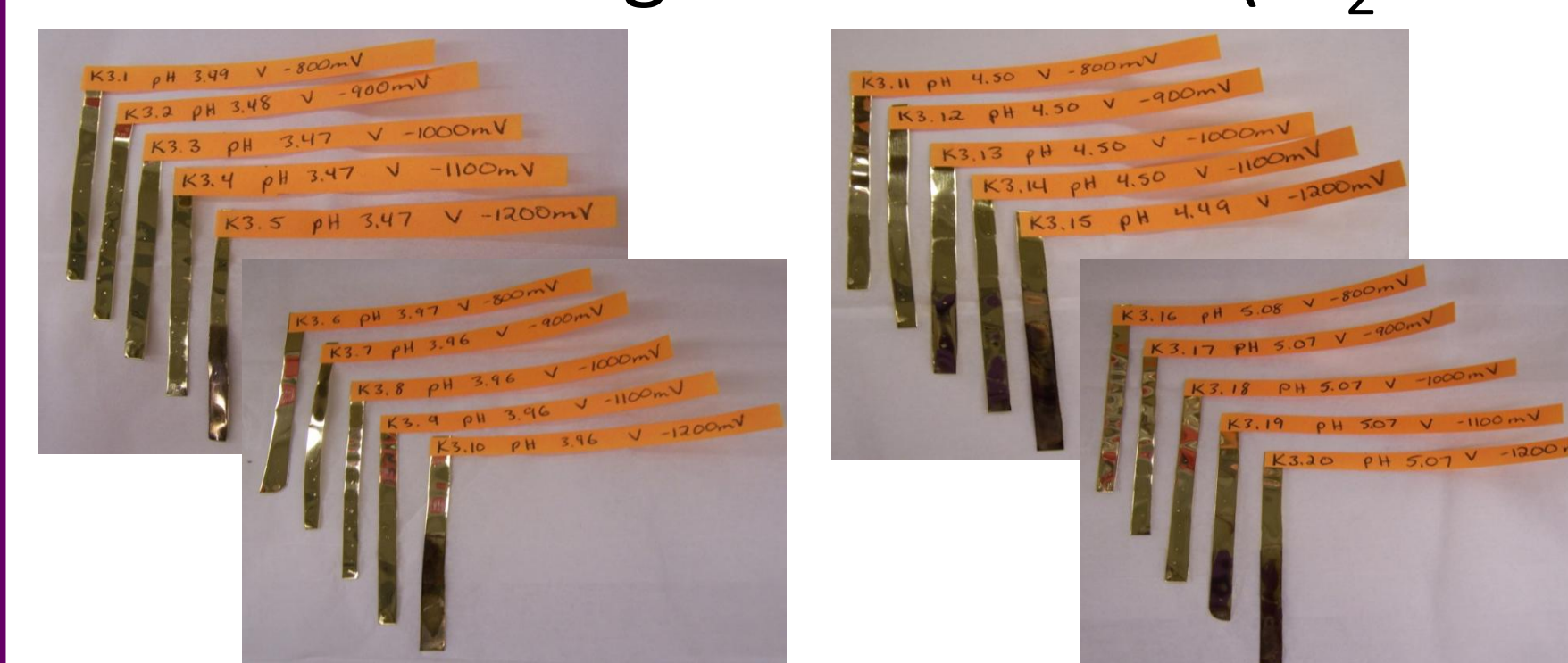
Cobalt Gallium (CoGa)



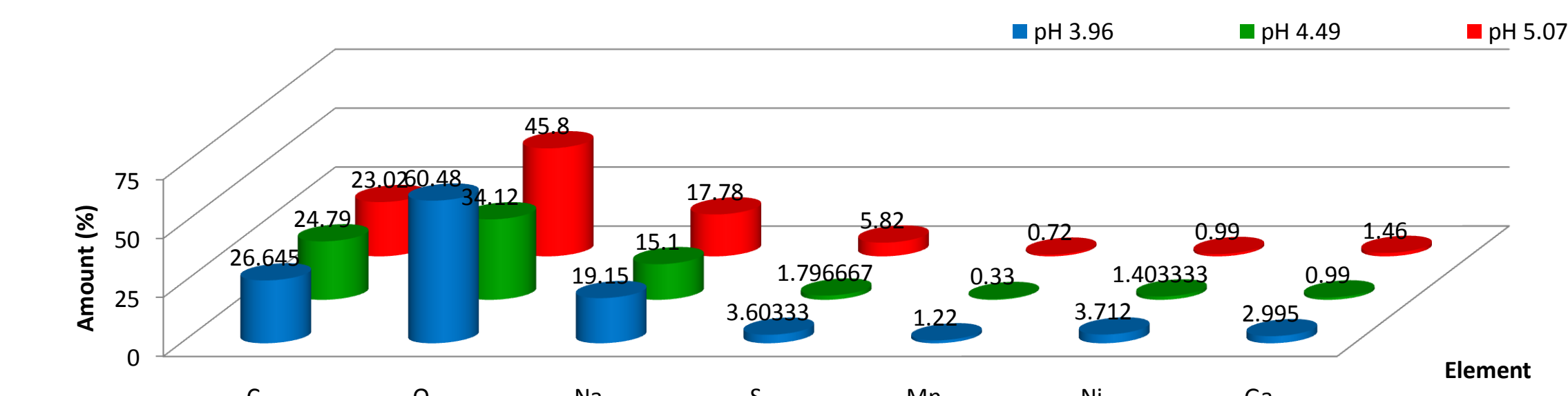
Cobalt Gallium (CoGa) Thin Films Composition vs pH



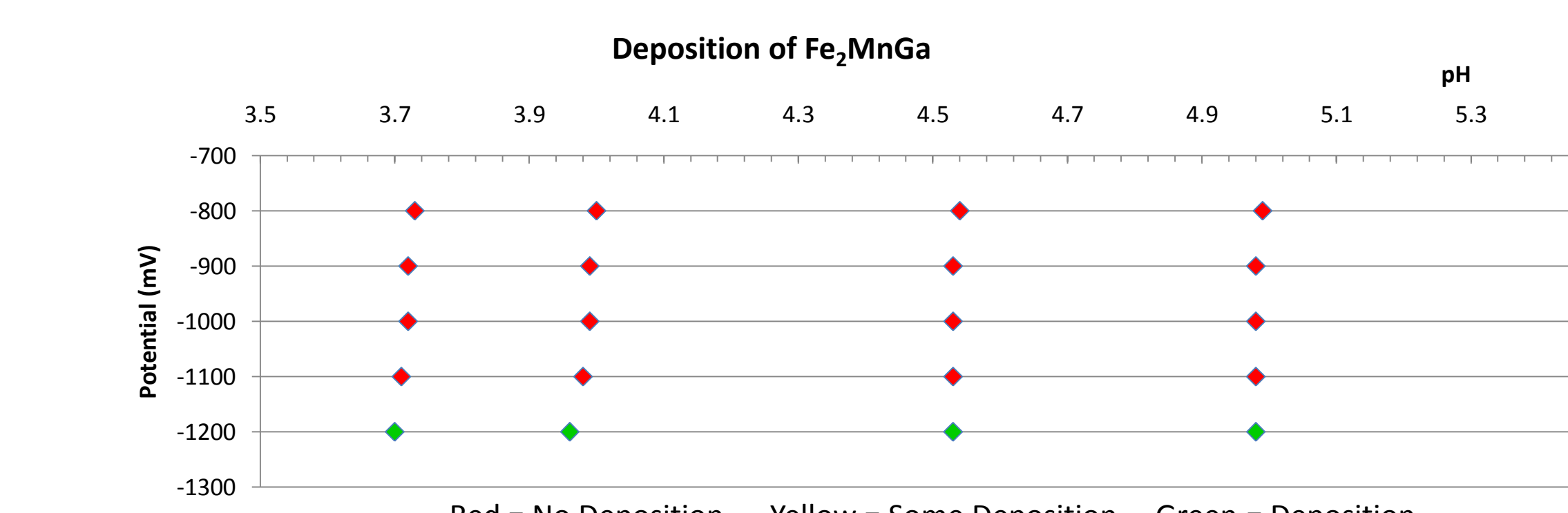
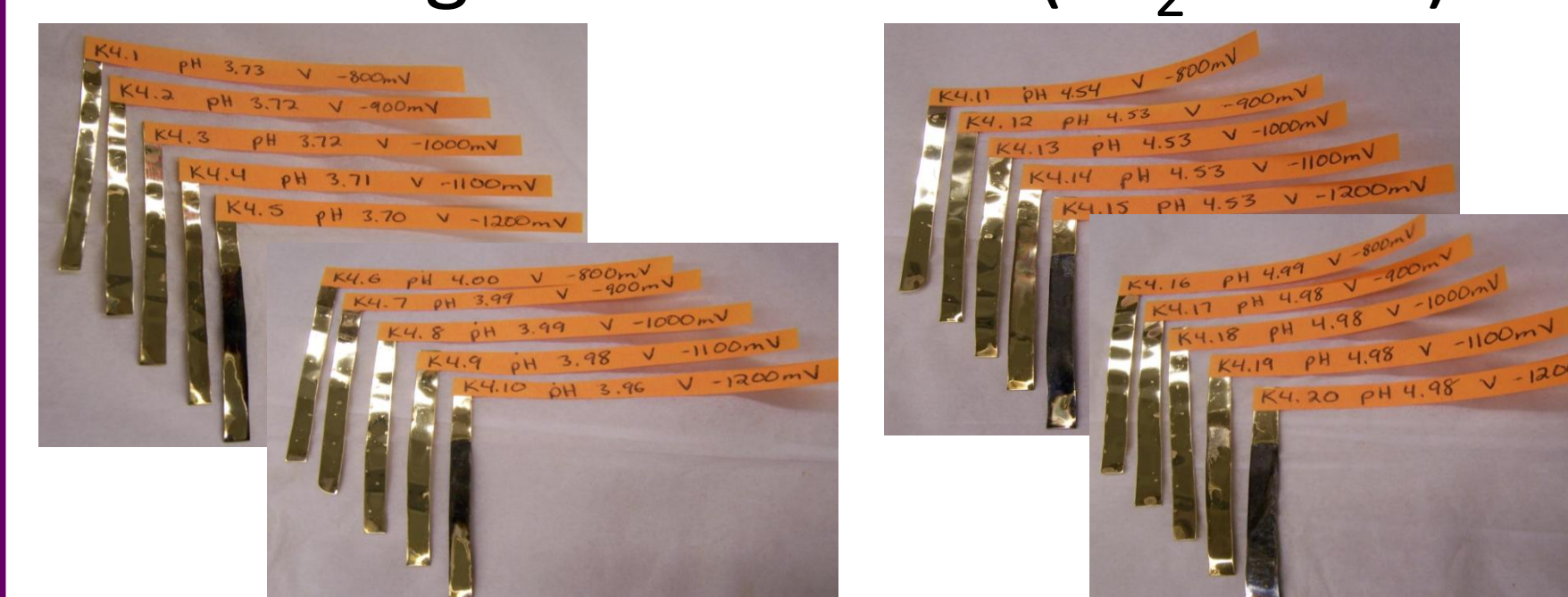
Nickel Manganese Gallium ( $\text{Ni}_2\text{MnGa}$ )



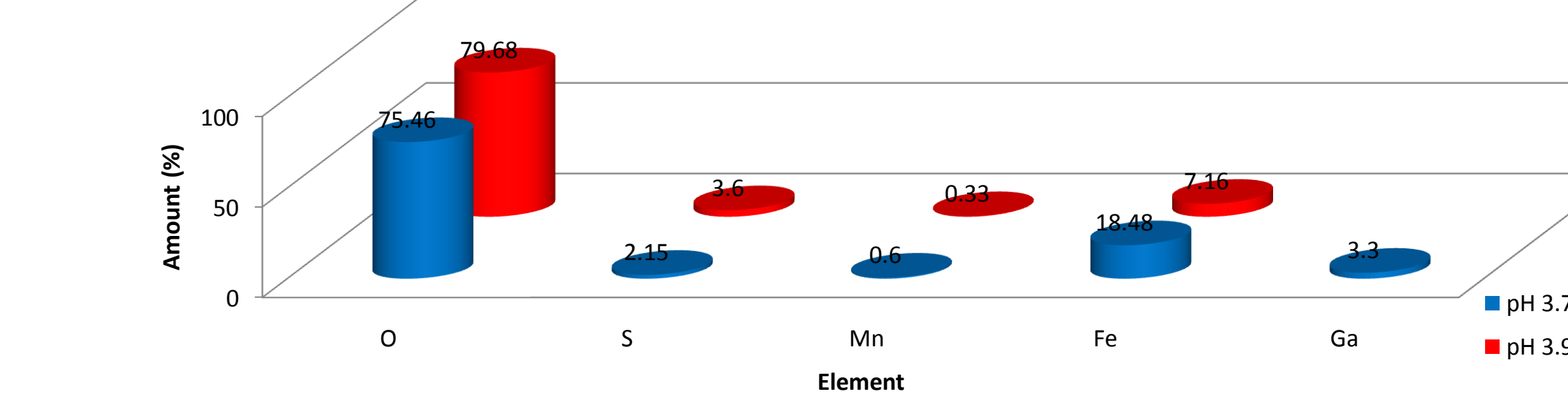
Nickel Manganese Gallium ( $\text{Ni}_2\text{MnGa}$ ) Thin Film Composition vs pH Potential: -1200 mV



Iron Manganese Gallium ( $\text{Fe}_2\text{MnGa}$ )



Iron Manganese Gallium ( $\text{Fe}_2\text{MnGa}$ ) Thin Film Composition vs pH Potential: -1200 mV



## Conclusions

- Nonideal metals such as Gallium and Manganese were codeposited with ferromagnetic metals
- Adjust Molarities to optimize electrolyte composition
  - Minimize oxides, more metal
- Nickel Manganese Gallium is especially interesting because of its shape memory characteristics

## Acknowledgements

- This work was supported primarily by the National Science Foundation MRSEC and REU programs under Award Numbers DMR-0754792 & DMR-0819885.

