

## INTRODUCTION

A great amount of interest has recently been shown in exploiting the magnetic properties of iron oxide nanoparticles for applications with biomedical importance, including:

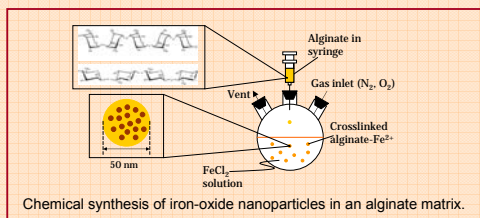
- use as a magnetic-resonance imaging contrast agent
- targeted drug delivery
- novel externally-controlled therapeutic treatments

Biomedical use of these nanoparticles requires their containment in a biocompatible matrix.

## SYNTHESIS OF $\gamma$ -Fe<sub>2</sub>O<sub>3</sub> IN AN ALGINATE MATRIX

Using the preparation method of *Kroll et al.*<sup>1</sup> nanoparticles of  $\gamma$ -Fe<sub>2</sub>O<sub>3</sub> have been synthesized inside alginate hydrogels. These alginates should be biocompatible and hydrophilic, more suitable characteristics for biomedical applications than competing technologies (i.e. polystyrene resin).

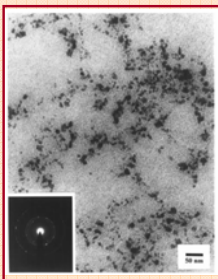
The alginate matrix is a naturally occurring polysaccharide that forms rigid cross-linked gels. The cross-linking ion is the reaction center for the *in situ* formation of nanocrystalline  $\gamma$ -Fe<sub>2</sub>O<sub>3</sub>.



## PROPERTIES OF THE ALGINATE/NANOPARTICLES

Iron-oxide-containing alginate beads precipitate out of solution. Multiple loadings are performed to increased Fe concentration and bead size. After several loadings:

- The alginate forms spherical beads of several mm diameter
- The  $\gamma$ -Fe<sub>2</sub>O<sub>3</sub> nanoparticles within the sample are 1-5 nm in diameter
- The hydrogels are 0.5-5.5 wt% of Fe in wet bead form or 10-50 wt% of Fe in dehydrated powder (composition completely unknown after synthesis!)



TEM of alginate/iron oxide bead; magnification 20 000. (Ref. 1).



A dehydrated powdered alginate-nanoparticle sample as presented to our group. The ferro-magnetism of the sample is evident due to the small magnet the sample sits upon.

Testing the Fe mass fraction of samples is performed by costly atomic emission spectrometry at labs outside the state. We wished to develop the in-house capability to measure Fe concentrations in these samples using LIBS.

<sup>1</sup> E. Kroll, "In situ preparation of nanocrystalline  $\gamma$ -Fe<sub>2</sub>O<sub>3</sub> in Iron(II) cross-linked alginate gels," *Chem. Mater.* 8, pp.1594-1596 (1996)

## SAMPLE PREPARATION

To measure the Fe concentration in an unknown alginate/Fe<sub>2</sub>O<sub>3</sub> sample, a calibration curve was prepared from 13 standard concentrations of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> and silver compressed into thin, solid pellets.

### Why use $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>?

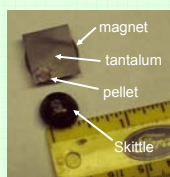
1. Differences with  $\gamma$ -Fe<sub>2</sub>O<sub>3</sub> purely structural → will not effect a LIBS (atomic) measurement.
2. Easier and cheaper to obtain sufficient quantities.

### Why mix the $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> with Ag?

1. The lab synthesizing these samples also pelletizes the alginate with Ag to facilitate low-temperature magnetic measurements. These standard pellets most closely resemble their samples.
2. The Ag acts as a structural binder for the alginate/Fe<sub>2</sub>O<sub>3</sub> (which is extremely crumbly and does not pelletize well).
3. The presence of Ag in the standard samples allows us to make Fe/Ag emission line intensity ratio measurements rather than absolute Fe emission intensity measurements.

## PELLETIZATION PROCEDURE

- Precisely measured masses of research-grade  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> nanopowder (5-25 nm) and Ag powder (2-3.5  $\mu$ m) were combined and mechanically agitated as well as agitated in an ultrasonic water-bath.
- Mixtures were compressed in a hardened machine-steel dye by a 20 ton hydraulic press.
- Pellets were 5 mm diameter, 200 micron thickness and had a total mass of ~60 mg.



Sample Number	Fe Mass Fraction	Ag Mass Fraction	Sample Number	Fe Mass Fraction	Ag Mass Fraction
1	0.0888	0.8729	8	0.2543	0.6360
2	0.1263	0.8192	9	0.2938	0.5795
3	0.1447	0.7929	10	0.3151	0.5490
4	0.1604	0.7704	11	0.3495	0.5000
5	0.1959	0.7197	12	0.4047	0.4209
6	0.2105	0.6988	13	0.4237	0.3937
7	0.2460	0.6480			

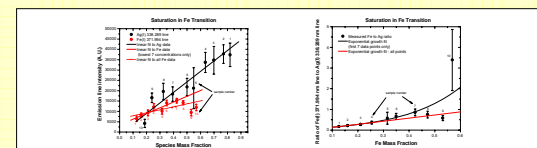
## IDENTIFICATION OF SPECTRAL LINES

- Simultaneously monitor emission intensity from 12 Ag I and II lines and 25 Fe I and II lines.
- Use Ag (I) at 338.289 and Fe (I) at 371.994 nm for calibration curve.
- Other lines exhibit similar behavior but become hard to measure at low concentration.
- Area of Lorentzian fit to emission line profile determines intensity.

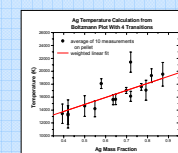
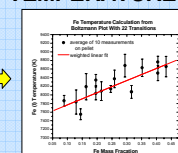
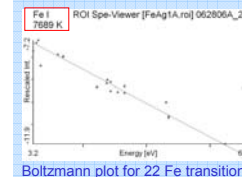


## SATURATION

At Fe mass fractions greater than ~0.45 the Fe transition at 371.994 nm begins to exhibit saturation. Only calibrated standards of Fe mass fraction less than this value were used to construct the calibration curve. The Ag transition at 338.289 exhibited no such behavior.



## TEMPERATURE



## APPARATUS

### LASER

Spectra-Physics LAB 150-10 Series, 650 mJ/pulse max, operating at 1064 nm, pulse repetition frequency = 10 Hz (fixed), pulse duration = 10 ns

### SPECTROMETER

LLA ESA3000 Echelle spectrometer with fiber-coupled input. Detection with a 1024 x 1024 pixel Intensified CCD-array (24  $\mu$ m<sup>2</sup> pixel size). Spectral range = 200 - 834 nm with 0.005 nm resolution (in the UV).

### OPTICS

3x beam-expander expands beam from original 9 mm diameter to 27 mm. 9 mm iris transmits central 1/3 of diameter to clean Gaussian mode. Beam splitter for overlay of visible HeNe laser for beam visualization. 20x high-damage threshold infinite-conjugate microscope objective (OFR).

Spot size at target near diffraction limit (~10  $\mu$ m). Energy at substrate = 10 mJ/pulse.

### TARGET HOLDER

X-Y translation stage with pico-motor control capable of 0.5 $\mu$ m movement with nm-stepping resolution.

## EXPERIMENTAL PARAMETERS

Measurement delay time after laser shot = 1  $\mu$ s; Gate width = 20  $\mu$ s

1. 5 laser shots for one spectrum, then sample translated horizontally
2. 10 spectra averaged for one "measurement" (50 shots per measurement)
3. 10 measurements taken per sample. (500 laser shots for one point on calibration curve)

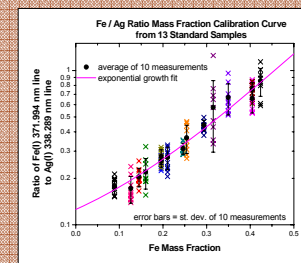


This work funded in part by the National Science Foundation – Wayne State University Smart Sensors and Integrated Microsystems (SSIM) REU program and by Wayne State University.

## CALIBRATION CURVE

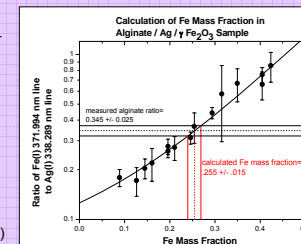
- Final calibration curve constructed from 15 measurements taken on 13 calibrated standards over the course of one month.
- Weighted fit to an exponential growth curve.

Parameter	Value	Error
Model: Exponential Growth		
Equation: $y = A1 \cdot \exp(x/t1) + y0$		
Weighting: $w = 1/x^2$		
Chi <sup>2</sup> /DoF	R <sup>2</sup>	
0.27685	0.97373	
y0	0.06523	0.03523
A1	0.06063	0.02067
t1	0.16662	0.02174



## CALCULATION OF UNKNOWN CONCENTRATION

- A known mass of Fe<sub>2</sub>O<sub>3</sub>-containing-alginate powder was mixed with a known mass of Ag powder and pelletized.
- Ratio of Fe to Ag emission line measured.
- Matrix effect due to alginate composition assumed to be negligible.
- Fe mass fraction of alginate sample calculated from curve.
- Resulting value in agreement, but on the high end of estimated Fe mass fraction.



Calibration with alternate matrices (such as Cu powder) yet to be investigated