Sensors in an Alternating Magnetic Field for Magnetic Nanoparticle Hyperthermia Cancer Therapy

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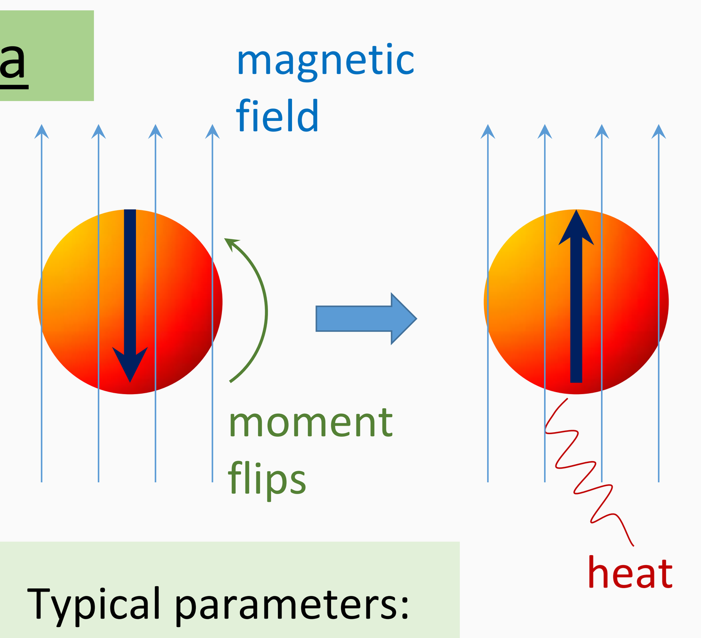
Summary: Magnetic nanoparticle hyperthermia is a promising method of cancer therapy. Accurate characterization of nanoparticle heating is required to further this technology. One problem is that metallic sensors undergo their own eddy current heating in an alternating magnetic field. We explore the useful limits of metallic sensors in the alternating magnetic field environment. Patterned thin film sensors in particular may be advantageous, as the heating is size dependent and patterned thin films are scalable into arrays of sensors.

Magnetic Nanoparticle Hyperthermia

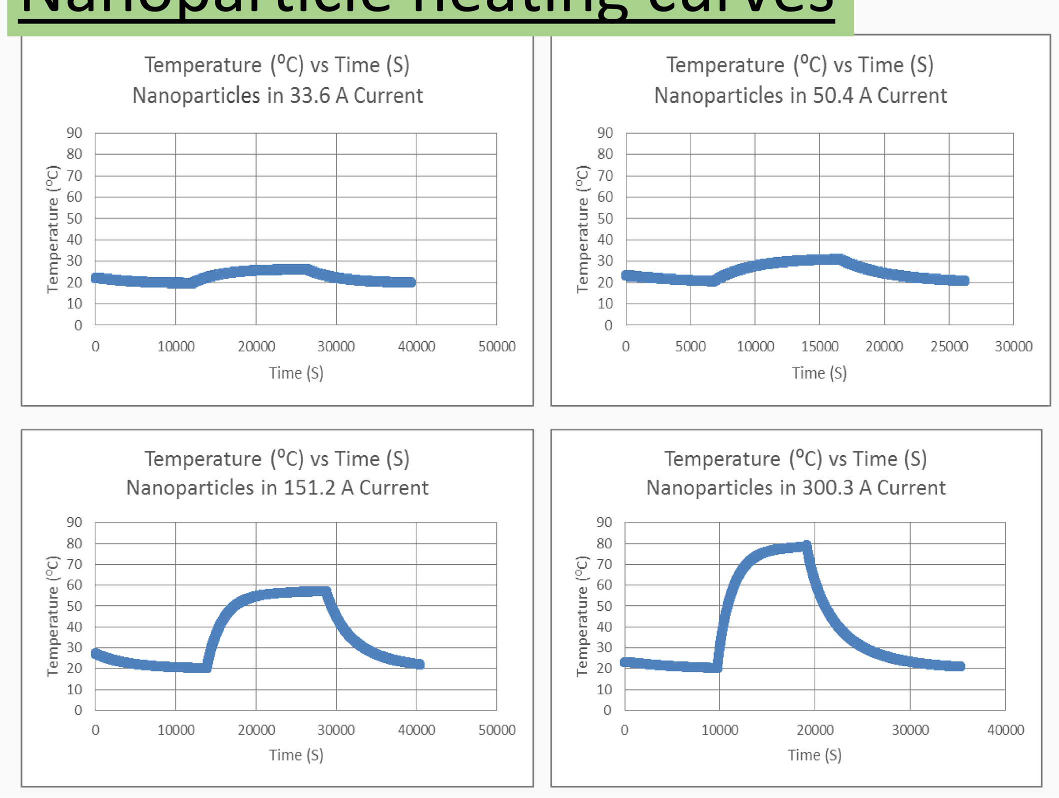
A promising method of CANCER THERAPY

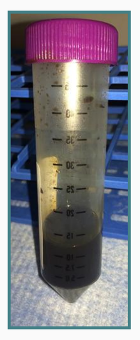
How it works:
- Magnetic nanoparticles injected into tumor
- Alternating magnetic field applied
- Nanoparticle moments flip
- Energy released as heat
- Tumor cells damaged 43-44 °C
- Healthy cells damaged ~45 °C



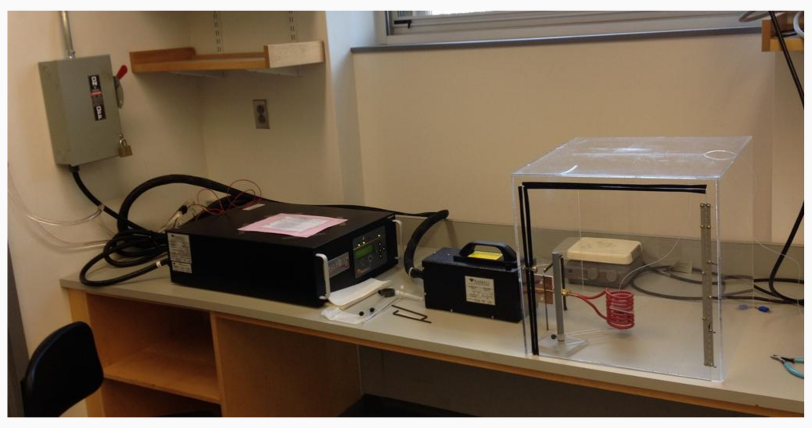
Typical parameters:
- 100-500 kHz
- 0.01-0.1 Tesla
- 33-42°C

Nanoparticle heating curves





10 nm Fe_3O_4 nanoparticles in H_2O, 20 mg/mL, from Liquids Research. Heating in max 0.04 T field



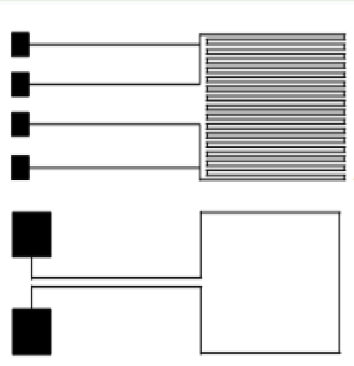
Alternating magnetic field generator (Easyheat)

Patterned thin film sensors

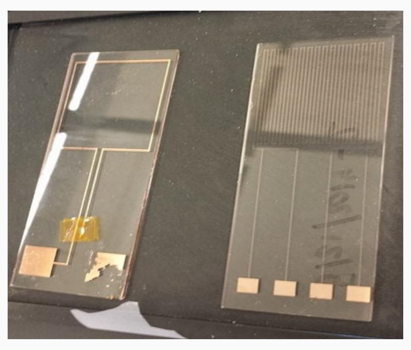
Design and Fabrication

a. Resistive Sensor Design (thermometer)

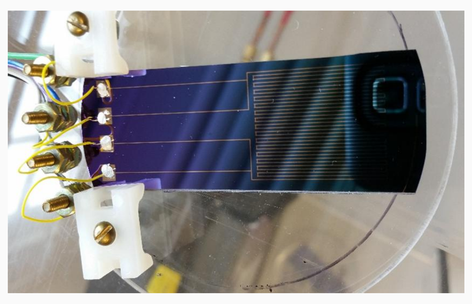
b. Inductive Sensor Design (magnetic field sensor)



Process:
- Thermal evaporation:
  - 30ÅCr sticking layer
  - 500-2000ÅCu
- Photolithography

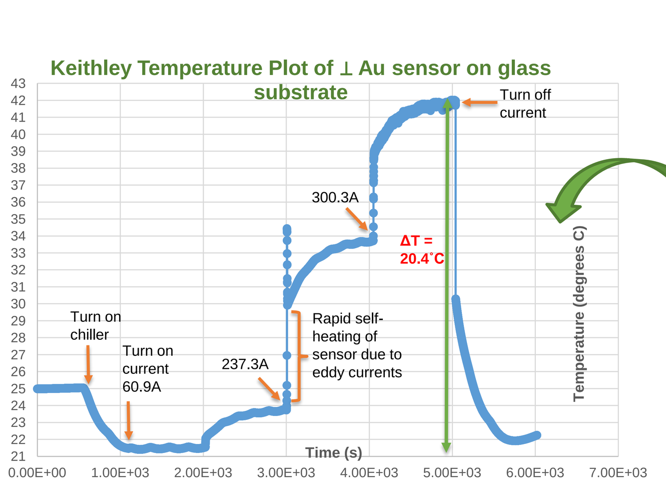


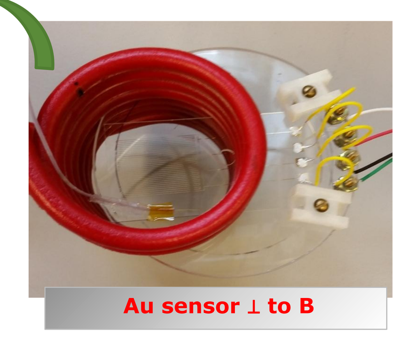
Inductive and Resistive sensor on glass slide



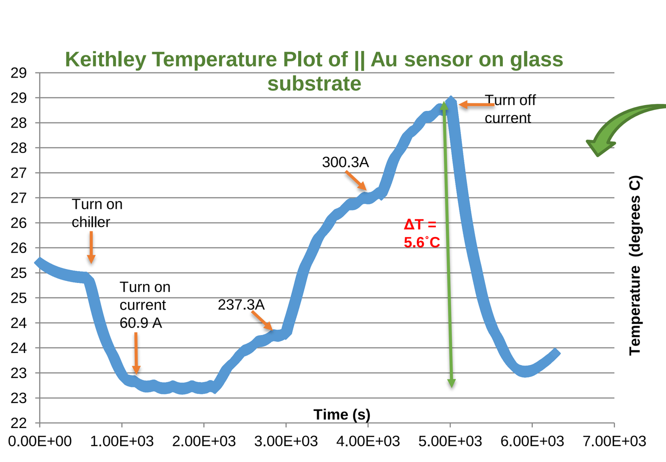
Sample Au thin film resistive sensor on a thermal oxide silicon substrate

Temperature sensor:

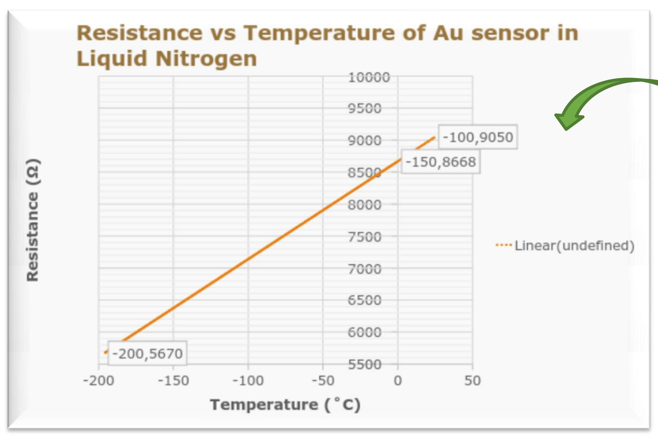


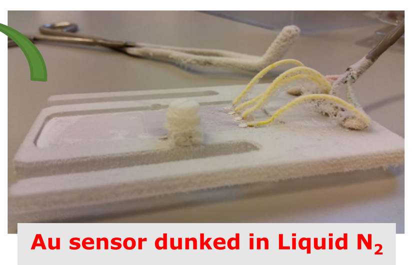


Au sensor ⊥ to B



Au sensor || to B





Au sensor dunked in Liquid N_2

Results:

Position of Au sensor	Keithley Data (ºC)	Opsens Data (ºC)	Net ΔR (Ω)
Sensor | | to B	5.6	7.2	1.04E+02
Sensor ⊥ to B	20.4	9.1	3.89E+02

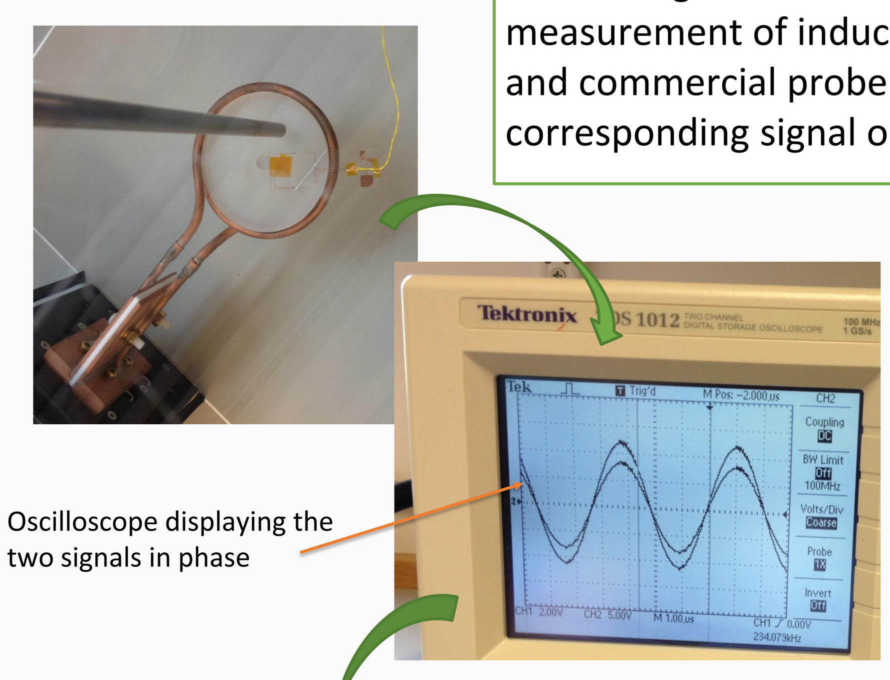
Opsens data:
- Temperature measured at the tip of the fiber optic, which is near the sensor.
- Data collected better at estimating the surrounding heating of the various components used with the sensor.

Keithley data:
- Temperature of sensor directly measured by passing current through sensor, making it a more accurate measurement of sensor self heating.

The same Au sensor tested in alternating magnetic field was dunked in liquid Nitrogen in to observe the resistance relation with change in heat in the cold extreme:
- Correct linear resistance-temperature relation
- In room temperature the dunked sensor returned to the original 9kΩ resistance

Magnetic field sensor:

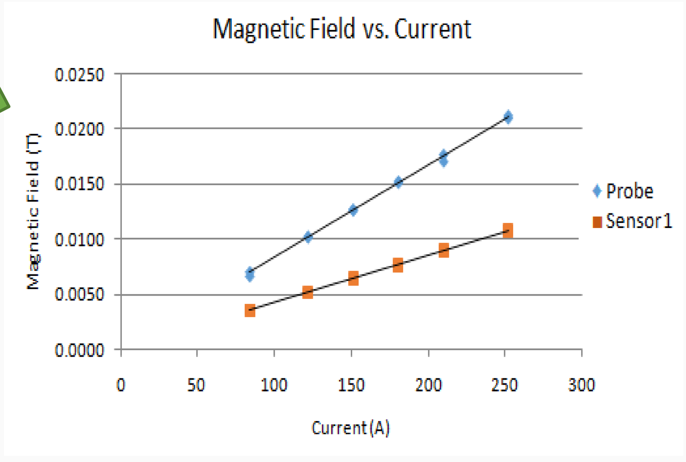
In situ magnetic field measurement of inductive sensor and commercial probe and their corresponding signal output



Oscilloscope displaying the two signals in phase

Results:

Thin film magnetic field sensor compares well to commercial magnetic field probe:
- Signals in phase
- Correct magnetic field dependence



Future Work

Future work will focus on characterizing Au thin film sensors of varied thicknesses and stroke sizes as metal heating in alternating magnetic field (AMF) is a function of size. Also, a careful calibration and scale down of both resistive and inductive sensors.

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