DESIGN AND POTENTIAL APPLICATIONS OF STOCHASTICALLY NANOSTRUCTURED METAL FILMS

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ABSTRACT

Due to their unique morphology, stochastically nanostructured metal films can exhibit a broad range of unusual physical, chemical, and quantum mechanical properties. Physically, structures can vary from fields of spherical aggregates to reefs of coral-like branching structures that form through diffusion limited aggregation. Such nanostructured thin metal films may be condensed on a cooled substrate from thermally evaporated metals in the presence of a buffer gas. The simplicity and low costs of this preparation technique are particularly appealing from the point of view of ultimate scalability. Our immediate objective is to determine the effects of varying metallic composition, temperature, pressure, and gas species on properties of the film. Films will be characterized using SEM, transport measurements, and various optical and chemical probes. Measured properties will guide the search for novel applications. Potential applications include the identification of individual molecules through surface enhanced Raman spectroscopy, higher infrared absorptivity for single photon detectors, and the developments of solid catalysts with higher surface area to mass ratios. The disordered structure of the films may also result in novel low-temperature quantum transport properties. Our ultimate goal is to correlate depositional parameters with structure, and structure with properties, in order to enable the design of nanostructured thin metal films suitable for various applications in science and industry.

INTRODUCTION

- Nanostructured thin metal films are nanometer to micrometer thin layers of metal that display structures at the nanoscopic and microscopic scales. Collectively, these structures amount to physical, chemical, and quantum mechanical properties beyond what t altering composition can allow.
- These properties and novel methods to produce them, may serve useful in applications in science and industry.

Potential Applications

<u>Condensed Matter Physics</u>
Superconductivity: Variances in structural disorder enhance superconductivity in thin metal films.
<u>Cosmology and Astrophysics</u>
Near Infrared Photometry: Higher resolution infra red images for mapping the universe may be possible with thin metal films performing as single photon detectors.
<u>Chemistry</u>
Catalysis: Thin film's low mass and high surface area may be very useful for solid state catalysis.
<u>Biology</u>
Surface-Enhanced Raman Spectroscopy: The detection and identification of individual molecules that bind to the film's surface may be possible and allow for the sequencing of the nucleotides of the genome.

OBJECTIVE

- Vary the deposition parameters
  - Metallic composition, temperature, pressure, and gas species
- Characterize the resulting morphology
  - Examination of scanning electron micrographs
- Measure the properties
  - Electrical and thermal conductance, optical absorptivity and emissivity, photoacoustic response, superconductivity
- Search for potential applications
  - Higher temperature superconductors, single photon detectors, catalysis, surface enhanced Raman spectroscopy

MATERIALS

- <u>Thermal evaporator</u>: Capable of supplying250Amps of current for heating metal up to 3000K. Thermally evaporates metal at pressures down to 420 nTorr.
- <u>Substrates</u>: Glass, muscovite, copper foil, or aluminum foil substrates provide the metal vapor a surface to condense on.
- <u>Metal evaporant</u>: Copper, indium, and aluminum pellets serve as the evaporant.
- <u>Argon tank</u>: Supplies the chemically unreactive buffer gas that fills the vacuum chamber.


Thermal Evaporator

METHODS

- Evaporation

Appropriate metal evaporant and substrates are chosen and mounted for evaporation.

The vacuum chamber is pumped down to the appropriate pressure are repeatedly flushed with argon to eliminate the presence of oxygen in the vacuum chamber.

Electric current is supplied to heat a resistive boat that heats the metal to the appropriate pressure for evaporation.

Evaporation continues until the desired film thickness is reached.

Evaporation ceases, the machine is cooled down and the vacuum chamber is vented.

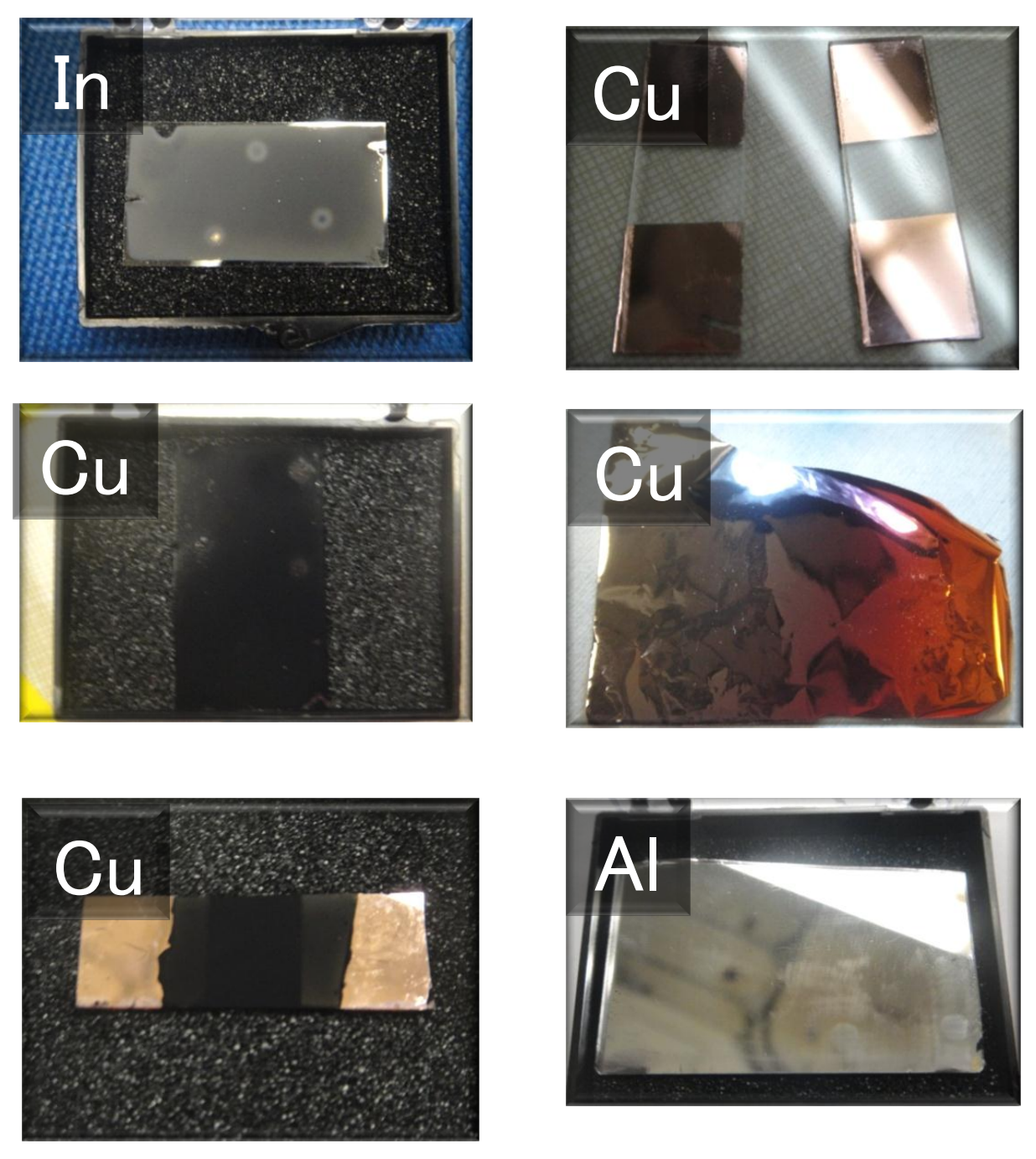
Thin metal films are collected and documented.

- Examine Morphology

Scanning electron micrographs are taken of the films, images are compared, and the structures are described. Images of a single metal at various depositional parameters are compared and similar structures are correlated with their respective depositional parameters.

- Measure properties

Thin films are measured for their electrical conductivity, photoacoustic response, and optical absorptivity.



<u>Thin Films</u>
Changing deposition parameters yield monoelement films of various colors and structures.

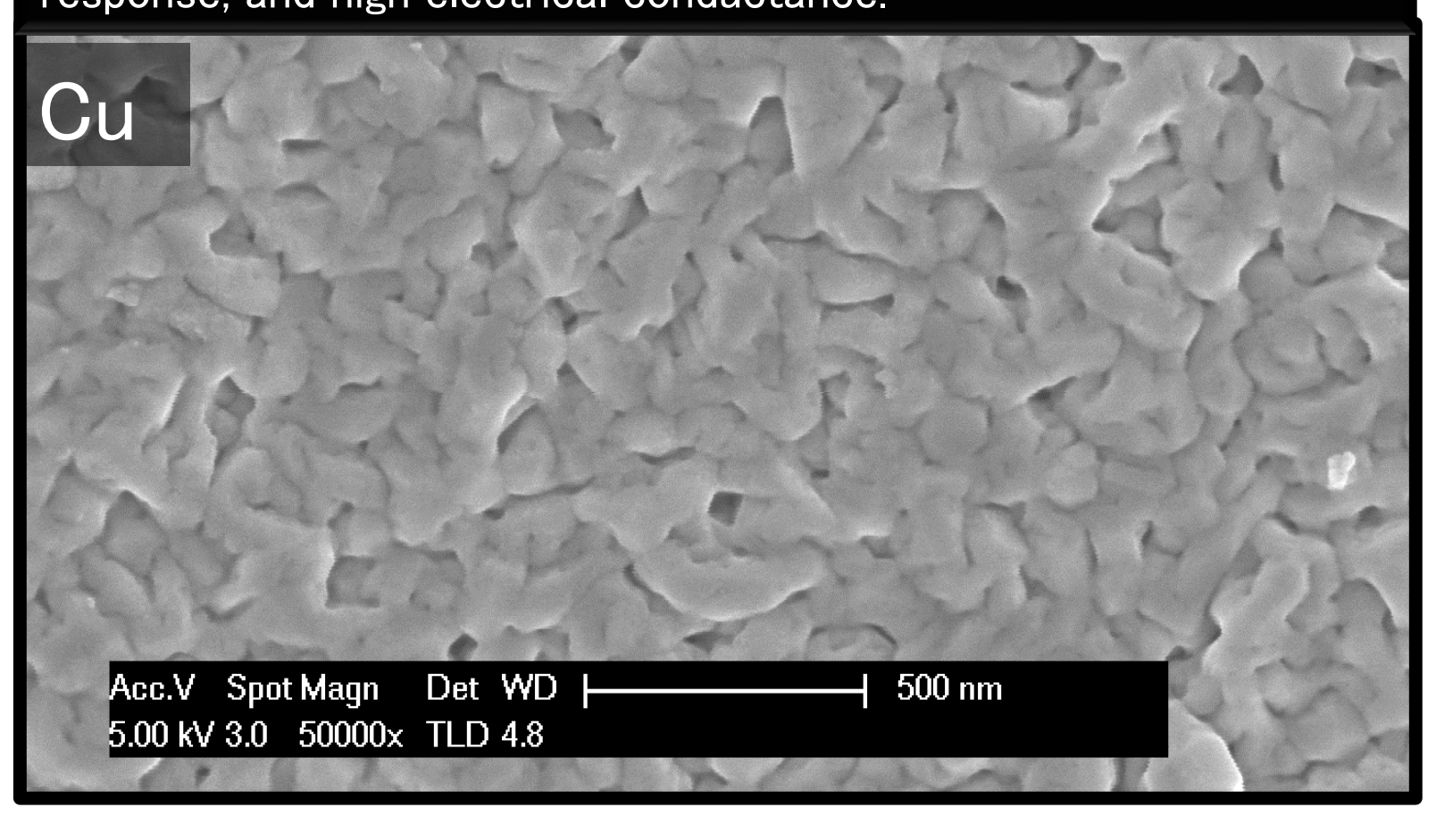
RESULTS

<u>Thin Film Morphology</u>
High deposition pressures, on the range of 1- 5 Torr, yield films with higher relief structures that resemble diffusion limited aggregates.
Low deposition pressures , on the range of 0.5 – 1000 µTorr, yield films with lower relief structures.

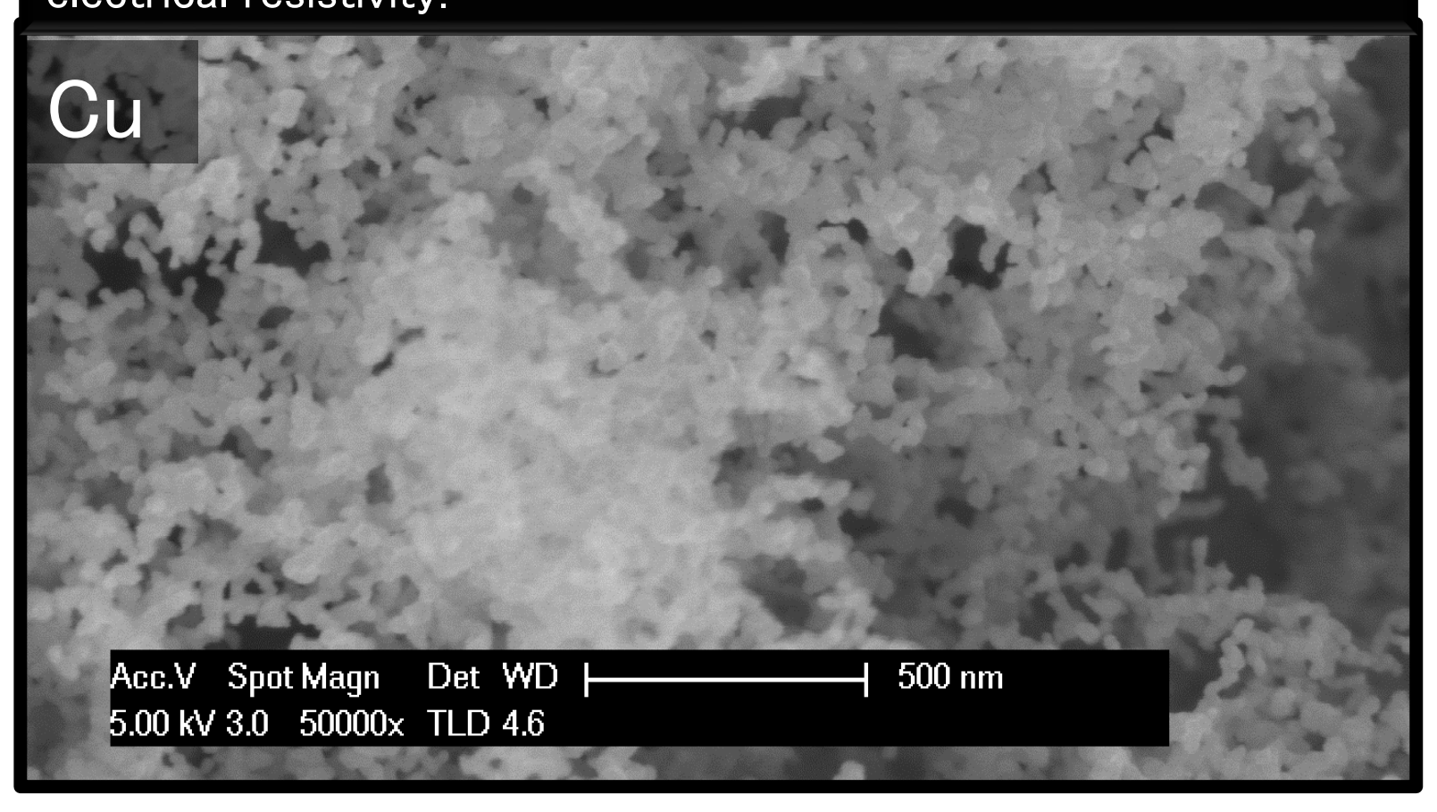
The distance and direction from the evaporation source also affects the structure the films will have and is currently under investigation.

<u>Thin Film Properties</u>
High structural relief thin films have higher optical absorptivity, a stronger photoacoustic response, and higher electrical resistivity ; on the order of 50Ω for copper.
Low structural relief thin films have higher optical reflectivity, a weaker photoacoustic response, and very low electrical resistivity; less than 0.1Ω for copper.

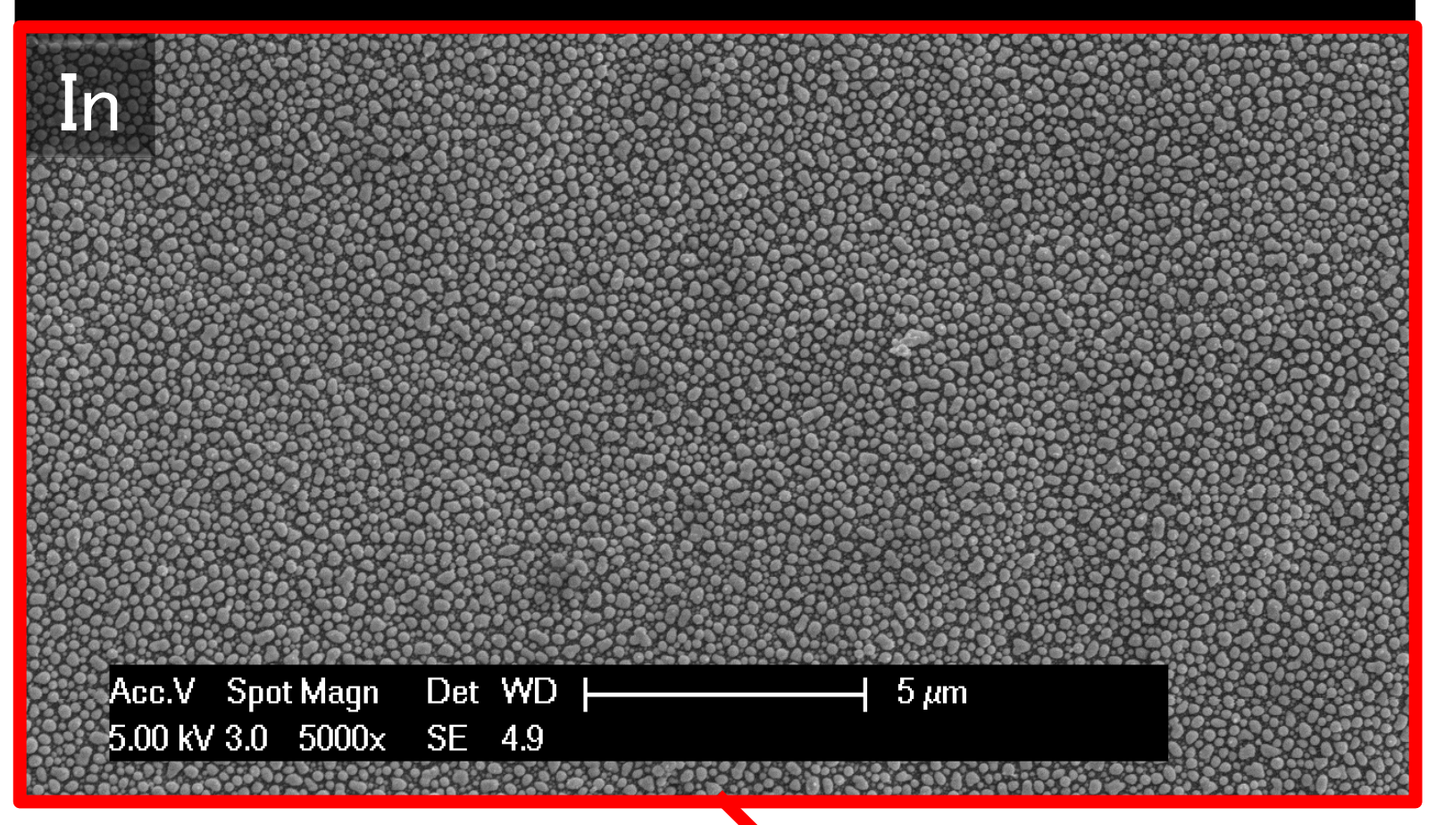
<u>Copper Thin Film</u>
.A deposition pressure of 10 µTorr results in a low relief thin film with high optical reflectivity, no detectable photoacoustic response, and high electrical conductance.



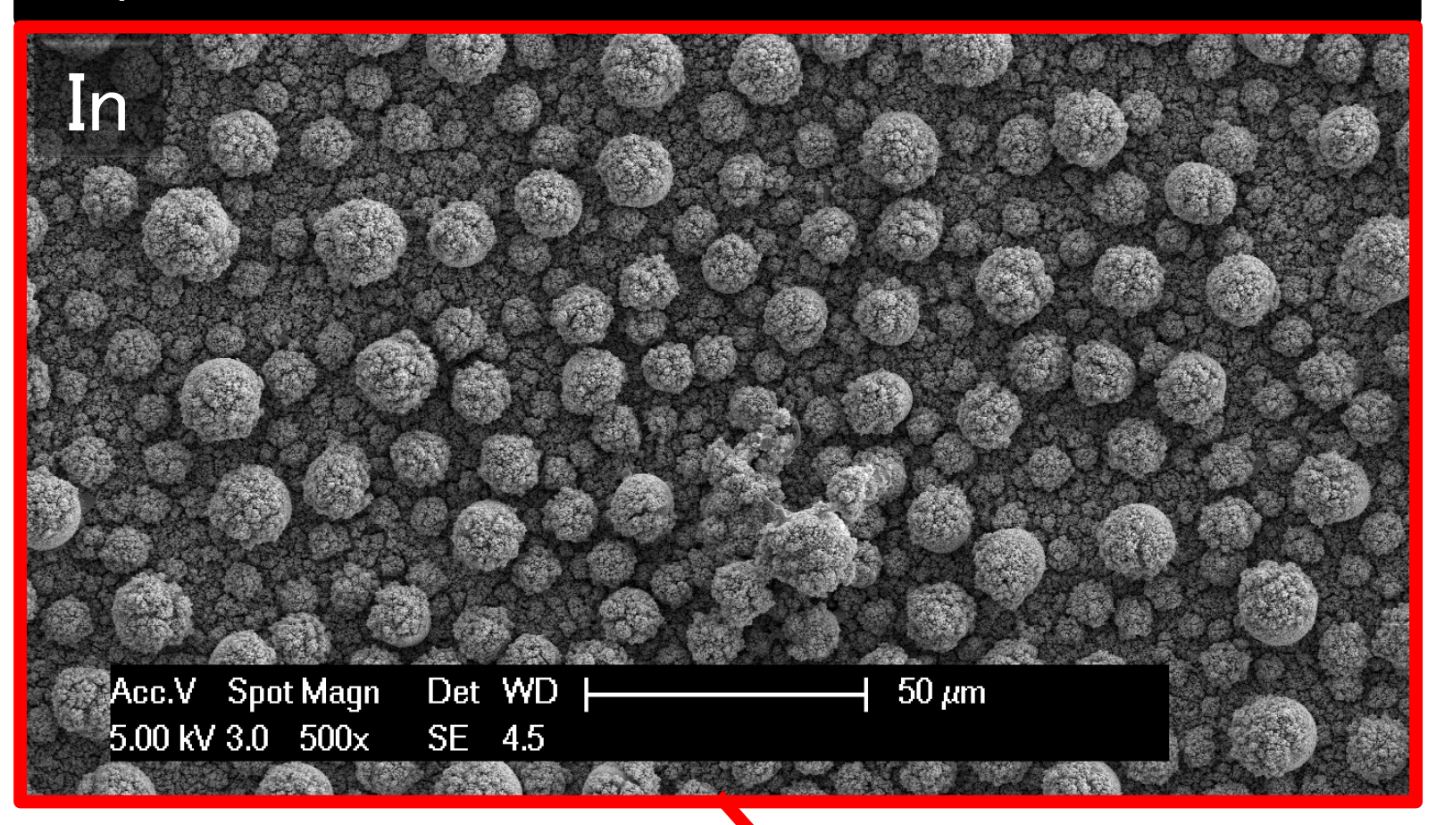
<u>Copper Thin Film</u>
A deposition pressure of 4 Torr results in a high releif film with high optical absorptivity, a strong photoacoustic response, and high electrical resistivity.

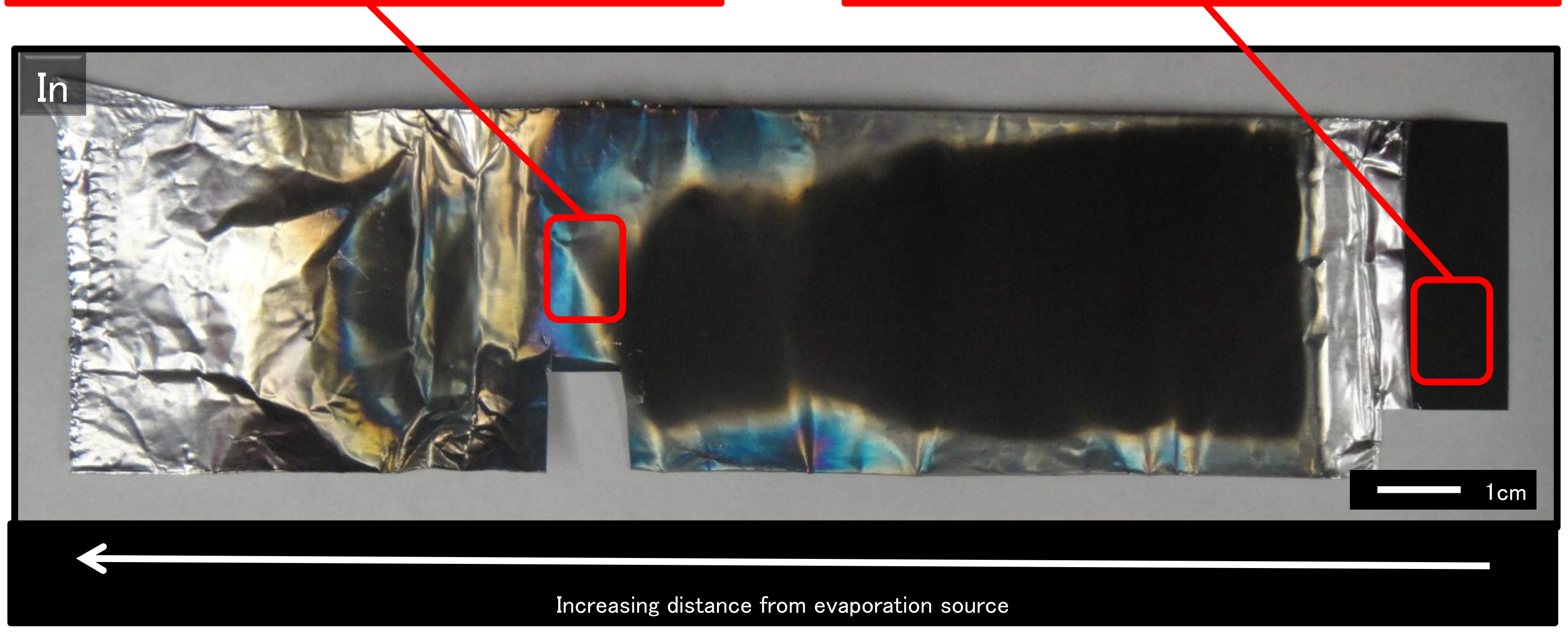


<u>Indium Thin Film</u>
Thin indium blue film is composed of nanoparticles that do not exhibit a detectable photoacoustic response.



<u>Indium Thin Film</u>
Thin indium black film is composed of structures resembling diffusion limited aggregates that exhibit a strong photoacoustic response.

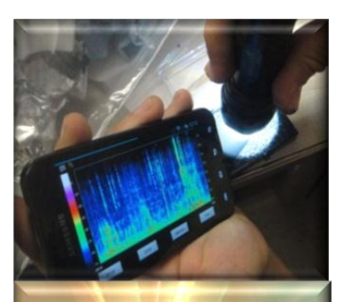




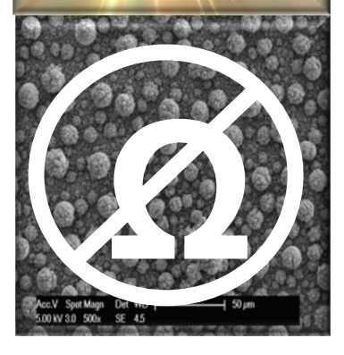
CONCLUSIONS

- The depositional parameters largely determine the structures that will comprise the thin films.
- The properties of these films are largely an effect of or determined by their structure.
- Because these properties are ultimately a function of depositional parameters and composition, nanostructured thin metal films can be designed to meet the needs of various applications.
- Because thin metal films are relatively cost effective to produce and the process of thermal evaporation has a capacity for larger scalability, these films may serve useful to science and industry.

FUTURE WORK


Photoacoustic effect:
Measure the frequency range the films can broadcast and search for applications.


High emissivity light sources:
Determine the best geometry to allow for high emissivity thin films.


Disorder enhanced superconductivity:
Explore the role nanostructure plays in superconductivity.

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