Electrochemical Growth of Superconducting Rhenium

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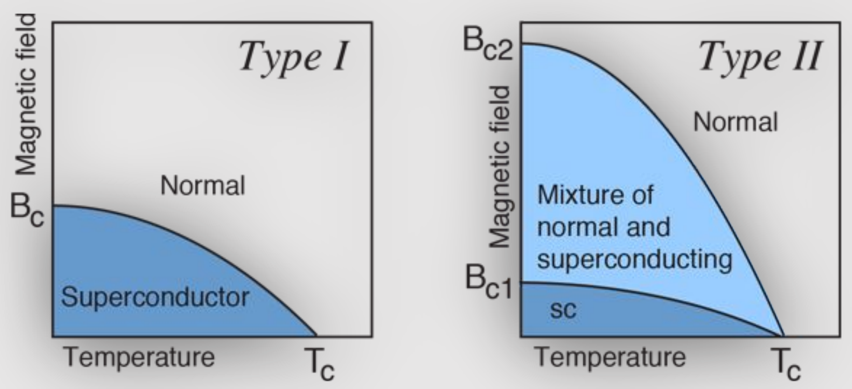
Purpose and Objectives

- In this research project, we designed an experimental apparatus to grow rhenium films.
- Transport measurements were performed on the films to test their superconducting properties, such as the superconducting transition temperature T_c.
- Rhenium has applications in ultra-low temperature quantum computers. It has an advantage to the typical metals used because it is resistant to oxidation and therefore is easier to solder [1].
- Electrodeposition allows for growth directly onto patterned circuits, making them superconducting.

Background

Type I and Type II Superconductivity

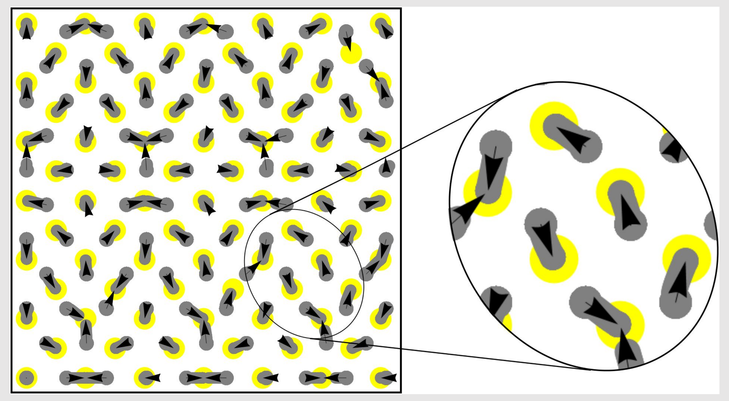
- Superconductivity exists when a material has no electrical resistance and expels magnetic field lines through it. This occurs when the material is cooled near absolute zero temperature.
- Type I superconductors will expel magnetic field when the applied magnetic field is below the critical value, H_c.
- Type II superconductors have two critical fields, H_{c1} and H_{c2}, and can expel field lines completely under H_{c1}, and partially under H_{c2}.



Phase diagram for Type I and Type II superconductors [2]

Rhenium and its superconducting properties

- In its metallic form, rhenium (Re) is a well known Type I superconductor with a critical temperature of 1.8 K.
- It has been shown that when the Re lattice is put under shear strain, the material becomes a Type II superconductor with a critical temperature of over 3 K [1].
- This can be achieved by electroplating Re onto noble metals (Au, Cu, and Pd) [1].



Simulation of the Re-Au interface reveals shear strain in the Re lattice.

Experimental Methods

Electrochemical Deposition

- Electrochemical Deposition a method of depositing a thin film (usually a metal) onto a conductive substrate.
- It relies on electrochemical oxidation-reduction reactions to deposit aqueous ions onto the surface of the substrate.
- In this project, aqueous ammonium perrhenate (NH_4ReO_4) was used to deposit metallic rhenium onto a gold plated silicon substrate.
- The perrhenate ion is reduced to solid rhenium by the oxidation-reduction reaction [3].

$$(1)\ \mathrm{ReO_4^- + 2H^+ + e^- \rightarrow ReO_3 + H_2O}$$

$$(2)\ \mathrm{ReO_3 + 2H^+ + 2e^- \rightarrow ReO_2 + H_2O}$$

$$(3)\ \mathrm{ReO_2 + 4H^+ + 4e^- \rightarrow Re + 2H_2O}$$

$$(4)\ \mathrm{ReO^- + 8H^+ + 7e^- \rightarrow Re + 4H_2O}$$

Methods

- The solution consisted of 0.025 M ammonium perrhenate (NH_4ReO_4) and 0.1 M sulfuric acid (H_2SO_4), for a pH of ~ 1.
- Substrates were prepared using two different methods:
  - Method 1: The substrates consisted of a doped silicon base layer (3.5mm x 3.5mm), a titanium seed layer, and a top gold layer. A copper wire was attached to the substrate using silver epoxy.
  - Method 2: The substrates used the same silicon base layer, but the titanium/gold thin films were replaced with thermally evaporated copper films. This method uses more affordable, readily available materials.
- A Pt-coated metal anode was used, and the substrate served as the cathode.
- Growth was carried out at 10 mA, and the voltage at the cathode was approximately 0.6 V (relative to the solution).
- The solution was heated to 30 °C and stirred at 500 RPM.

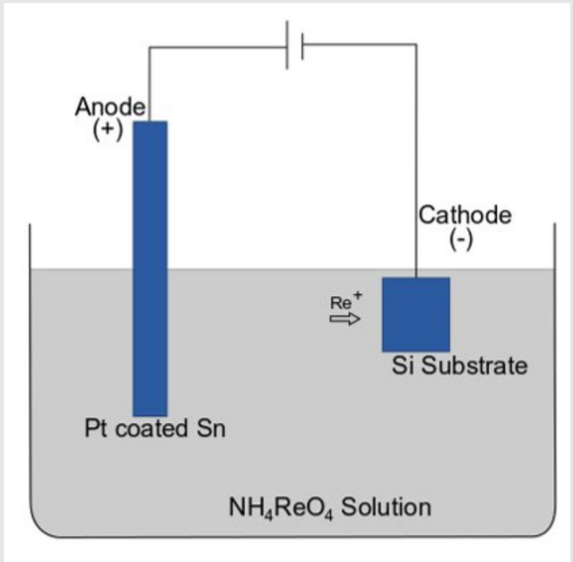
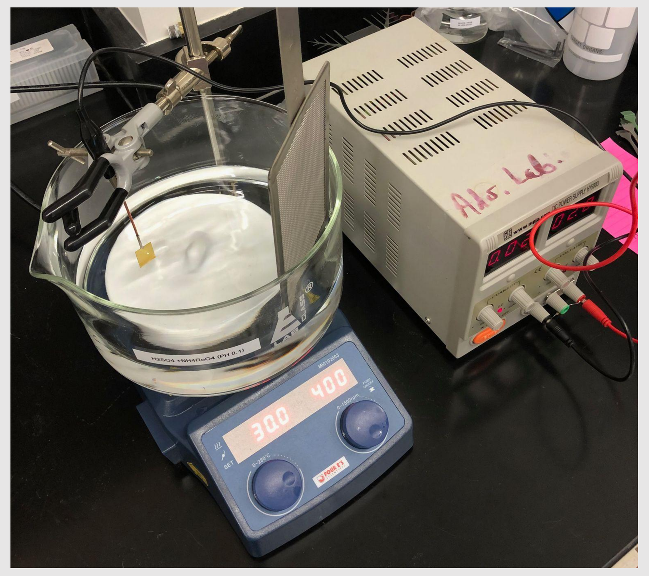


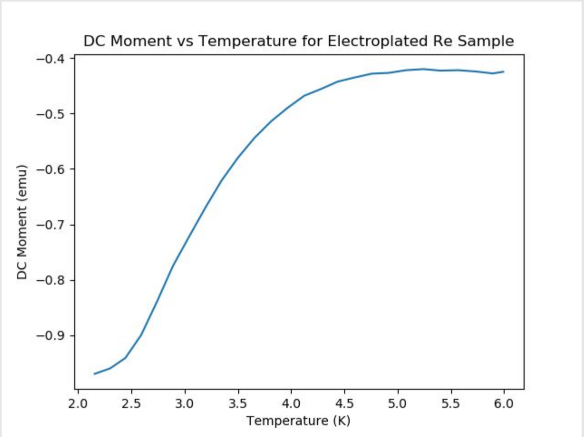
Diagram of Electrodeposition setup used.



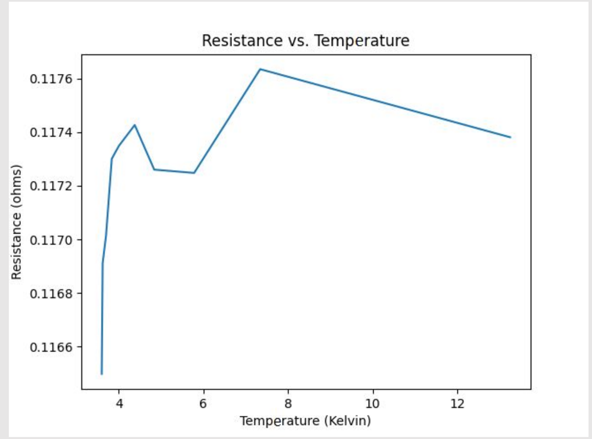
The experimental setup. The substrate hung from the black wire and was dipped in the solution. The platinum anode was attached to the red wire.

Results

- The substrates prepared using evaporated copper failed to exhibit electrochemical growth.
- The substrates prepared using Au over a titanium seed layer successfully supported electrochemical growth of rhenium.
- For the successful films, a superconducting transition was measured using low temperature magnetometry (left image). The transition was too broad to accurately characterize the critical temperature. According to [1], thinner Re films may correct this issue.
- Attempted to take electrical transport measurements to more precisely characterize the superconducting transition (right image). However, the measurements contained a large amount of noise, and the system failed to reach the necessary temperatures for the sample to reach a transition.



Magnetization vs Temperature curve for electroplated rhenium. Measurements were taken using a Quantum Design low-temperature magnetometer.



Resistance vs Temperature curve shows what may be the beginning of a superconducting transition. Note that the drop in R is only 0.001 ohms, thus it is unlikely that a superconducting transition is shown.

- Attempted to produce Re/noble metal multilayers (as done by [1]).
  - First, thermally evaporated copper was used to serve as a mid-film, however the Re failed to stick to copper.
  - Next, sputtered Au was used in place of copper, however this did not improve the results.

Future Work

- Determine the cause of Re failing to stick to certain metals such as copper.
- Grow multilayers of Re and measure its effect on the superconducting transition temperature.
- Take creep measurements on Re multilayers.

References

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