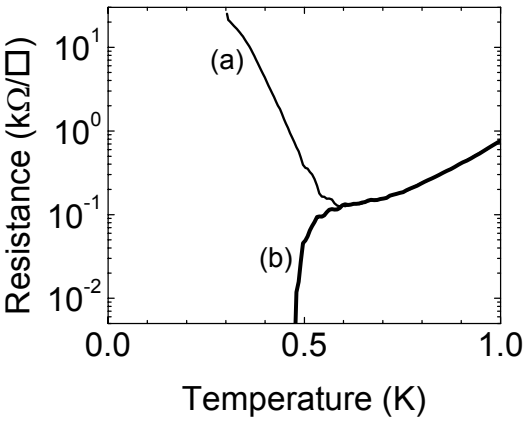
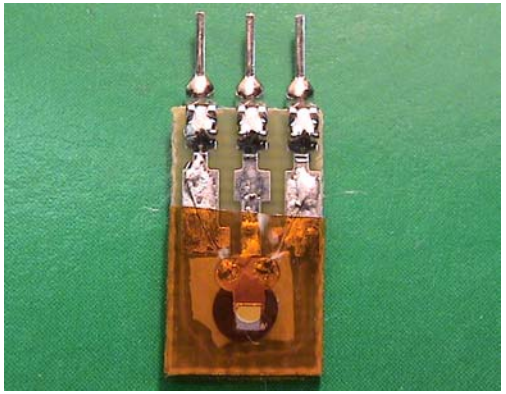
Electron Correlations in Strongly Disordered Low Dimensional Systems

W. Wu, University of Rochester, DMR-0305428

The development of new electronic devices depends critically on our understanding of electron transport in materials of various dimensions and compositions. This grant supports research to address these issues in two areas. In one area, we investigate how superconductivity is suppressed as superconducting films become thinner and disordered. The graph on the right illustrates that when it is near a threshold for the suppression of superconductivity, it may be possible to switch a film between an insulating state and a superconducting state; this work may lead to a superconducting field effect transistor. In the other area, we have developed an in-situ technique which allows us to make electric contact to single nanowires fabricated in a porous template. These nanowires can be made out of magnetic, semiconducting, or superconducting materials. We are investigating various single nanowire materials for application as single-nanowire sensing devices. We are also exploring methods which may one day allow us to integrate various nanowire devices on a single porous template.



Current-tuned insulator-to-superconductor transition: a film that is insulating (curve a) can be tuned into a superconductor when a dc current of 500 μA is applied (curve b).



Our newly developed in-situ technique allows us to fabricate single-nanowire devices on a surface mounting board pictured here.

A superconductor is a material whose resistance drops to zero below a certain temperature known as the superconducting transition temperature. In a ideal superconductor, electrons form Cooper-pairs which flow in a coherent manner without resistance. The situation is much different in the case of “dirty” superconductors. One type of “dirty” superconductor are thin film materials that are strongly disordered—without the nice periodic atomic arrangements of crystalline materials. In “dirty” superconductors, Cooper-pairs can be so strongly scattered by random disorder that they loss their coherence and become immobile. In this limit, a “dirty” superconductor becomes an insulator—its resistance can increase sharply with decreasing temperature. Is it possible to turn a “knob” to restore the coherence destroyed by disorder? This is one of the many questions we attempt to address in our laboratory. If it is found, such a “knob” would allow one to tune a dirty superconductor between a high-resistance insulating state and a zero-resistance superconducting state, resulting in a superconducting switching device. The graph shown above illustrates that a dc electric current is one of the possible “knobs.” However, a truly useful “knob” is the electric field, which is used to control the field-effect transistors in all of our computers. We are currently investigating whether it is possible to control a superconducting switch using an electric field.

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Education:

Five undergraduates, Albert Wang (now in graduate school), Kelly Gresham (now in industry), John DiMaria (now in graduate school), Brittney VornDick (now on a one-year fellowship program in Germany), and Matt Lott (entering senior year in the fall), as well as three graduate students, Edward Bielejec (now a scientist at Sandia National Labs), Jinhao Ruan, and Han Yoo contributed to this work. This research program has provided training opportunities for the students in the areas of materials fabrication and characterization, data acquisition and analysis, nanofabrication, vacuum technologies, low-temperature technologies, and writing and presentations.

Societal Impact:

The observed current-tuned insulator-to-superconductor transition is an exciting effect. We are currently gating these films to investigate if a superconducting field effect transistor can be realized. This work may lead to the development of new devices in superconducting electronics. Work on electrochemical nanofabrication may lead to new sensor devices using semiconducting, magnetic, and supercondicting materials. It may lead to the development of new technologies for integrated nano-device fabrication that are compatible with the mature semiconductor technology.