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Principal investigator: Sidney Perkowitz, Physics Department, Emory University
Atlanta, GA 30322

~~Telephone number: (404) 329-6584~~

~~social security number: 102-30-7943~~

Endorsements:

Principal Investigator

Chairman

Authorized University
Representative

Sid Perkowitz
Sidney Perkowitz

Sid Perkowitz
Sidney Perkowitz

Ellen Miekiewicz
Ellen Miekiewicz

Professor and Chairman

Professor and Chairman

Dean of the Graduate
School of Arts and
Sciences

2/23/81
Date

2/23/81
Date

2-27-81
Date

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Abstract

Optical techniques in the far infrared region (10 to 200 cm^{-1}) will be used to explore the basic superconducting behavior of the high temperature superconductors V_3Si , Nb_3Ge , Nb, and granular NbN. Such spectroscopy will yield accurate gap values, information about the temperature dependence of superconducting properties, values of the electron-phonon spectral function, and insight into grain-to-grain coupling in inhomogeneous geometries. These results will be used to calculate basic superconducting parameters such as the coupling constant and the transition temperature with the aim of explicating the underlying physics of superconductors.

Introduction

Far infrared techniques are one of the most useful experimental tools available to examine superconducting behavior. These methods are especially effective for two classes of superconductors which are now of great interest, the A-15 family and inhomogeneous or granular materials. The fundamental reason for the generally high T_c 's found in the A-15's is not yet understood. Although much work has been done in these materials,¹ far infrared methods have not been used extensively and they offer important advantages. Inhomogeneous superconductivity is an area of very recent development,^{2,3} and many of the most fundamental questions remain unanswered. Not only are these basic questions important for superconducting theory;^{3,4} they also touch on a multitude of other questions of broad scope, such as an understanding of the two-dimensional behavior of solids.^{5,6} The A-15's and the inhomogeneous materials are important not only because they pose unanswered questions. Both classes of materials also show considerable potential for application, the A-15's because of their high transition temperatures, and the granular superconductors because of interesting microwave properties⁷ and because they are flexible systems which can be tailored.

This proposal reviews a year's activity under Department of Energy auspices in the far infrared study of the high-temperature and A-15 superconductors V_3Si , Nb_3Ge , and Nb , and the granular superconductor NbN . Following the progress report a proposal for a renewal year is presented.

PROGRESS REPORT

Activities in the contract year now ending include: the completion of a detailed theoretical analysis of far infrared data in bulk V_3Si ; an extension of far infrared measurements in thin film Nb; the completion of data taking in a set of NbN samples and the start of a preliminary data analysis; the extension of laser thermal spectroscopy and related critical current work; and the addition of improvements in our far infrared instrumentation.

1. Theoretical analysis of $\alpha^2F(\omega)$ in bulk V_3Si

In earlier work⁸ we have used far infrared transmission data to derive the all-important electron phonon spectral function $\alpha^2F(\omega)$ in thin film V_3Si above T_c . The resulting function exhibited two peaks at 18 and 42 meV, like those seen in neutron scattering data for V_3Si ;⁹ and it showed a new third peak at the very low energy of 6 meV. This peak has a profound effect on the superconducting behavior.

In this past year, a similar analysis has been carried out for bulk V_3Si below T_c .¹⁰ We have used the Allen formulation¹¹ to derive $\alpha^2F(\omega)$ from earlier data below T_c .¹² These results also showed a three-peak structure shifted to somewhat lower frequencies. The peaks are notably sharper than were observed above T_c . The shift to lower frequencies and the peak sharpness may be connected to mode softening in V_3Si and to the better quality of the bulk material.

This analysis of V_3Si via the Allen formulation is an incomplete one. For instance, it yields only a so-called "transport" spectral function and does not include strong coupling behavior. To gain a more refined analysis, we are now collaborating with Professor J. Swihart, Indiana

University, who has available on the computer a detailed theory for strong coupling materials. He has begun an analysis of the bulk V_3Si data.

2. Data collection and analysis in Nb

We have considered measurements in Nb of high priority, because such results will give a good test of our methods. We have taken a complete set of transmission data on one sample with the far infrared laser and obtained data of very good quality but with a puzzling structure.

To give an independent check of these unexplained results, we have attempted to obtain Fourier transform spectra of this sample. Because Nb has a high conductivity, its transmission is so low that we have not been able to obtain a satisfactory signal-to-noise ratio even with an excellent cooled detector in the Fourier spectrometer. Alternate methods for examining Nb are proposed for the next contract year and we are now redoing the laser measurements as well.

3. Data collection and analysis in NbN

We have been highly interested in examining a suite of samples of this inhomogeneous material and have now completed a set of transmission measurements. We examined four samples with surface resistances $R_{\square}$ (at room temperature) of 50, 200, 600, and 6000 ohms, that is, ranging from an undisturbed homogeneous film to an extremely inhomogeneous film with large sections of etched oxide regions. Our measurements use both laser and Fourier methods, which yield consistent results for all the samples. We observe a clear cut peak in the ratio of superconducting to normal transmissions T_s/T_n for the homogeneous sample. The entire curve for T_s/T_n vs. frequency between 20 and 100 cm^{-1} can be fitted excellently with the ¹³Leplae formulation of the BCS theory. The fit yields a value of $2\Delta/kT_c$ well above the BCS value, however, indicating strong coupling effects.

For the other inhomogeneous samples, the peak height decreases with increasing $R_{\square}$ as would be expected from a simple model that describes the samples as a set of non-interacting BCS-like granules separated by regions of insulating material. The curve shapes, however, appear to be non-BCS like, and this deviation may represent granule-to-granule interaction.

We have been especially interested in the temperature dependence of the transmission, since we have preliminary indications of structure at temperatures below T_c . Such structure may well be connected with two-dimensional transitions. This year we have extended the measurements down to sample temperatures as low as 2 K, by mounting the sample in the cooled detector Dewar. These very recent results have not yet been analyzed.

4. Extension of laser thermal spectroscopy and critical current measurements

In laser thermal spectroscopy, the sample is irradiated at a fixed far infrared laser frequency while the sample temperature is swept through T_c . This technique compensates for the fact that the laser frequencies are not continuously tunable. A preliminary report on the technique as used in V_3Si was completed this year and is now in press.¹⁴ We are currently applying the method to our Nb samples, where it should help explain the anomalies mentioned above. We had hoped to install a temperature modulation system to give the derivative of transmission with temperature, a potentially very sensitive technique, but the necessary equipment has been delayed because of a model change by the manufacturer.

In related work, we have tried a new approach in obtaining T_S/T_N . We have connected leads to a NbN sample well below T_c and have turned it