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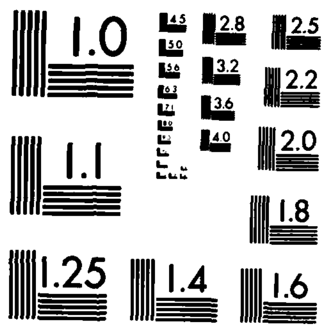

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Specialized vacuum deposition systems were developed with the necessary monitoring and control to synthesize or react refractory superconducting films. NbN, VN, NbTi, and VTi films of high quality have been produced and their transport and tunneling properties studied. Ultra-thin films of pure Nb have been successfully made to study spin-orbit scattering in transition metals. The structural properties and penetration depth of NbN films prepared by reactive sputtering have been studied. Many-body effects which are important in superconductivity have been observed by spin-polarized tunneling and the antisymmetric Fermi liquid parameter has been measured for the first time in Al. The technique of

deconvoluting tunneling conductance curves to obtain the superconducting density of states has been improved. A comprehensive study was made of amorphous Ge tunnel barriers between superconductors.

AFOSR-TR- 88-0117

SUMMARY OF RESEARCH GOALS AND PLANS

The research goals of this contract are as follows:

Synthesize materials potentially useful in superconducting electronics.

Characterize the physical and chemical properties of the materials and their surfaces with analytical instrumentation.

Form tunnel junctions on thin films of these materials and investigate their characteristics.

Make transport and tunneling measurements to define the material and junction parameters.

Explore techniques to enhance the properties of Josephson and single particle tunnel junctions.

Make spin-polarized and electron-phonon spectroscopy measurements on superconducting thin films.

Exploring promising unusual and advanced materials for superconducting electronics.

Evolve practical theories to explain the properties of the superconducting materials and the tunnel junctions.

Compare results with the basic theory of high temperature superconductors to guide research in such materials.

STATUS OF THE RESEARCH EFFORT

Development of Equipment and Facilities

Major emphasis was placed on developing equipment to synthesize high transition temperature superconductors and superconducting tunnel junctions. Major emphasis was placed on improving the operation of the dual electron gun deposition system and optimizing its performance. The water cooling system for the electron guns was redesigned and rebuilt. The substrate heater was changed from an electron beam unit to a resistively heated unit to improve the uniformity of the substrate temperature. Two Inficon IC-6000 rate monitors were installed to allow programmed control of the rate and thickness deposited from the two electron guns. A residual gas analyzer was installed. The base pressure of the system was then 5×10^{-8} Torr and was normally 3×10^{-7} during refractory metal depositions on a substrate held at 400 C. To improve the system further, a liquid-nitrogen-cooled baffle was installed. The evaporant passes through a hole in this baffle, which is between the evaporation source and the substrate and serves to trap much of the gas which is evolved from the source during evaporation. This cooled baffle has led to marked improvement in the vacuum conditions during depositions.

In addition to the above system, an rf sputtering system was modified to allow reactive sputtering to form the nitrides of Nb and V on substrates heated to temperatures up to 500 C. Another vacuum system was outfitted to allow electron beam evaporation and reaction of thin films in a gaseous atmosphere up to temperatures of 1400 C for the formation of nitrides.

The Hewlett-Packard data acquisition system was made operational to make and to process spin-polarized and electron-phonon spectroscopy measurements. This system includes two digital voltmeters (3456 A), a minicomputer system (87 xm) with plotter and printer. Computer software was developed for the data acquisition system and used in the analysis of spin-polarized tunneling measurements (see below). A cryogenic station for measuring transition temperatures was assembled together with the substrate measuring probes and electrical circuitry and sensors for electrical and temperature measurements.

Several low temperature substrate holders were built to allow measurements of the superconducting properties and tunneling characteristics from room temperature to 0.45 K.

Synthesis of Superconducting Materials. NbN films were formed by reacting Nb in a nitrogen atmosphere at near 1400 C and by rf reactive sputtering of Nb in a nitrogen-argon gas mixture. Thick films formed by sputtering had transition temperatures up to 15 K and their perpendicular critical fields were higher than their parallel critical fields, an indication of the well-known columnar structure found in NbN film made by sputtering. Films as thin as 400 Å had depressed transition temperatures but were planar as judged by the critical field measurements. The Nb films which were nitrided at high temperature had low perpendicular critical fields, indicating that the columnar structure did not develop when these films were made. This result is particularly interesting for superconducting electronics because it implies that NbN can be made with a comparatively short penetration depth, thus increasing the frequency response of lines of this material.

A technique for measuring the penetration depth λ of the NbN films was developed. The penetration depth is an important parameter for superconducting electronic applications because it is proportional to the self inductance of a superconducting stripline. The technique uses a tunnel diode driven resonant circuit in which a meander line pattern etched from the NbN film is the inductive element. For a stoichiometric NbN film 310 nm thick and T_c = 15.5, $\lambda(0)$ = 276 nm. For a Nb deficient film 55 nm thick and T_c = 13.5 K, $\lambda(0)$ = 175 nm. This method appears to offer a simple routine method of measuring $\lambda(0)$. For films with columnar structure such as NbN it is important to measure the self inductance rather than the mutual inductance as reflected by an external coil because the current configurations are different in the two cases. Our technique more closely represents the configuration in actual electronic devices. Also for very thin films where the kinetic inductance (that associated with the mass of the superconducting pairs) dominates the magnetic inductance, it is essential to measure the self inductance to determine circuit characterisitcs of such films.

VN films have been successfully made by heating V films on a sapphire substrate to about 1300 C in a nitrogen atmosphere. Films as thin as 5 nm have been prepared with transition temperatures close to those of much thicker films. These ultra-thin films were necessary for spin-polarized tunneling measurements. Tunnel junctions were formed on the VN films using amorphous Si oxidized in air. More reliable junctions were formed by treating the amorphous Si with a nitrogen glow discharge giving an effective barrier height of 1.05 eV. Pb counterelectrodes were used. Tunneling measurements showed that $2\Delta/kT_c$ = 3.7 for the VN films. showing fairly weak phonon coupling. Spin-polarized tunneling measurements were made at 0.45 K with magnetic fields up to 15 T. The tunnel curves showed that the spin-orbit scattering of these VN films is rather small although greater than that of Al. The data have been compared with theory to obtain a quantitative measurement of the spin-orbit scattering parameter, b = 0.3.

Films of Nb, Nb-Ti, and V-Ti have been prepared and are of high quality with superconducting transition temperatures as high as have been attained previously. A series of V-Ti alloys have been prepared over a composition range where the bcc crystal structure is stable.

Ultra Thin Films of Transition Metal Elements

Films of Nb as thin as 100 Å were successfully made with a transition temperature of 8.5 K and 50 Å thick with T_c of 6.0 K by using a 10 to 15 Å surface layer of Al to prevent the formation of Nb suboxide. Similar films without the covering film of Al were not superconducting. Such thin films are necessary in order to determine the spin-orbit scattering in a magnetic field of 7 T by spin-polarized tunneling. As yet no direct measure of this parameter has been made in good quality samples of the transition metal elements Nb, V, and Ta. Combined with critical magnetic field measurements the tunneling measurements can be used to determine the spin-orbit scattering parameter, the penetration depth, the coherence distance and perhaps the many-body corrections, thus determining all of these fundamental parameters. The Al-coated Nb films were analyzed by XPS and found to have no detectable trace of the suboxides of Nb, which seriously degrade tunnel junctions. Tunnel junctions were formed by oxidizing the Al surface layer and depositing a Pb counterelectrode. The tunnel junctions displayed good superconductor-superconductor tunneling characteristics with little leakage. The "knee" above the sum energy gap of the superconductors, which is characteristic of the proximity effect, gave an indication of the thickness of the metallic Al layer. Measurements of the tunneling conductance in a parallel magnetic field of up to 7 T showed no trace of Zeeman splitting of the quasi-particle density of states indicating a large amount of spin-orbit scattering in Nb. To make a quantitatively determination of the amount of spin-orbit scattering the use of ferromagnetic Fe was tried as the counterelectrode. This method has not yet been successful and the tunnel barriers need improvement.

Various facilities of the Center for Materials Science at MIT were used to analyze the thin Nb films and films of various vanadium-based superconductors. The instruments employed include SEM, microprobe, X-ray diffractor, and ESCA. Particularly interesting are the ESCA results on the thin Nb which verify that a thin coating of Al prevents the formation of Nb oxides. Depth profiles of these films using ESCA and argon ion milling imply no oxide formation at the Nb-substrate interface. The reasons for depression of T_c in these thin films of Nb is not as yet certain, but may be a fundamental property attributable to the boundary rather than a proximity effect.

Many Body Effects in Superconductors.

Another major effort was the determination of the many body effects in Al by tunneling measurements. Using spin-polarized tunneling the energy separation δ of the spin states in thin superconducting Al films in a magnetic field was measured as a function of temperature and field near the normal-superconductor phase boundary. The ability to measure δ in the region inspite of the great broadening of the tunnel curves by temperature and magnetic field was accomplished by using a ferromagnetic counterelectrode together with the programmed data acquisition system for resolving the conductance curves for each electron spin orientation. A decrease in the magnitude of δ near the phase boundary was related to the antisymmetric Fermi liquid parameter G^o using a theory and computer program provided by D. Rainer. This research measured G^o for the first time in Al and demonstrated that the technique is practical for high temperature superconductors where this many-body correction is important in the characterization of materials and has not been previously measured.

Further progress has been made in understanding the many-body effects in Al by comparing the data to recent theoretical calculations of the tunneling conductances. These numerical calculations were developed by D. Rainer and are now an integral part of our tunneling data analysis and are a major advance in interpreting experimental data. The agreement between the theory and experiment for thin films of Al is good. Furthermore, the results indicate that the same parameters (spin-orbit scattering, pair-breakers, and many-body enhancements) can be used to fit both the tunneling conductance and the upper critical field.

Fourier Analysis of Tunneling Data

We have demonstrated that a specialized type of Fourier analysis, known as Cepstrum analysis, allows determination of the Zeeman splitting in superconducting conductance data, even for those conductances where the Zeeman splitting in the raw data appears to be inaccessible. The determination of the Zeeman splitting for a range of magnetic fields and temperatures can be used to measure both the g-factor of the conduction electrons and the $\ell = 0$ antisymmetric fermi-liquid parameter. Cepstrum analysis of the moderate field tunneling data of Bending, Tsui, and Beasley on V_3Ga show that the g-factor is approximately 2.0. Data in higher fields and temperatures will be needed to determine the fermi-liquid effects on the Zeeman splitting in V_3Ga.

Moreover, finding the Zeeman splitting is analogous to finding the delay between any two nearly identically shaped signals. Consequently, Cepstrum analysis is used widely in many areas of engineering and physics. It is, for example, used in geophysics to determine the delay between a shockwave and its echo caused by an earthquake. It is also used in similar applications in electronic speech analysis, data transmission, doppler shifting, and time of flight estimations. Cepstrum analysis can also be extended by keeping the phase information of the transforms and can then be used to reconstruct undelayed signals. Furthermore, it is noted that these methods are possible because efficient algorithm exists for implementing Cepstrum analysis which demands neither long computer time nor much computer memory.

Tunnel Junctions with Amorphous Ge Barriers

An extensive series of measurements has been made on the preparation and properties of amorphous Ge tunnel barriers. Amorphous Ge forms junctions with very low effective barrier heights (20 - 60 meV). This allows junctions of useful impedance to be formed in the thickness range of 5 - 10 nm. In contrast, tunnel barriers of Al_2O_3 have a height of the order of 1 eV and must be 1.5 - 2.5 nm thick to be of useful impedance. The fact the Ge can be deposited at 77 K to form quite uniform barriers makes it a candidate for applications in both quasiparticle and Josephson tunneling. Elastic tunneling behavior has been demonstrated by observing the exponential dependence of the resistance with barrier thickness in the low temperature region and by observing the energy gap with superconducting counterelectrodes. The voltage dependence of the conductance is also in agreement with the standard tunneling theory. The temperature dependence of the tunnel current has been observed from 300 K to 1.1 K. For temperatures above 30 K the conduction mechanism obeys the $T^{-1/4}$ law predicted by temperature-activated hopping. Below this temperature the mechanism is mainly elastic tunneling. However, the energy gap structure with superconducting tunneling is broadened and there is conduction at voltages well below the gap which apparently is not the result of elastic tunneling through a simple barrier. The effect of plasma discharges in O_2, N_2, and H_2 on the tunneling properties of a-Ge was studied.

PUBLICATIONS

What Can We Learn from H_{c2} (T)?. T.P. Orlando, Proceedings of the Tenth Conference on d- and f- Band Metals. edited by W. Buckel and W. Wegner, Karlsruhe, 1982.

Spin-Polarized Tunneling Measurement of the Antisymmetric Fermi Liquid Parameter G^o and Renormalization of the Pauli Limiting Field in Al, P.M. Tedrow, J.T. Kucera, D. Rainer, and T. P. Orlando. Phys. Rev. Lett. 52, 1637 (1984).

Tunneling Studies in VN Thin Films, P.M. Tedrow and R. Meservey, Advances in Cryogenic Engineering, (Materials) Vol. 30, A.F. Clark and R.P. Reed, eds. Plenum, New York (1984), p. 601.

Tunneling Measurement of Fermi Liquid Effects in High Field Pauli-Limited Superconductors, J.A.X. Alexander,P.M. Tedrow, T.P. Orlando. Bull. Am. Phys. Soc. 29, 407 (1984).

Reduction of Thermal Broadening in Superconducting Tunneling Data, G.B. Hertel and T.P. Orlando, Bull. Am. Phys. Soc. 29, 406 (1984).

Amorphous Ge Tunnel Barriers, G.A. Gibson and R. Meservey, Bull. Am. Phys. Soc. 29, 406 (1984).

Properties of Ultra-thin Niobium Films, J.H. Quateman and R. Meservey, Bull. Am. Phys. Soc. 29, 554 (1984).

Tunneling Properties of Amorphous Ge Barriers, G. Gibson and R. Meservey, submitted to the Journal of Applied Physics.

Vanadium Nitride Spin-Orbit Scattering Rate Measured Using Spin-Polarized Tunneling, P.M. Tedrow and R. Meservey, Proceeding of the 17th International Conference on Low Temperature Physics, LT-17, Editors, V. Eckern, A. Schmid, W. Weber, and H. Wükl, North Holland, Amsterdam, 1984, p. 837.

Determination of the Penetration Depth of Type II Superconducting Films, J.S. Moodera, R. Meservey, and P.M. Tedrow, Applied Superconductivity Conference, San Diego, September 1984.

Fermiflussigkeitseffekte in Superleitern, Verhandl. Deutsche Physik. Gesels. VI, 19, 509 (1984), J.A.X. Alexander, G.B. Hertel, T.P. Orlando, and D. Rainer.

Measurements of Fermi Liquid Effects and Spin Orbit Scattering in Pauli-Limited Superconductors, J.A.X. Alexander, D. Rainer, P.M. Tedrow, and T.P. Orlando, presented at 17th International Low Temperature Conference, Karlsruhe, Germany, published in Proceedings of the 17th International Conference on Low Temperature Physics, North Holland Press, U. Eckern, A. Schmid, W. Weber, H. Wuhl, Eds., LT-17, 1984,p. 839.

A Comparison of Theoretical Expressions Commonly Used in Analyzing Tunneling Measurements, G. Gibson and R. Meservey. In preparation, to be submitted to the Journal of Applied Physics.

Spin-Orbit Scattering Rate in VN, P.M. Tedrow and R. Meservey. In preparation to be submitted to the Physical Review.

Theory of Fermi Liquid Effects in High Field Tunneling, J.A.X. Alexander, T.P. Orlando, D. Rainer, and P.M. Tedrow. Submitted to Physical Review B.

Determination of the Zeeman Splitting of Superconducting Tunneling Conductance with Fourier Analysis, G.B. Hertel and T.P. Orlando, in preparation.

Superconducting Properties of VN Prepared by Nitriding V Films. P.M. Tedrow and R. Meservey, in preparation.

THESES

Spin Polarized Tunneling Measurement of Many-Body Field Renormalization in Pauli-Limited Superconductor, J.T. Kucera, for B.S. degree in Physics at MIT May 20, 1983. Supervised by T. P. Orlando.

The Detection of Single Flux Quanta in Type II Superconducting Thin Films and A Study of Trapping Energies Associated with Various Hole Structures, F. Patrick Rogers, May 1983. Thesis done at IBM Yorktown Heights. Supervised by T.P. Orlando, August 1983.

Modulation of Superconducting Strip Lines by Energy Gap Suppression, D. Matthew Weinberg, May 1983. Thesis done at IBM Yorktown Heights. Supervised by T.P. Orlando, May 1983.

PROFESSIONAL PERSONNEL

Professional personnel who have bε ↄ associated with the project are:

Prof. T.P. Orlando, Dept. Electrical Engineering and Computer Science

Dr. R. Meservey, Staff member, National Magnet Laboratory

Dr. P.M. Tedrow, Staff member, National Magnet Laboratory

Dr. J.S. Moodera, Post-doctoral associate

Dr. J. Quateman, Post-doctoral Associate

J. Alexander, Graduate student, Physics Department

G. Hertel, Graduate student, Physics Department

G. Gibson, Graduate student, Physics Department

J. Kucera was a member of the group until he received his B.S. degree in June 1983.

In addition to the persons working on this project there has been much interaction with others in the National Magnet Laboratory working on superconductivity including:

J.E. Traczyk, a physics department graduate student is a member of the superconductivity research group working on V_3Ga on a DOE contract.

Prof. D. Rudman of the Materials Science and Engineering Department.

S. Foner and E.J. McNiff, Jr., and co-workers of the Magnet Laboratory staff studying high field superconducting materials.

M. Dresselhaus, G. Dresselhaus, and co-workers studying superconductivity in intercalated graphites.

INTERACTIONS

Limiting the Pauli Limiting Process in High Field Superconductivity, Materials Research Society, 1982 Annual Meeting, Boston, MA. Invited talk, T.P. Orlando.

Resolution of the Spin States of a Superconductor by Tunneling, P.M. Tedrow, J.S. Moodera, and R. Meservey. Bull. Am. Phys. Soc. 28, 424 (1983).

P.M. Tedrow has collaborated with G. Timp and T. Sienko of the Dresselhaus group at MIT on measurements of the superconducting properties of intercalated graphite. Two-Dimensional Superconductivity in Graphite-Potassium Amalgam, G. Dresselhaus, P.M. Tedrow, G. Timp. and T. Sienko. Bull. Am. Phys. Soc. 28, 539 (1983). This work has continued with Dr. G. Roth and A. Chaiken.

Structural Order, Stoichiometry and Superconductivity in KHg_x-GIC, G. Roth, N.L. Yeh, A. Chaiken, G. Dresselhaus, and P. Tedrow. Materials Research Society, November 1984.

P.M. Tedrow attended the Gordon conference July 4 - July 8, 1983 on the Physics and Chemistry of Limited Dimensioned Systems.

T.P. Orlando gave seminar talk at Arthur D. Little on Applications of Superconductivity from a Materials Viewpoint, December 2, 1983.

T.P. Orlando is serving as co-chairman of the program committee for the 1985 International Cryogenic Materials Conference.

J.A.X. Alexander and T. P. Orlando have worked with T.H. Geballe and S. Yoshizumi in measuring critical fields of amorpohus Mo-Ge.

R. Meservey has worked with F. Steglich, Technische Hochschule Darmstadt, in attempting tunneling into the heavy fermion superconductor $CeCu_2Si_2$.

G. Bergmann, Julich, visited the National Magnet Laboratory in July 1983 to discuss spin-orbit scattering in superconductors and normal metals.

Prof. D. Rainer of Bayreuth University visited the National Magnet Laboratory from April 18 to 30, 1983 for collaboration on the theory of the determination of the antisymmetric Fermi liquid parameter G^o in Al by spin-resolved spin-polarized tunneling.

Dr. Dave Rudman of the Ohio State University visited MIT on May 20, 1983 and gave a seminar on the Tunneling Spectroscopy of Nb_3Sn and also the heat capacity of thin-films of Nb_3Sn. Much of this work was done with Dr. M.R. Beasley and Dr. T.H. Geballe of Stanford.

Dr. J.M. Tarascon of Bell Laboratories Murry Hill, visited MIT on June 6, 1983 and gave a seminar on the novel chemistry of high-T_c Chevrel phase materials. Some of his work was done with Dr. M. Sienko of Cornell.

P.M. Tedrow spent 6 weeks in July and August 1983 at Stanford University working with M. Beasley, R. Hammond, and S. Bending to learn techniques of codeposition of A-15 compounds.

P.M. Tedrow gave Physics colloquium talk at the University of Connecticut on Spin-polarized Tunneling, October 21, 1983.

P.M. Tedrow has begun a study of tunneling in junctions subjected to hydrostatic pressure in collaborating with Professors Ratnam and Gunther of Tufts University.

R. Meservey colloquium speaker at Northeastern University. Discussions with Prof. Robert Markiewicz on localization and Prof. Carl Shiffman on tunnel diode oscillators. March 4, 1984.

Visit and talk of NML by Dr. G.R. Stewart, Los Alamos Laboratory on Coexistance of Spin Fluctuations and Superconductivity. March 16, 1984.

Visit and talk by Andrzej Okoniewski, Ecole Polytechnique, Montreal on Tunnel spectroscopy of semi-magnetic semi-conductors. March 22, 1984.

Visit of Dr. Ivan Schuller, Argonne National Laboratory concerning multi-layered thin superconducting films. April 13, 1984.

Prof. F. Pobell, Univ. of Bayreath. Discussion of low temperature technique and superconductivity. April 27, 1984.

Talks given at the Univ. Virginia in Charllottsville and at Northeastern Univ. in Boston on Tunneling Measurement of Fermi Liquid Effects in High Field Superconductors by T.P. Orlando. April 1984.

Visit by Dr. Daniel Peirce, National Bureau of Standards to discuss spin-polorized surface analysis of solids. May 4, 1984.

Dr. W. Gallagher and S. Rader of IBM visited to discuss ultrathin films. May 15, 1984.

Visit of Dr. David Rudman. Discussion of materials problems of refractory superconductors and tunnel junctions. May 31, 1984.

Prof. William D. Johnson of the California Institute of Technology. Talk on the preparations of amorphous materials by solid state diffusion. June 6, 1984.

W. Gallagher, IBM, discussion and talk concerning superconducting electronic devices. June 7, 1984.

Dr. D. Capone. Discussion of NbN conductors for high-field applications. June 1984.

Dr. William Gallagher, IBM spoke on Application of Superconductivity in Electronics. July 21, 1984.

Gordon conference on localization attended by T.P. Orlando and J. Quateman. July 1984.

Low Temperature Conference in Karlsruhe, West Germany. Attended by R. Meservey P.M. Tedrow, and J.A.X. Alexander. Discussed problems in superconductivity particularly with the following:

Prof, D. Rainer, University of Bayreuth
Prof. P. Fulde, University of Stuttgart
Prof. F. Steglich, Technische Hochschule Darmstadt
Prof. W. Buckel, University of Karlruhe
Prof. J. Appel, University of Hamburg

P.M. Tedrow and J.S. Moodera attended Applied Superconductivity Conference in San Diego. Discussed problems of forming heavy fermion films with Dr. R. Hammond of Stanford Univ. September 1984.

Visit by Prof. O. Fischer to discuss superconducting materials. September 24, 1984.

Fermi Liquid Effects in High Field Superconductivity, AT&T Bell Laboratories, Murray Hill, NJ talk by T.P. Orlando. October 1984.

Other publications not supported by the AFOSR contract but on related subjects.

Improved Performance Powder Metallurgy and in situ Processed Multifilamentary Superconductors, S. Foner, S. Pourrahimi, C.L.H. Thieme, J. Otubo, H. Zhang, T.P. Orlando, A. Zieba, A. Zaleski, S. Sekine, E.J. McNiff,Jr., and B. B. Schwartz. Proceedings of the 1983 International Cryogenic Materials Conference Denver, CO, published in Advances in Cryogenic Engineering, Plenum Press, A.F. Clakr and R.P. Reed, Editors, 30, 1984, 805. DOE Support.

Low Frequency Losses at High Fields in Multifilamentary Superconductors, A.J. Zaleski, T.P. Orlando, A. Zieba, B.B. Schwartz, and S. Foner. Accepted for publication by J. Applied Physics. DOE Support.

Low Frequency AC Losses in Multifilimentary Superconductors up to 15 Tesla, T.P. Orlando, A. Zieba, C.B. Braun, B.B. Schwartz, S. Foner, and W. McDonald. Proceedings of the 1982 Applied Superconductivity Conference, Knoxville, TN, published in IEEE Trans. Magn. MAG-19, 435 (1983). DOE Support.

Critical Magnetic Field of V_3Ga Thin Films with Third Element Additions, P.M Tedrow, J.E. Tkaczak, R. Meservey, S.J. Bending, and R. Hammond. To be published in IEEE Trans. Magn. January 1985. DOE Support.

Improved Resolution in Superconducting Tunneling Spectroscopy by Numerical Deconvolution, G.B. Hertel and T.P. Orlando. Presented at the 17th Intl. Low Temperature Conference, Karlsruhe, Germany, published in Proceedings of the 17th Intl. Conference on Low Temperature Physics, North Holland Press. U. Eckern, A. Schmid, W. Weber, H. Wühl, Editors, LT-17, 1984, 841-842. NSF.

A Novel Technique for Tunnel Junction Diagnostics, G.B. Hertel and T.P. Orlando Proceedings of the L984 Applied Superconductivity Conference, San Diego, CA, to be published in IEEE Trans. Magn. January 1985. NSF Support.

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