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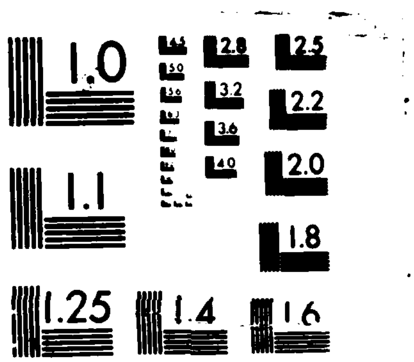

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RESEARCH ON CRYOGENIC VACUUM TUNNELING

Final Report

August 1, 1984 - January 31, 1987

Office of Naval Research

Contract No. N00014-84-K-0549

Principal Investigator:

C. F. Quate

G. L. Report No. 4194

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The Scanning Tunneling Microscope has been designed and constructed to operate at low temperature. In liquid helium at 4°K we have mapped the spatial variation of the superconducting energy gap. It, also, has been used for the first time to record the vibrational spectra of a molecule adsorbed on graphite and to image the molecule itself. The STM has also been used to record the phonon spectra of the graphite substrate. This is a new tool for low temperature studies which enables us to study the spatial variations in structure and spectra.

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The work that has been carried out under this program has been adequately covered in the previous progress reports. Much of the work was completed some time ago. The latest period represents an extension to the original contract period. The extension was requested in order to allow us to complete certain unfinished details. We do not plan to review those details here, rather we want in this final report to look back and comment on the possible impact of the work that was done.

The contract officer encouraged us to construct a Scanning Tunneling Microscope in such a way that it could be operated at low temperatures and to use this kind of instrument to examine problems associated with low temperature phenomenon. We were fortunate in having picked a suitable subject. This stands as a tribute to the foresight of the contract officer at ONR.

We chose to work with tunneling in superconductors. In these materials the tunneling characteristic can provide valuable information on the physics of the conducting mechanism. In the tunneling experiments one measures the curve of current versus voltage across a thin tunneling gap. With the STM we can use a vacuum gap for the tunneling. This together with the sharp probe gives us two advantages: (1) we can obtain tunneling curves in materials where it is difficult to grow oxides since the vacuum gap does not require a grown dielectric layer, and (2) we can obtain information on the spatial variations in the superconducting gap by moving the probe to a new area, repeating the I-V curve, and computing the size of the gap.

With the encouragement of the contract officer, we designed and constructed an STM that could be cooled with liquid helium. We used it to study the properties of Niobium 3 Tin. We were successful in measuring the spatial distribution of the superconducting energy gap. We were able to show a large variation in the size of the gap as we scanned the tip over a range of about 100 Angstroms. This kind of variation in gap was inferred from other data but this was the first direct measurement.

Tunneling has been used as a tool for measuring the gap for many years. In the usual mode a thin dielectric is formed on the superconductor and this is followed by the deposition of a top layer of metal. Tunneling takes place through this dielectric barrier. The drawback of this system is the difficulty of forming insulating films of high quality on some of the more interesting superconductors. The vacuum barrier that comes with the STM makes it possible to use tunneling with all materials.

In our most interesting work under this contract, we have demonstrated two important characteristics of the STM: (1) it can be used to measure the gap via tunneling on all superconductors, and (2) it can be used to measure the variation in the size of the gap as a function of the spatial position on the sample surface.

That work under the ONR contract was completed some time ago when we were exploring the potential of this new technique. But, suddenly we are in a position to explain why it is important, why the foresight of the ONR contract officer has paid a dividend. As the entire world now knows, we have a truly high temperature superconductor in the form of a metallic oxide. The materials with a transition temperature near 90 Kelvin contain Yttrium and Barium. It is not easy to carry out tunneling in the conventional sense, since the formation of insulating films is not yet under control. Furthermore, these materials are granular and inhomogenous where only a few grains are in the superconducting phase.

Our work with the cooled STM has continued under different sponsorship and when the high temperature material became available at Stanford we were able to immediately call upon the experience developed under the ONR contract and use the cooled STM to study the gap in the new high temperature materials. We not only measured the gap at a given point but we were able to translate the tip and position it over the grain with the highest conductivity. This data is important in these hectic times when there is no available theory to guide us. It's importance is emphasized by the fact that virtually every cooled STM, both here and abroad, is now being used to study the new superconducting materials.

This worldwide effort stands as a tribute to the ONR contract officer who encouraged us some years ago to undertake this effort.

List of Technical Reports

Progress Report - August 1, 1984 - January 31, 1985 (G.L. No. 3860)

Annual Report - August 1, 1984 - July 31, 1985, AD No. ADA176363 (G.L. No. 4132)

Progress Report - August 1, 1985 - January 31, 1986 (G.L. No. 4145)

Annual Report - August 1, 1985 - July 31, 1986, AD No. A176390 (G.L. No. 4133).

Progress Report - August 1, 1986 - January 31, 1987 (G.L. No. 4193)

List of Publications

C.F. Quate, "Low Temperature Vacuum Tunneling Microscopy," BA4, Bull. Am. Phys. Soc., 30, No. 3, 251 (March 1985).

A.L. de Lozanne, S.A. Elrod & C.F. Quate, "Spatial Variations in the Superconductivity of Nb_3Sn Measured by Low-Temperature Tunneling Microscopy," Phys. Rev. Lett. 54, 2433-36 (3 June, 1985), partial support.

Sang-il Park & C.F. Quate, "Tunneling Microscopy of Graphite in Air," Appl. Phys. Lett. 48, 112-14 (13 January, 1986), partial support.

A. Bryant, D.P.E. Smith & C.F. Quate, "Imaging in Real Time with the Tunneling Microscope," Appl. Phys. Lett. 48, 832-34 (31 March, 1986), partial support.

S.A. Elrod, A. Bryant, A.L. de Lozanne, S. Park, D. Smith & C.F. Quate, "Tunneling Microscopy from 300 to 4.2K," IBM J. Res. Develop. 30, 387-95 (July 1986), partial support.

D.P.E. Smith & G. Binnig, "Ultrasmall Scanning Tunneling Microscope for Use in a Liquid-Helium Storage Dewar," Rev. Sci. Instrum. 57, 2630-31 (October 1986), partial support.

List of Publications, continued

D.P.E. Smith, G. Binnig & C.F. Quate, "Detection of Phonons with a Scanning Tunneling Microscope," Appl. Phys. Lett. 49, 1641-43 (15 December, 1986), partial support.

R.J. Colton & C.F. Quate, "Scanning Tunneling Microscopy - STM '86," ONRL European Science Notes, 41, 25-30 (January 1987).

Unpublished Thesis

S.A. Elrod, "Low Temperature Tunneling Microscopy," Stanford University (June 1985), G.L. No. 3884.

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