



Unravelling superconducting gap structure by low temperature STM

Dr Hermann Suderow and co-workers in the group headed by Prof. S. Viera at the Autonomous University of Madrid, Low Temperature Laboratory, are combining low temperature techniques with STM / STS (scanning tunnelling microscopy and spectroscopy) to study superconductivity at the surface of metallic compounds.

ULT as an enabling technology

The team employs Oxford Instruments Superconductivity's ultra low temperature (ULT) ^3He systems (HelioxVL) with dilution refrigerators (Kelvinox™ and home built dilution refrigerators) to cool their STM measuring device. To ensure the cooling of the experimental set up as well as the compound under study at temperatures below 1K, two very similar STM designs have been employed. One used a ^3He insert manufactured by Oxford Instruments Superconductivity, and the other used a lab-built dilution refrigerator. Several sample and STM tip preparation methods were also investigated and developed by the team. They explored very promising STM heads with superconducting tips. The superconducting tips enhance the overall sensitivity of STM detection. This high-energy resolution can, however, only be achieved when the system is cooled to the lowest temperature. Measurements are made by approaching the tip (of a normal, Pt-Ir or Au, or a superconducting, Pb or Al, material) into the vicinity of a superconducting sample. The differential conductance dI/dV is then measured as a function of the bias voltage V in different positions of the tip over the sample.

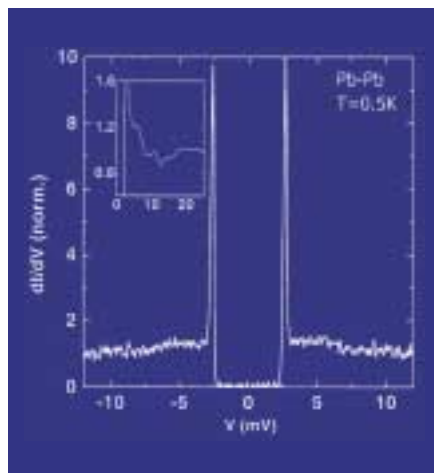


Figure 1: Two pronounced symmetric signals represents the peaks of quasiparticles

STM steps-up superconductivity studies

A review article by the team, published in *Physica C* this year, presented interesting new experimental STM techniques. The enhancement of spectral resolution through the use of superconducting tips on the STM (rather than normal tips) was particularly striking and opens fascinating unexplored avenues in the study of superconductivity.

STM and surface scanning microscopy have been acknowledged as powerful investigative techniques offering potential in studying the physics of superconducting vortices. These techniques provide a means of studying the form of the superconducting energy gap and the properties of the electronic density of states at the atomic level.

The authors reviewed recent advances in very low temperature scanning microscopy in superconductors and profiled latest developments allowing high resolution measurement on superconductors. The researchers presented results on the newly

discovered magnesium di-boride (MgB_2) superconductors and the borocarbide material $\text{TmNi}_2\text{B}_2\text{C}$. Magnesium di-boride is cheap to use and can be produced as filament wires. Researchers have found that the current flow through the new superconductor is not compromised by leaps made between separate grains in the compacted powder normally used to make wires. The borocarbide materials have the general formula $\text{RNi}_2\text{B}_2\text{C}$ where R is a rare earth such as Lu, Y, Tm or Er. In borocarbide materials the interaction or competition of superconductivity with magnetic excitations makes very rich phase diagrams in an accessible temperature range (T_c between 6 and 16 K).

Tunnel exploration – Dr Suderow's findings

Using STM/STS with superconducting tips opens many new possibilities. For instance, interesting experiments can be made in one of the most prominent families of strongly correlated electron materials, heavy fermions, where several unconventional p-wave superconductivity modes have been unravelled. Their superconducting temperatures are, however, very low and significant experimental development at these low temperatures is necessary. The main attraction of using superconducting tips with STM/STS is to allow direct microscopic probing of the superconducting gap structure. This technique allows researchers to study the structure and the characteristic energy of the superconducting gap, D . For example, experiments in the new MgB_2 superconductor ($T_c = 40\text{K}$) the value of the superconducting gap is about one third of the expected value, based on estimations from BCS theory. This was possibly due to the presence of two different gaps.

STM spectroscopy allows a study of the local density of states at the atomic level. However the signal observed with STM is the convolution of the density of state value and the temperature of the system. At too high a temperature the signal becomes 'smeared' and the resolution is lost. Hence, ULT experimental equipment is required. An example is given in Dr Suderow *et al.*'s paper *Physica C* where a superconducting tip is used to study a lead (Pb) sample. At such a low temperature of 0.5K the two pronounced symmetric signals represent the peaks of quasiparticles and the gap in the middle of the graph is the superposition of the two superconducting gaps, (Figure 1).

Low temperatures, high impact

Dr Suderow and his team have presented very promising results using very low temperature STM spectroscopy.



Preliminary results with Pb and Al have demonstrated the feasibility of tunnelling using a superconducting tip. This technique would enhance the resolution at the atomic level and would allow researchers to probe even deeper and with more insight into the structure of any superconducting gaps. These methods could open doors in the fundamental investigation of unconventional superconductors (heavy fermions such as UPt3) and a more thorough understanding of new superconductors properties (such as single crystalline MgB₂ and new borocarbides).

Reference:

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