Oxide Interfaces, Andreev Bound States and Spin Injection

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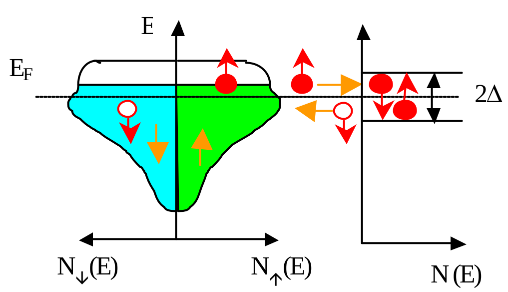
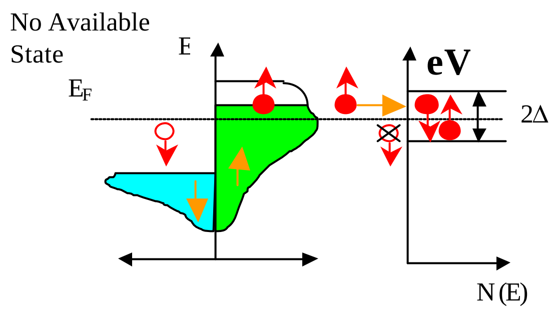
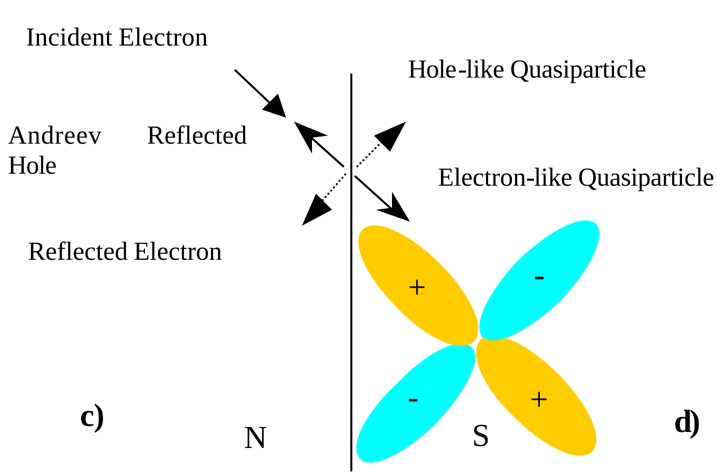
New devices based on novel oxide materials such as colossal magneto-resistance (CMR) mangnite and high T_c superconductor have received great attention recently. One example is the spin-injection device developed at Maryland, which shows the suppressive effects of spin-polarized current injection on the critical current I_c of high T_c superconductor. However, in order to fully understand the underlying physical mechanism of these devices, interface electrical properties between different oxides have to be investigated. In Maryland, we have now demonstrated the possibility of probing the so-called Andreev-bound states and surface polarization of CMR materials by Andreev reflection, as explained using the following diagrams. a) shows an interface between a normal metal (symmetric spin bands, no net magnetization) and conventional superconductor. If electron is injected into the superconducting gap, the superconductor via Cooper pair formation, which requires reflection of a hole with opposite spin, a process named as Andreev-reflection can accommodate it. Clearly, the conductivity is doubled in the process. For a ferromagnetic material, however, as shown in b), the spin bands have an asymmetry (net magnetization). Therefore, there are no available states for a hole to be reflected in an Andreev process, and hence Andreev-reflection is necessarily suppressed. In the high-T_c superconductor case, things are a little different because of the d-wave symmetry of its order-parameter in the ab-plane. As shown in c), an electron incident on the ferromagnetic-superconductor interface within the ab-plane, will either be reflected or Andreev-reflected (as a hole), and the two trajectories will possess different phases picked up from different lobes of the order-parameter. As a result of the wave functions, current-carrying bound states are created near the zero energy in the ab-plane surface, leading to zero conductance peak (ZBCP), as seen (panel d) from the conductance



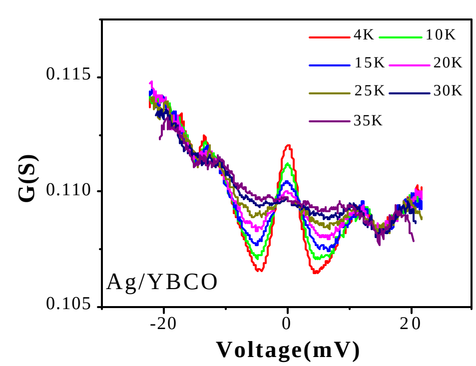
a) Normal Metal (P=0) Superconductor



b) Ferromagnetic Metal(P=100) Superconductor



c)



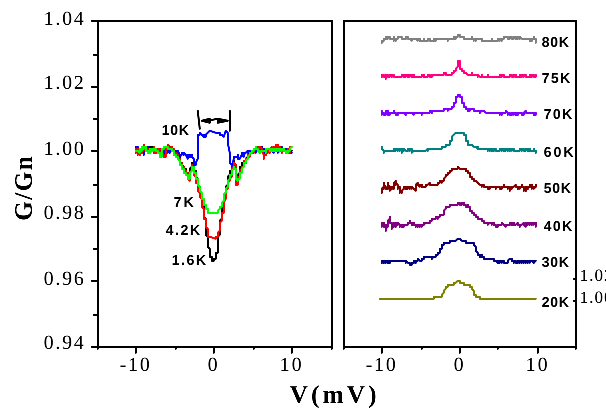
d)

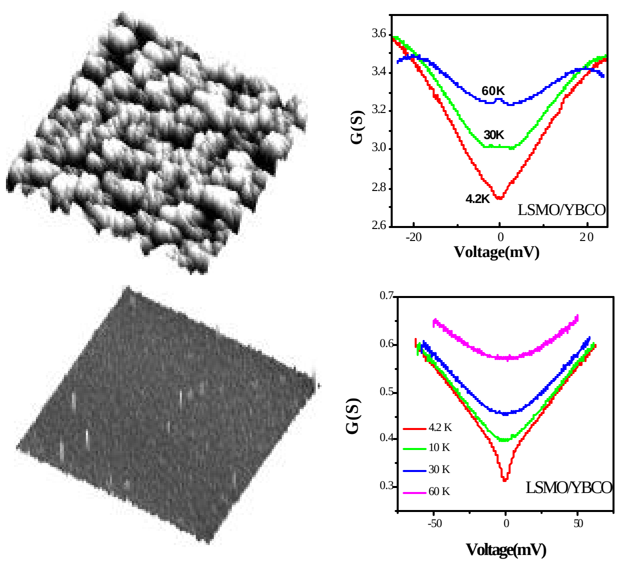
vs voltage characteristics for the Ag/$YbaCu_2O_{7-x}$ junction. As in the previously stated situation this ZBCP should also be suppressed, if we replace the normal metal by a ferromagnent. Of course, the degree of the suppression must depend on the surface spin-polarization of the ferromagnetic material. Indeed, as we show, this measurement helps reveal the temperature dependence of surface spin polarization of a CMR manganite material, which has been a subject of interesting scientific debate.

In our experiment, we prepared the $La_{0.7}Sr_{0.3}MnO_3$ / c-$YBaCu_2O_{7-x}$ interfaces, and patterned them into pads the size of 150µm × 200µm with superconducting layer on the bottom, in order to almost eliminate thermal effects. Note that, since the YBCO film is grown with the c-axis normal to the film plane, if the interface were ideally flat, the sample should not display any effects of Andreev bound states or their suppression, because no ab-plane features would be present at such a flat interface.

In real life the interfaces are not ideal, and the relative contribution of ab-plane effects would depend on the degree of interface faceting or roughness. Indeed, we could observe the ZBCP at high temperature only for the case of rough interfaces. This is shown in the upper panel. In the lower panel, for the case of a flat YBCO surface, only V-shaped backgrounds are seen, which indicate little ab-plane properties.

that no ZBCO is present, or that the ZBCP is completely suppressed, indicating nearly 100% surface spin polarization of the CMR material. As the temperature is increased to ~10 K, the ZBCP shows up. This can be attributed to the loss of surface polarization of LSMO, long before its Curie temperature (Tc ~ 380 K) is reached. This loss of surface spin polarization should explain the discrepancy between the claimed high polarization of LSMO (for the bulk case), and low performance in the magnetic tunneling devices.





The normalized conductance - voltage (G-V) characteristics for the same device are presented in the following panel. At extremely low temperature, such as1.6 K, one can clearly see

Reference

Suppression of Zero Bias Conductance Peak by spin polarized injection across an $YBa_2Cu_3O_{7-x}$/ $La_{0.7}Sr_{0.3}MnO_3$ Interface, Z. Y. Chen, Amlan Biswas, T. Wu, Igor Zutic, S. B. Ogale, A. Orozco, R. L. Greene and T. Venkatesan.. To be published.