Chapter 7
Point-Contact Spectroscopy of Multigap Superconductors

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Abstract  Point-contact spectroscopy offers a unique possibility to study the fundamental superconducting properties. Namely, the superconducting energy gap, its symmetry, multiplicity, the temperature and magnetic field dependence can be addressed usually on the scale of hundreds of nanometers.

From the very beginning of the discovery of superconductivity in magnesium diboride, this technique has been applied for the investigation of the two-gap superconductivity in this compound. Very recently discovered superconducting iron pnictides are intensively studied by this technique as well. Here, we shortly review the point contact experiments leading to one of the first experimental evidences of the fact that MgB$_2$ represents an extraordinary example of the multigap superconductivity. We show that particularly the measurements by point contacts in magnetic fields with the sample in the vortex state provide additional important informations directly in the raw data, thus not depending on a particular model used for fitting. Namely, the direct experimental evidence of the coexistence of two well-distinct superconducting energy gaps up the common transition temperature is shown. The small gap and small superconducting coupling below the BCS value characterize the $\pi$ band, while the large gap and the strong coupling are found in the hole $\sigma$ band.

Also the carbon and aluminum doped MgB$_2$ samples have been intensively studied. It is shown that the hole band filling effect leading to a decrease in the density of states due to electron doping by carbon and aluminum is very important. It prevails over the interband scattering introduced by doping MgB$_2$ by these elements in the investigated doping range. This is the reason why the two gap superconductivity is preserved also in the case when $T_c$ is significantly suppressed. The effect of applied magnetic field on the point-contact spectra is also used to study the intraband scattering processes within the two bands indicating that the carbon doping enhances significantly the scattering inside the $\pi$ band. This leads to a strong increase in the upper critical magnetic field, particularly at the low temperatures, with importance for practical applications.

Recent point contact measurements performed on the iron pnictides also show a presence of multigap superconductivity underlying the multiband character of this new class of the high temperature superconductors.
7.1 Point-Contact Andreev Reflexion Spectroscopy

Microconstriction or point contact (PC) between two metals can be modeled as a hole of radius \( a \) in an insulating sheet separating them. If the electron mean free path is much longer that the orifice radius \( l \gg a \), the charge transfer through the contact is ballistic and the resistance is due to the geometrical impeding this ballistic transport through the hole. In such a point contact, the excitation energy \( eV \) of charge carriers is controlled by the applied voltage \( V \). Let one of the metals forming the point contact be a superconductor. Below \( T_c \), a phase coherent state of Cooper pairs is formed in a superconductor with the superconducting energy gap in the quasiparticle excitation spectrum. For a quasiparticle incident on the N/S interface with an excitation energy \( eV < \Delta \), a direct transfer of the charge carriers is forbidden because of the existence of the energy gap \( \Delta \) in the quasiparticle spectrum of the superconductor. Then, the transport of charge carriers through the point contact with transmission probability \( T = 1 \) is accomplished by the unique process of Andreev reflection. The electron transfer takes place via the retroreflection of a hole back into the normal metal with the formation of a Cooper pair in the superconductor. At excitation energies above the gap, quasiparticles can be transferred directly across the interface. The Andreev reflection process leads at \( V < \Delta/e \) and in the zero-temperature limit to a current as well as differential conductance twice as large as in the normal state or as what is at large bias where the coupling via the gap is inefficient. When an insulating barrier is formed at the interface in the point contact, with \( T \ll 1 \) the opposite limit to the ballistic transport is given by the tunneling process. For this Giaever-like tunneling between a superconductor and a normal metal, it is well known that the conductance drops to zero for \( eV < \Delta \) (again in the zero-temperature limit). A more general case for arbitrary transmission \( T \) has been treated by Blonder, Tinkham and Klapwijk (BTK) [1]. In this model, the voltage(energy) dependence of the conductance of a N/S point contact is defined as

\[
G = \frac{dI}{dV} \propto \int_{-\infty}^{\infty} \left[ \frac{df(E - eV)}{eV} \right] [1 + A(E) - B(E)]dE, \quad (7.1)
\]

where \( A(E) \) is the Andreev reflection probability and \( B(E) \) is the probability of the normal reflection. The experimentally measured PC conductance data can be compared with this model using as input parameters the energy gap \( \Delta \), the parameter \( Z \) (measure for the strength of the interface barrier with transmission coefficient \( T = 1/(1 + Z^2) \) in the normal state), and a parameter \( \Gamma \) for the quasi-particle lifetime broadening [2]. The evolution of the \( dI/dV \) vs. \( V \) curves for different interfaces characterized by the barrier strength \( Z \) is schematically presented in Fig. 7.1a.

In the case of a two-gap superconductor, the normalized PC conductance represents a weighted sum of two contributions \( g_S \) and \( g_L \)

\[
\frac{G}{G_n}(V) = \alpha g_S + (1 - \alpha) g_L, \quad (7.2)
\]