Anomalous Resistive Oscillations in Mesoscopic Al Superconducting Wires

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Abstract

Oscillations in *R*-*T* curves of mesoscopic Al wires near superconducting transition temperature were observed under weak AC currents. We attribute this observation to the nonequilibrium superconductivities near the N-S interfaces and the movement of these interfaces.

Key words: mesoscopic system;Superconductivity;N-S interface

1. Introduction

Since anomalous superconducting transition in mescoscopic aluminium wires was observed in 1991, there were lots of experiments on the superconducting transition characteristics of mesoscopic Al wires and loops. Oscillations in *R*-*T* curves were observed under special conditions, e.g., with rf. or magnetic fields[1,2]. In this paper we will report, for the first time, the observation of oscillations in *R*-*T* curves of mesoscopic Al wires without any rf. or magnetic field.

2. Experiments

The mesoscopic Al wire samples were prepared on Si substrates by standard electron beam lithography followed by thermal evaporation method. The wires were 0.2 μm wide and 36 nm thick; the length between the two voltage probes was 3 μm, as shown in the inset of Fig. 1. At 4.2 K, the resistivity ρ of the samples is 3×10^{-8} $\Omega\cdot$m and the sheet resistance $R_\square$ is 10.08 Ω. The ratio $R_\square$(300K)/$R_\square$(4.2K) is 1.75. The mean free path l is 13 nm by ρl=4×10^{-16} Ωm^2[3]. Since the superconducting coherent length of aluminium ξ_0=1.6 μm, our samples are in dirty limit($l \ll \xi_0$).

3. Results and Discussions

Oscillations in *R*-*T* curves were observed in some of our samples, which were measured at different current without any additional conditions. When current is small, the differential resistance oscillates with increasing temperature, whereas as current becomes higher, the oscillation develops into an anomalous peak. Fig. 1 shows typical oscillations and the development with currents.

We suggest that normal (N)-superconducting (S) interfaces are responsible for this phenomena. Due to thermal fluctuation, N-S interfaces will appear between voltage probes when approaching T_c. As current flows through an N-S interface, quasi-particles $Q^\star$ are injected into the S-region and extend to a distance $\lambda_{Q^\star}$, forming a nonequilibrium distribution region near the interface. This nonequilibrium causes charge

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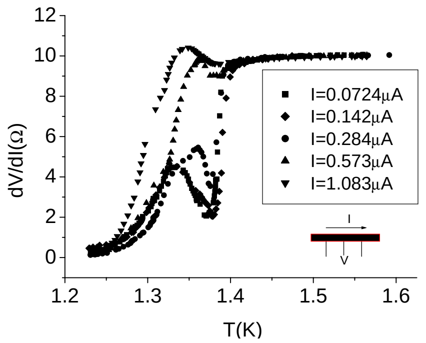

Fig. 1. oscillations in dV/dI-T curve.

imbalance. The electrochemical potential of Cooper pairs $\mu_{\rm s}$ is constant in the S-region. The electrochemical potential of quasiparticles $\mu_{\rm n}$ is different from $\mu_{\rm s}$ in the nonequilibrium region and varies continuously to $\mu_{\rm s}$ from the interface through the distance $\lambda_{\rm Q^\star}$[4]. Hence, the voltage V between S-region and N-region at the N-S interface is $I\rho\lambda_{\rm Q^\star}$, where I is the current flowing through the interface. Therefore the effective resistance of the interface $R_{\rm N-S}$ is $\rho\lambda_{\rm Q^\star}$. For $\lambda_{\rm Q^\star}$ is of micron dimension, $R_{\rm N-S}$ is considerably large in mesoscopic samples and shouldn't be neglected. Fig. 2 shows 3 possible distributions of N-S interfaces. According to the interpretation above, the resistances measured by the probes will be the following values respectively: (a)$R_{\rm a}(T)=\ \rho[2\lambda_{\rm Q^\star}+L_{\rm N}]$, $L_{\rm N}<L$; (b) $R_{\rm b}(T)=\ \rho[\lambda_{\rm Q^\star}+L_{\rm N}]$; (c) $R_{\rm c}(T)=\ \rho[2\lambda_{\rm Q^\star}+L_{\rm N}]$, $L_{\rm S}>2\lambda_{\rm Q^\star}$, where $L_{\rm N}$ and $L_{\rm S}$ are the length of the N-region and S-region, respectively, and L is the length between the two probes.

Comparing (a) and (b), the difference is the number of N-S interface. Consider the following situation when (a) transfers to (b) with increasing temperature via the movement of the right N-S interface across the right node, where the probe connects to the wire. The number of N-S interface within the two probes changes from 2 to 1 though the length of N-region has been increased. The variation of $R_{\rm N-S}$ is: $\triangle R(T)=\ R_{\rm b}(T)$-$R_{\rm a}(T)$=-$\rho\lambda_{\rm Q^\star}$. At the very moment when (a) transfers to (b),i.e.,the interface moving from the left side of the right node to its right side, it is reasonable to assume that the two situations have the same $\lambda_{\rm Q^\star}$ and $L_{\rm N}$. Therefore while the resistance gradually increases with increasing temperature due to the extending of the normal region, a sudden decrease in resistance appears if the above discussed (a) to (b) transformation occurs, resulting in an oscillation R-T curve.

On the other hand, the nodes have stronger superconducting quality than the region between the probes[5]. With strong ac current flowing through the wire, it is more probable that the region between the probes will transfer to N state before the node regions.

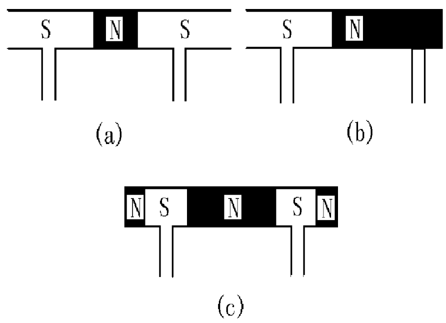

Fig. 2. Movement of N-S interface.

Therefore, (a) would more likely develop directly into (c) instead of (b). In this situation, if $L_{\rm N}$ increases to make $2\lambda_{\rm Q^\star}+L_{\rm N}>L$, we have $R_{\rm c}(T)>\rho L$, i.e., there is an anomalous peak in the R-T curve near $T_{\rm c}$.

It is important to emphasize that the situation discussed above is only from one of many possible N-S interface configurations. It will occur by chance. This is why the oscillations can be observed only in some of our samples.

4. Conclusions

Oscillations in R-T curves were observed without any additional bias or magnetic field. We attribute the oscillations to the movement of the N-S interface between the voltage probes. Resistive oscillations with temperature rising occur at lower current, whereas anomalous peak appears at higher current. The difference between the two phenomena is the different ways the interfaces move with temperature rising. Such oscillations, however, were observed only in some of our samples, implying that such anomalous superconducting transition occurs by chance.

Acknowledgements

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