Explanation of the resistance-peak anomaly in nonhomogeneous superconductors

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An anomalous superconducting transition consisting of a very sharp peak in the resistance versus temperature curve just above T_c has been observed in (NbV)N films and other superconducting compounds. Using a simple concentrated constant-equivalent circuit, it is proved that sample nonhomogeneity together with an out-of-line contact arrangement can produce the observed effect.

In a number of recent papers[1–4] an anomalous superconducting transition consisting of a very sharp peak in the resistance versus temperature curve just above the critical temperature T_c has been observed. Very similar effects have often been observed by other groups when dealing with nonhomogeneous superconducting films.[5,6]

In our laboratory we have observed strong resistance peaks (of amplitude up to 50% of the resistance value far above T_c) in many films of the superconducting compounds NbN, VN, (NbTi)N, or (NbV)N. The resistance-peak amplitude was strongly dependent on the four contact arrangement used to measure the sample resistance, weakly dependent on the bias current and was never observed when an in-line contact arrangement was used.

In Fig. 1 the resistive transition at low bias current of a $(Nb_{80}V_{20})N$ film is shown for the contact arrangement reported in Fig. 2(a) (configuration A). The giant, narrow, resistance peak just above the transition disappeared by changing the contact arrangement to an in-line one and has a rather trivial explanation in terms of current redistribution in the sample. Though this idea has been around for a while, to our knowledge, no clear treatment of the effect has been reported in the literature.

In Fig. 2(a) we consider a thin rectangular slab of a superconducting material with three different contact arrangements (A,B,C). In Fig. 2(b) we present the corresponding simplified concentrated constant-equivalent circuits. The values of the four resistances R_1-R_4 depend on the contact distances. The "measured resistance" $R_m = V/I$ has different expressions in the three cases:

$$R_m(A)=R_1R_3/\sum_{i=1}^{4} R_i \ , \tag{1a}$$

$$R_m(B)=(R_1R_3-R_2R_4)/\sum_{i=1}^{4} R_i \ , \tag{1b}$$

$$R_m(C)=R_1(R_2+R_3+R_4)/\sum_{i=1}^{4} R_i \ . \tag{1c}$$

Now, if the superconductor is nonhomogeneous, different parts of the film (i.e, the four resistors R_1-R_4 in the equivalent circuit picture) can have slightly different transition temperatures. As is clear from Eqs. (1a) and (1b), in the configurations A and B [Fig. 2(a)] a resistance drop of R_2 or R_4 clearly produces a sharp increase in the

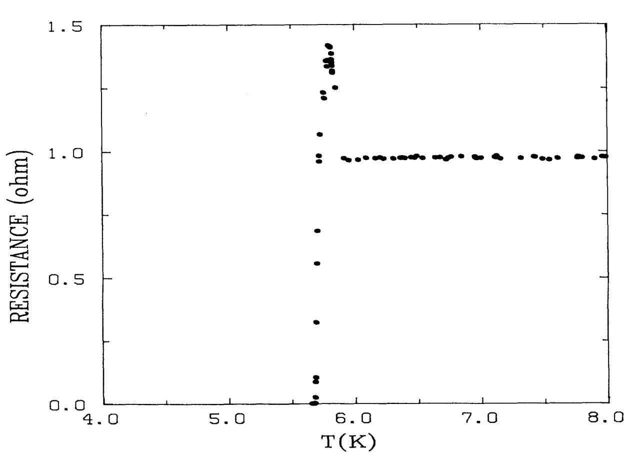

FIG. 1. Resistive transition of a $(Nb_{80}V_{20})N$ superconducting film at low bias current. The current arrangement is the same as in Fig. 2(a) (A).

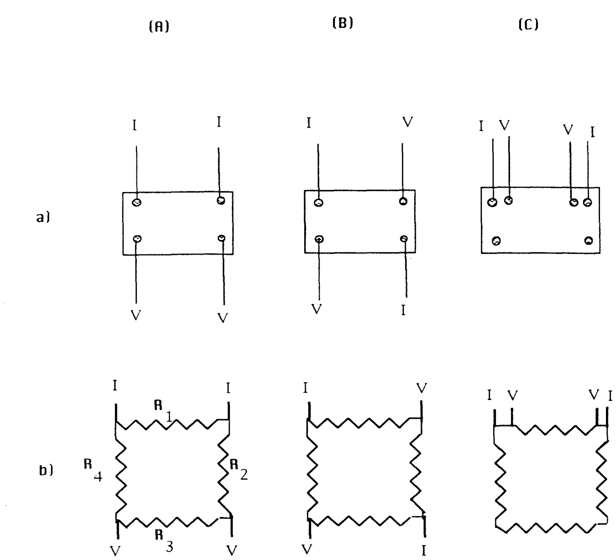

FIG. 2. (a) Three different possible contact arrangements on a rectangular thin superconducting slab (A,B,C). (b) Corresponding concentrated constant-equivalent circuits.

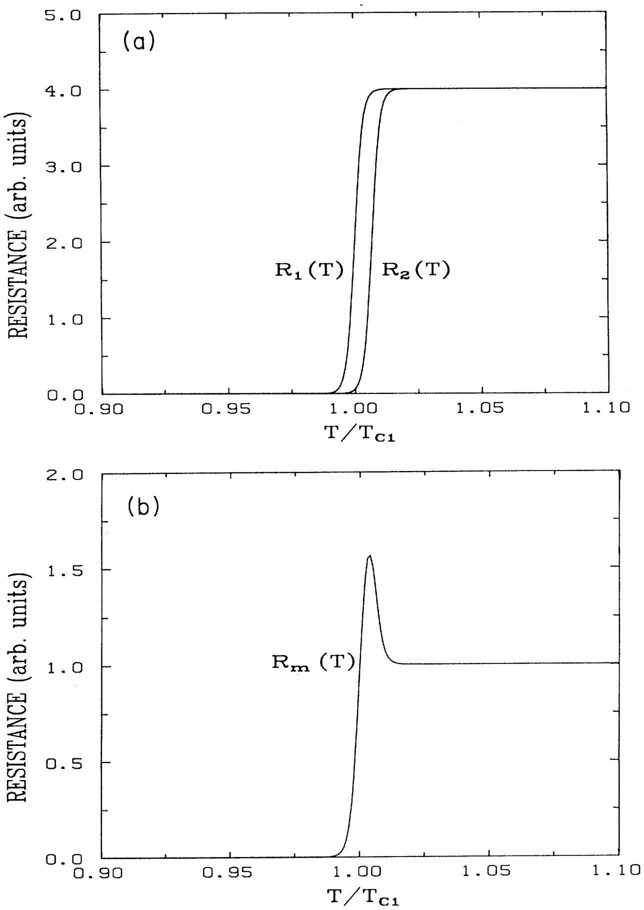

FIG. 3. (a) Assumed superconducting transition for the resistors R_1 and R_2. (b) Calculated temperature dependence of R_m [from Eq. (1a)] assuming $R_1=R_3$ and $R_2=R_4$ at any T ($T_{c2}=1.007T_{c1}$).

measured resistance R_m. No such effect can be present in configuration C [Eq. (1c)].

We have used the equivalent circuit (configuration A) to simulate the resistive transition of a nonhomogeneous film. We assume $R_1=R_3$ and $R_2=R_4$ at all temperatures, and for R_1 and R_2 the temperature dependence reported, close to T_c, in Fig. 3(a) ($T_{c2}=1.007T_{c1}$). In Fig. 3(b) the temperature dependence of R_m as deduced by Eq. (1a) is reported. An anomalous peak in the resistive transition, similar to the one found experimentally (Fig. 1), is clearly reproduced.

It is worth stressing that, in spite of its crudeness, the model has been proved to be consistent with all our experimental observations, giving the correct predictions on the behavior of $R_m(T)$ for the different contact arrangements. In particular, by accurate measurements of $R_m(T)$ with in-line contacts as in Fig. 2(c) across R_1 or across R_2 a difference in the measured T_c values of about 1% was indeed found, proving the slight nonhomogeneity of our film.

The peak amplitude, for a given configuration, is independent from the bias current for low current densities in the sample, and tends to shift to lower temperatures and then to decrease in amplitude at very high current densities, presumably due to the depression of the superconductivity in parts of the film.

In our opinion the possibility that "current redistribution" effects related to sample nonhomogeneity as described by our simple model play a role, has to be seriously considered in any measurements where peaks are seen at the superconducting transition.[1,4]

As an example we can fit the data of Refs. 1 and 2 by our model with the assumptions of $R_1=50R_2$ far above T_c (due to sample geometry), $R_1=R_3$ and $R_2=R_4$ at all temperatures, and a sample nonhomogeneity such that $T_{c2}=1.02T_{c1}$. The fact that no difference is found in $R_m(T)$ using configurations A and B is naturally related to the condition $R_1, R_3 \gg R_2, R_4$ [Eqs. (1a) and (1b)].

In our model, if configuration B is used and we assume $R_1=R_2=R_3=R_4$ far above T_c, we have $R_m=0$ both for $T \gg T_c$ and for $T \ll T_c$ but R_m presents a peak (either positive or negative) at T_c if sample nonhomogeneity causes one of the four resistors to have a slightly different different transition temperature. A similar effect is observed in Ref. 3 in which, however, the authors present strong arguments to prove the absence of nonhomogeneities.

In conclusion, we have observed an anomalous superconducting transition consisting of a sharp, giant peak in the resistance versus temperature curve just above T_c in (NbV)N films and other superconducting compounds.

We have then proved that sample nonhomogeneity together with an out-of-line contact arrangement can produce a resistance peak at the superconducting transition due to current redistribution effects. A simple concentrated constant-equivalent circuit easily accounts for the main features of the experimental observations.

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