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Resistance-peak anomaly in metallic glasses: Dependence on currents and contact arrangement

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A peak in the electrical resistance has been observed previously by Lindqvist, Nordström, and Rapp in some superconducting amorphous metals. In this paper we report on further variations of the contact arrangement and on variations of the measuring current over a larger range than used before. It is found that the resistance peak is independent of transport current for low currents and, above a threshold value, decreases with increasing current and slightly shifts toward lower temperatures. The peak is not observed in contact arrangements where current and potential contacts are on one line.

A resistance anomaly has been observed in some metallic glasses.[1] It consists of a peak in the electrical resistance in the lower part of the superconducting flutuation region, just above the superconducting transition. Three conditions were found for this observation; i.e., the effect occurred only for a certain range of Zr concentration in Cu-Zr metallic glasses and for a certain small range of magnetic impurities. The magnetic field must not be too strong, since the effect is quenched in a few tenths of a tesla.

Recently, resistance peaks similar in shape to those of Ref. 1 have been observed in other experimental situations such as in thin films,[2] in one-dimensional wires,[3] and in high-temperature superconductors.[4] The question must therefore be raised, is there a common origin for this phenomenon?

Francavilla and Hein[2] discussed the possibility that such an effect could be induced by vortex motion. As suggested by Glazman,[5] the annihilation of spontaneously created vortex-antivortex pairs could lead to a transverse voltage in thin films. The effect should be observable above a threshold value of the transport current and should persist in a certain current range. Some features of the observations were in agreement with this theory. However, the predicted magnitude of the transverse peak was two orders of magnitude smaller than the observations.

In our first report[1] we checked that the peak effect in our amorphous alloys was not affected by interchanging current and potential leads to the sample and also that it was independent of an increase by a factor of 2 of our low measuring currents, of order 20 μA. The observations quoted above, however, led us to investigate further our samples. We report here on the results from a larger variation of the measuring current and from further experiments with contact arrangements.

In measurements of the electrical resistance of thin ribbon samples of disordered metals, we have found it convenient to cut small notches at both ends of the samples in order to isolate current and potential contact areas from the investigated part of the sample. Small displacements of the contacts, which may be induced, e.g., by thermal strain between contact glue and sample, are then eliminated. The normal contact arrangement for current and voltage leads is shown in *B* in Fig. 1. This allows for accurate resistance measurements over a large temperature range which are reproducible in repeated cooling cycles in the same experiment.[6]

For the present experiment eight leads were attached to a sample. We used knots and silver paint with epoxy for mechanical stabilization. Some different contact arrangements are shown in Fig. 1. By interchanging one of the current and potential leads, one obtains *A* from *B*. Two other possibilities are *C* and *D*, which were presently investigated, but are not normally used. The thickness of our ribbon samples is typically 30 μm and the width 1–2 mm. The length of the sample between potential contacts is 25–30 mm. Sample resistance is about 2 Ω and contact resistance below about 1 Ω.

With a current comparator bridge (Guildline), we used currents down to 10 μA ($\approx 20 \mathrm{mA/cm^2}$), while retaining a sensitivity for detection of resistance peaks below 10^{-4}. Two samples I and II of disordered $Zr_{60}Cu_{40}$ were investigated, which were taken from different parts of the same melt-spun ribbon as in Ref. 1. Details of preparation and properties have been given previously.[7]

Results for sample II with variation of sample current in a wide range are shown in Fig. 2. Contact arrangement *A* was used. The peak height, measured as peak resistance divided by background resistance, was about

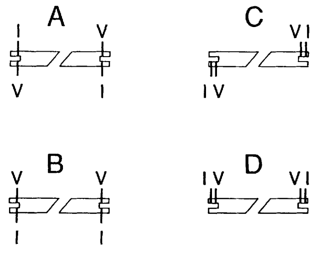

FIG. 1. Four different contact arrangements tested in the present investigation.

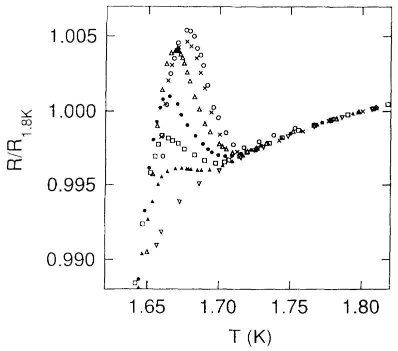

FIG. 2. Resistance peak in sample II vs temperature for different sample currents: 20 μA, (○), 100 μA (x), 0.50 mA (Δ), 2 mA (●), 3.0 mA (□), 4.0 mA (▲), and 10.0 mA (∇). Contact arrangement *A* was used.

0.8% in this sample and about 1.2% in sample I. At larger currents the peak decreases and shifts slightly toward lower temperatures. However, the peak maximum always occurs at about 35 mK above T_c. This shift is likely due to critical-current effects.

Peak magnitude vs current on a logarithmic scale is shown in Fig. 3. For the lowest currents the accuracy is reduced, thus giving some scatter of the data. We note that the peak magnitude is approximately constant over a variation of the sample current of more than one order of magnitude. Above about 1 mA the peak decreases strongly and disappears at 4–5 mA. For sample I the peak disappears at 8–9 mA. When plotted on a linear current scale, this decreasing peak height can be seen to be fairly linear in current.

Results for different contact arrangements on sample I are shown in Fig. 4. We checked that the results for arrangements *A* and *B* did not depend on whether the inner or outer contacts on each tongue were used. For arrangements *D* and *C*, the normal-state resistance is somewhat larger than for *B* and *A*, since the sample length also includes a small part of the tongues. Therefore the resistance was normalized to 4.2 K in order to compare these results.

The results from contact arrangements *A* and *B* are indistinguishable, as shown in Fig. 4, both showing a resistance peak in the fluctuation region, while those in arrangements *C* and *D* are also indistinguishable and show the usual monotonous variation of the electrical resistance. These measurements were made at 1 mA. We also checked that the results for each sample were identical for increasing and decreasing temperatures.

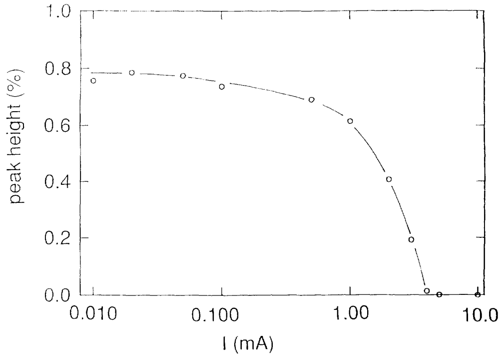

FIG. 3. Normalized peak height for sample II vs sample current.

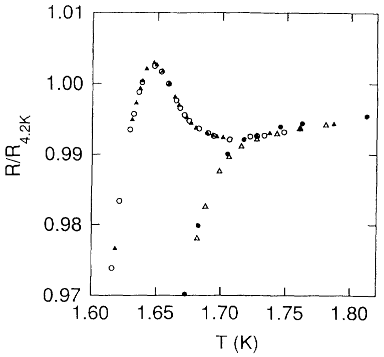

FIG. 4. Electrical resistance in the fluctuation region for the different contact arrangements of Fig. 1: A (▲), B (○), C (△), and D (●). It can be seen that either arrangement *A* or *B* is required to observe the peak.

These results were surprising to us. Since we always use contact arrangement *B* or *A* in our measurements on amorphous metals, the present results give a fourth condition for the observation of a resistance peak in metallic glasses, in addition to the three mentioned in earlier: There must be a nonlinear arrangement of current and potential contacts in the experiment. In arrangement *A* there is an angle between current lines and the line between potential contacts of 2°–3°. In arrangement *B* such an angle is less obvious, but could possibly arise from current distribution in an inhomogeneous sample.

In the thin-film experiments by Francavilla and Hein,[2] a resistance peak was most reliably observed with a 90° Hall-probe arrangement of the current and potential leads. However, in the one-dimensional wire experiment,[3] large resistance peaks were observed and any misalignment between current and potential contacts should be at least an order of magnitude smaller than in our arrangement *A*, i.e., $<0.2°$. For the high-T_c experiments,[4] the contact arrangement was not specified.

The temperature at which the peak occurs is independent of current in the range 10–100 μA in sample II, as can be seen in Fig. 2. Only for further increased current is there a noticeable shift toward lower temperatures, which amounts to about 20 mK or 1% of T_c, when the current is increased from 100 μA to 1 mA. In the experiment of Francavilla and Hein[2] the peak shifts toward lower temperatures by a similar fraction of T_c when the current in their thin film is increased from 1 to 10 mA. However, in their experiment the peak resistance is apparently constant in this current range, while in our experiment a shift of peak position at higher current densities is accompanied by a decrease in peak magnitude.

In Glazman's theory[5] a peak is observed only in a range of currents between a lower and an upper threshold, while in our experiment we cannot observe such a lower threshold current. Furthermore, this theory is applicable to thin films, where the creation of vortex-antivortex pairs could occur, while in our much thicker samples the probability for such events would seem negligible. Thus it appears that this theory is not applicable to our observations.

We must conclude that the peak phenomenon in the electrical resistance of various superconductors remains unexplained. For amorphous metals we have found a condition for the observation of such a peak in addition to previous results.[1] That is, current and potential contacts must be nonlinearly arranged.

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