Comment on "Experimental determination of superconducting parameters for the intermetallic perovskite superconductor $MgCNi_3$"

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In a recent paper [Phys. Rev. B **67**, 094502 (2003)] Mao *et al.* investigated the bias-dependent conductance of mechanical junctions between superconducting $MgCNi_3$ and a sharp W tip. They interpreted their results in terms of "single-particle tunneling." We show it is more likely that current transport through those junctions is determined by thermal effects due to the huge normal-state resistivity of $MgCNi_3$. Therefore no conclusion can be drawn about the possible unconventional pairing or strong-coupling superconductivity in $MgCNi_3$.

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In a recent paper Mao *et al.*[1] reported bulk transport and specific-heat measurements on superconducting $MgCNi_3$. Additionally, they investigated the conductance of mechanical junctions between superconducting $MgCNi_3$ and a sharp W tip with 15 μm curvature radius. By postulating that tunneling dominates the conductance they interpreted the observed zero-bias conductance peak (ZBCP) as caused by Andreev-bound states which result from a possible unconventional pairing state in $MgCNi_3$. Besides that, Mao *et al.*[1] attributed the simultaneously appearing two conductance dips to the characteristic superconducting energy scale in $MgCNi_3$. On this basis Mao *et al.* suggested that this result can be taken as further support of strong-coupling superconductor of $MgCNi_3$.

We believe that before dealing with more exotic phenomena, such as Andreev-bound states, more trivial effects should be considered to explain the observed conductance anomalies of those junctions.

First, Mao *et al.*[1] assumed that a tunneling barrier forms at their junctions with rather low resistance $<0.1\ \Omega$. This assumption was based only on the fact that the shape of the superconducting transition in the resistance $R(T)$ of the junctions deviates from that of the bulk resistivity $\rho(T)$. According to our experience, such deviations are typical for mechanical junctions (or point contacts) with highly resistive metals. The sharp tip damages the sample surface in the contact area, which means the material there is more degraded than in the bulk. This can locally change ρ as well as T_c. Figure 1 shows as an example the behavior of $R(T)$ for several contacts between an amorphous superconducting Zr_2Ni ribbon (its residual normal-state resistivity $\rho_0 \approx 170\ \mu\Omega$ cm is comparable to that of $MgCNi_3$) and a Cu tip.[2] While $R(T)$ of low-Ohmic contacts has a rather sharp transition similar to that of $\rho(T)$, the transition broadens for larger R_N. The same kind of broadening was observed for URu_2Si_2 break junctions[3] (also a metal with large ρ). In the latter experiments breaking the samples at helium temperatures prevented the formation of any oxide or other contaminating layer on the surface which could otherwise produce a tunneling barrier.

Second, ZBCP's are characteristic features of junctions formed with superconductors that have a high normal-state resistivity, as shown in the inset of Fig. 1 for a $ZrNi_2$-Cu contact. As another example, Gloos *et al.*[4] observed pronounced zero-bias minima in dV/dI (corresponding to ZBCPs in dI/dV) for contacts between the heavy-fermion superconductor UBe_{13} and a W tip (UBe_{13} also has a very high resistivity, comparable to that of $MgCNi_3$). They concluded that the dV/dI anomalies were due to diffusive and thermal transport through the junctions, while significant Andreev reflection currents were missing.

Third, $MgCNi_3$ has a huge residual resistivity $\rho_0 \approx 400\ \mu\Omega$ cm (see the inset of Fig. 3 in Ref. 1) like that of amorphous metals. With the carrier density $n \approx 10^{28}\,m^3$ from Ref. 6 and the Drude formula $l = \hbar k_F/(e^2 n \rho)$, where k_F is the Fermi wave number, we calculate an elastic electron mean free path (mfp) $l_{el} \approx 0.7$ nm. This is comparable to the lattice constant. The inelastic mfp $l_{in} \sim \hbar v_F / k_B T \approx 1.5\ \mu$m at 1 K according to Ref. 5. Here v_F is the Fermi velocity. This results in a very small diffusive inelastic mfp $\Lambda \approx \sqrt{l_{el} l_{in}} \approx 30$ nm. Applying the Maxwell formula that describes the spreading resistance of large metallic contacts

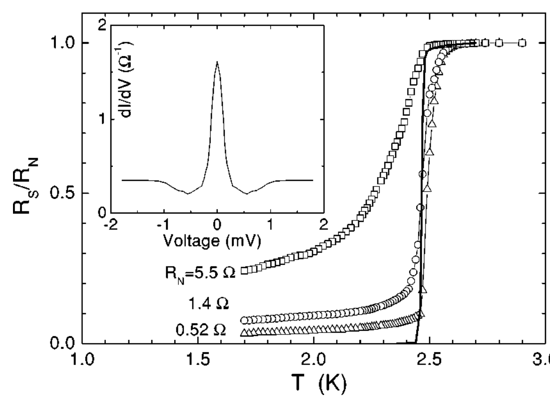

FIG. 1. Temperature dependence of the differential resistance at zero bias $[R \equiv dV/dI(V=0)]$ of three junctions between an amorphous Zr_2Ni ribbon and a Cu tip (open symbols, redrawn from Ref. 2). The solid line shows the bulk resistance of the Zr_2Ni ribbon. All curves are normalized to the normal-state resistance R_N, which is also indicated for each junction. Inset: Numerically derived, from I-V curve in Ref. 2, differential conductance $dI/dV(V)$ at 1.7 K of one of the $ZrNi_2$-Cu contacts.

$$R_N \approx \rho/2d, \tag{1}$$

and taking into account that W has a negligibly small resistivity compared to that in $MgCNi_3$ we estimate a contact radius $r=d/2$ between 12–20 μm for the junctions presented in Ref. 1. *This fits very well the curvature of the W tip* (15 μm), *supporting our model of a direct metallic contact*. Since d is much larger than the diffusive inelastic electronic mfp Λ, these contacts are in the thermal regime[7] in which the temperature inside the contact rises with applied bias voltage, and the differential conductance depends only on $\rho(T)$.[7] In the thermal regime the bias voltage no longer determines the excess energy of the electrons; and this makes it impossible to obtain any spectral information about the transport processes through the junctions and seriously questions the conclusions in Ref. 1 with respect to the characteristic superconducting energy scale in $MgCNi_3$.

Fourth, the current density can be quite large for the contacts investigated in Ref. 1. For example, at $V=1$ mV the current density is larger than $j=V/(R_N d^2)\simeq 10^7$ A/m^2. The ZBCP's, the abrupt decrease of dI/dV with increasing bias voltage, are very likely caused by the continuous growth of the normal phase due to the temperature rise inside the constriction discussed above as well as due to the increasing current density.[9] The pulsed-current method used by Mao *et al.*[1] to measure the *I-V* curves with a pulse duration of $t=5\times 10^{-2}$ s certainly reduces heating of the bulk sample itself, but it does not prevent local heating of the junctions. A junction with diameter of about 10 nm typically has a thermal relaxation time $\tau\approx 10^{-9}$ s.[7,8] Since $\tau\propto d^2$, the $MgCNi_3$-W contacts with $d\approx 20-40\,\mu$m, as estimated above, should have $\tau\sim 10^{-3}$ s. This is still much smaller than the pulse duration t, meaning that the local temperature will respond to the applied bias voltage almost without delay.

In conclusion, to obtain reliable information from point-contact experiments, the regime of current flow through the constrictions has to be properly established and/or analyzed. For junctions with highly resistive metals such as $MgCNi_3$ thermal effects have to be expected. Apparently, here they play the role of preventing us from energy-resolved spectroscopy.

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