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

Z. Q. Mao, M. M. Rosario, K. D. Nelson, K. Wu, I. G. Deac, P. Schiffer, and Y. Liu
Department of Physics, The Pennsylvania State University, University Park, Pennsylvania 16802, USA

T. He, K. A. Regan, and R. J. Cava
Department of Chemistry and Princeton Materials Institute, Princeton University, Princeton, New Jersey 08540, USA

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This Reply responds to the criticism raised by Yu. G. Naidyuk in the preceding Comment [Phys. Rev. B. **69**, 136501 (2004)].

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We recently reported[1] our electrical transport, specific heat, and tunneling measurements on $MgCNi_3$. From these measurements we determined parameters of this new superconductor. In addition, we concluded that $MgCNi_3$ is a strong coupling superconductor based on the specific heat data.

Naidyuk's Comment[2] specifically concerns our interpretation of the zero-bias conductance peak (ZBCP) observed in the tunneling spectrum obtained on single-phase, but polycrystalline $MgCNi_3$. In our paper,[1] we clearly stated that, although the observed ZBCP could be due to the presence of surface Andreev bound states (ABS's) originating from an unconventional pairing state, the interpretation was *not consistent* with the observation of a coherence peak in the NMR $1/T_1$ measurements. As an alternative we pointed out that multiple-band superconductivity proposed theoretically within an s-wave pairing scenario[3] could have also caused the observed ZBCP. Naidyuk proposed a different model based on heating effects. We would like to point out here that the proposed heating model is not applicable to our experiment.

Naidyuk showed a dI/dV vs V spectrum and the temperature dependence of junction resistance between amorphous Zr_2Ni ribbon and a Cu tip that exhibited features similar to those seen in our $MgCNi_3$-W mechanical contacts. Based on this, Naidyuk questioned if a tunnel barrier existed in our mechanical contacts. In fact, Gloos raised the same question in a Comment[4] on the ABS interpretation of the ZBCP observed in a heavy-fermion superconductor UBe_{13} (Ref. 5) and this was shown to be irrelevant.[6] Naidyuk employed the Wexler formula to estimate the tip size as Gloos did.[4] While the estimated tip size turned out to be consistent with our experimental value, this is likely coincidental. Wexler's formula is based on the assumption that the two electrodes in the junction should have at least similar Fermi liquid parameters and resistivity. This assumption clearly does not apply to our experiment—$MgCNi_3$ and W are very different materials.

Naidyuk further argued that heating effects might dominate the behavior of our mechanical contacts and suggested that the measured junction conductance was essentially that of the bulk. However, if this was indeed the case, dI/dV at zero bias would depend only on bulk resistivity $\rho(T)$, reaching the maximum when $\rho(T)$ reached zero. From the inset of Fig. 1 in Ref. 1, it can be seen that the resistivity of bulk $MgCNi_3$ dropped to zero at 7 K. Therefore dI/dV would have reached maximum at 7 K and remained a constant at lower temperatures. This is *inconsistent* with the experimental observation: The ZBCP observed experimentally grew gradually with decreasing temperature. Naidyuk also stated that the decrease in dI/dV with increasing bias voltage (therefore larger current) was due to the continuous growth in the normal phase as temperature was raised. However, this picture cannot explain the presence of a dip in the same spectrum.

It is important to note that features observed in the tunneling spectrum of $MgCNi_3$-W mechanical contacts were also found in planar $MgCNi_3/Al_2O_3/Au$ junctions, as pointed out in Ref. 1. In these planar junctions the thermal effects should be irrelevant. However, a significant ZBCP was observed (Fig. 1). Two important features should be noted in Fig. 1. First, the normalized height of ZBCP is 6, much greater than the normalized maximum height expected

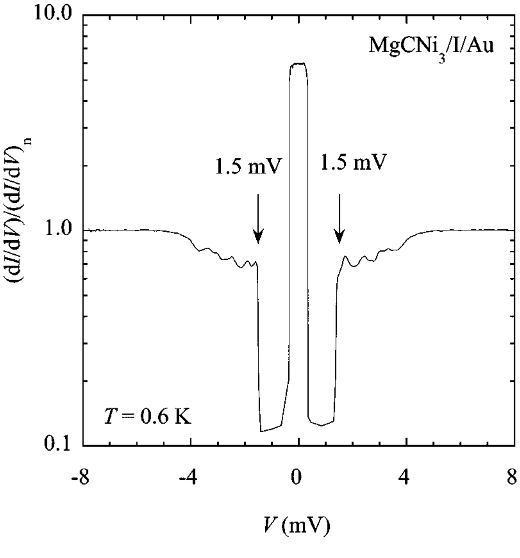

FIG. 1. Tunneling spectrum of a $MgCNi_3/Al_2O_3/Au$ planar junction normalized by $(dI/dV)_n$, the normal-state tunneling conductance. The junction is a planar junction prepared by evaporating a 100-Å-thick insulating Al_2O_3 and a 500-Å-thick Au evaporated on polished $MgCNi_3$ surface.

for conventional Andreev reflection ZBCP, $(dI/dV)_s/(dI/dV)_n=2$. Second, the dI/dV shows a steep drop around 1.5 mV. This energy scale is the same as the characteristic energy E_c we defined in Ref. 1. These features are fully consistent with those found in MgCNi$_3$-W mechanical contacts.

Finally, we would like to stress that MgCNi$_3$ was identified as a strong coupling superconductor in our paper[1] based on specific heat rather than tunneling data. E_c, defined in the tunneling spectrum, was carefully referred to as a characteristic energy scale rather than the superconducting energy gap. We stated that if E_c indeed corresponded to the gap, it would provide an additional support to our strong-coupling conclusion, a statement that remains correct.

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[1] Z. Q. Mao, M. M. Rosario, K. D. Nelson, K. Wu, I. G. Deac, P. Schiffer, Y. Liu, T. He, K. A. Regan, and R. J. Cava, Phys. Rev. B **67**, 094502 (2003).

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[6] Ch. Walti, H. R. Ott, Z. Fisk, and J. L. Smith, Phys. Rev. Lett. **85**, 5258 (2000).