Comment on "Tunneling $\alpha^2F(\omega)$ from sputtered thin-film NbN"

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Certain disadvantages of the choice of the material of the counterelectrode and hence the inadequacies of the results of the paper on tunneling $\alpha^2F(\omega)$ from thin-film NbN by Kihlstrom, Simon, and Wolf [Phys. Rev. B **32**, 1843 (1985)] are pointed out, and suggestions are made to improve upon the present results. Pb is not an ideal choice as a counterelectrode material because the electron-phonon interaction in Pb is strong and this can manifest itself in the tunneling characteristics even if the superconductivity in Pb has been quenched by the application of a magnetic field. An ideal choice would be a Bardeen-Cooper-Schrieffer superconductor (preferably Al) and the data should be taken with both the electrodes in the superconducting state to avoid thermal broadening effects in the normal state. Contribution of the Al density of states can be taken care of by the deconvolution of the integral for the normalized conductivity of the junction.

In a recent Rapid Communication Kihlstrom, Simon, and Wolf[1] report their results for tunneling $\alpha^2F(\omega)$ from sputtered thin-film NbN. Their samples were made by ultrahigh-vacuum rf sputtering[2] using a niobium target and an argon (75 mtorr)–nitrogen (10 mtorr) gas mixture. The pressure before addition of the Ar-N_2 mixture was 5×10^{-9} torr. The substrate table was heated to about 800 °C and about 2500 Å of material was deposited. Such samples normally contained about 2% of carbon, even in the absence of added carbon-containing gases. The tunneling barrier was formed using chemical anodization.[3] The junction areas were defined by photoresist and a Pb counterelectrode was then deposited giving rise to a NbN-oxide-Pb tunnel junction. I-V and dI/dV characteristics were studied for two such samples. Differential conductance for the two samples was measured at 1.5 K in the superconducting state with the Pb electrode driven normal by an applied magnetic field (0.1 T), and then with the temperature elevated above T_c (14.0 K) of the NbN so that both the electrodes were normal. The reduced tunneling density of states was then input into the modified McMillan-Rowell gap inversion program (originally developed by McMillan and Rowell[4] and modified by Arnold,[5] Wolf *et al.*,[6] and Wolf *et al.*[7]) and $\alpha^2F(\omega)$ and other related parameters were obtained.

In this note we would like to point out certain disadvantages in the choice of the material of the counterelectrode and its manifestation in the results on $\alpha^2F(\omega)$ for NbN. Pb is not an ideal choice as a counterelectrode material because the electron-phonon interaction in this material is strong and it would certainly show up in the tunneling characteristics even if Pb is driven normal by the application of a magnetic field.[4] The structure in the tunneling characteristics due to the combination of a transverse phonon and a longitudinal phonon of Pb occurring around 13 MeV can interfere with the low-energy peak of $\alpha^2F(\omega)$ for NbN occurring around 14 MeV. Since the structures in the tunneling characteristics due to the lead phonons and the NbN phonons could be of comparable magnitudes, the error that could be introduced by using a lead counterelectrode would be quite large. However, an exact estimate of this error is not possible. This point shall be appreciated more if we keep in mind that the structure in the normalized density of states (Fig. 2 of the paper) has a maximum value of about 2% whereas the structure in Pb spectrum even in the normal state due to the states in the barrier could be around 1%. Moreover, driving of Pb normal has the disadvantage of introducing thermal broadening in the structure of the tunneling characteristics. The ideal choice for the counterelectrode material should be a Bardeen-Cooper-Schrieffer superconductor (preferably Al) and the data should be taken with both the electrodes in the superconducting state. This would avoid thermal broadening effects in the normal state and would not introduce any structure of its own. This has been the technique used in most of the earlier work using thin-film junctions for the study of the $\alpha^2F(\omega)$ for a large number of strong-coupling and intermediate-coupling materials. Contribution of the Al density of states can be taken care of by the deconvolution of the integral for the normalized conductivity of the junction. A computer program for this was developed in the late sixties and has been extensively used.[8]

We would like to make a final comment about the quality of the junctions used by Kihlstrom *et al.*[1] The authors claim that the excess conductance below the sumgap (implying that the data in Fig. 1 are without the applied magnetic field) was 5% of the above-gap conductance. This means that the contribution to the conductance from the nontunneling mechanisms is 5% and this is going to be affected adversely due to the thermal broadening effects when Pb is driven normal. This high value of the nontunneling conductance is much above the accepted norms for high-quality tunnel junctions.[4] The fact that a structure in the tunneling characteristics $\simeq 2\%$ is being obtained from a tunnel junction with 5% nontunneling contribution to the conductance does not inspire much confidence in the results. It is not advisable to make an estimate of the error introduced by the subgap conductance because it is not possible to be sure about the mechanisms responsible for this. Normally it is assumed to be due to the presence of pinhole shorts in the oxide barrier. The exact behavior of these pinholes as a function of the applied bias, temperature cycling, or a change in their behavior as a function of elapsed time are some of the points guesses about which could be very hazardous. Some kind of subtraction could be tried. Some of these inadequacies in the published results can be taken care of by using the suggested material of the counterelectrode, and the rest can be improved by making better quality junctions. The calculated values of the parameter μ^* and the transition temperature T_c point to the inadequacies of the results.

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