Point-contact spectroscopy of the borocarbide superconductor YNi$_2$B$_2$C

Yu. G. Naidyuk$^a$, D. L. Bashlakov$^a$, I. K. Yanson$^a$, G. Fuchs$^b$, G. Behr$^b$, D. Souptel$^b$, S.-L. Drechsler$^b$

$^a$B. Verkin Institute for Low Temperature Physics and Engineering, National Academy of Sciences of Ukraine, 47 Lenin Ave., 61103, Kharkiv, Ukraine
$^b$Leibniz-Institut für Festkörper- und Werkstoffforschung Dresden e.V., Postfach 270116, D-01171 Dresden, Germany

Abstract

Point-contact (PC) spectroscopy measurements on YNi$_2$B$_2$C single crystals in the normal and superconducting (SC) state ($T_c \approx 15.4$ K) for the main crystallographic directions are reported. The PC study reveals the electron-phonon interaction (EPI) function with a dominant maximum around 12 meV and a further weak structure (kink or shallow broad maximum) at higher energy at about 50 meV. Other phonon maxima at 20, 24 and 32 meV specified in the phonon DOS of YNi$_2$B$_2$C by neutron measurements [PRB, 55, 9058 (1997)] are not resolved in the PC spectra pointing out to the main role of the low energy phonon modes in EPI. Directional study of the SC gap results in $\Delta_{[100]} \approx 1.5$ meV for the $a$- direction and $\Delta_{[001]} \approx 2.4$ meV along the $c$-axis which may point to anisotropic and/or multiband behavior. Noteworthy, the critical temperature $T_c$ in all cases corresponds to that of bulk samples. The value $2\Delta_{[001]}/k_B T_c \approx 3.6$ is close to the BCS one of 3.52, and the temperature dependence $\Delta(T)$ is BCS-like, while for the $a$-direction $\Delta(T)$ deviates from mean-field BCS behavior above $T_c/2$. The directional variation in $\Delta$ can be attributed to the multiband nature of the SC state in YNi$_2$B$_2$C predicted 10 years ago (PRL, 80, 1730 (1998)).

Key words: YNi$_2$B$_2$C, borocarbides, point-contact spectroscopy, superconducting gap, electron-phonon interaction

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PC EPI spectra. This points out the main role of the low energy phonons in EPI which contribution to the EPI constant $\lambda_{PC} = 2 \int \alpha_{PC}^2 F(\omega)\omega^{-1}d\omega$ is estimated to about 90%. PC EPI spectra were measured by suppressing of superconductivity by magnetic field or temperature to avoid features in the spectra due to SC gap. In this case we did not found in the PC EPI spectra any “soft” modes at about 5 mV mentioned, e. g., by Martinez-Samper et al. [2].

The SC gap $\Delta$ manifests itself in the $dV/dI$ curve of a N-c-S contact as pronounced minima around $V \simeq \pm \Delta$ at $T \ll T_c$. Such $dV/dI$ are presented in

Fig. 1. (a) PC spectra of two YNi$_2$B$_2$C homocontacts averaged for two polarities. The superconductivity is suppressed by a magnetic field. Dotted curves show the tentative background behavior. Dashed curves on the PC spectra are a guide for eyes to improve the visualization of the maximum around 50 mV. The bottom curve shows the phonon DOS for YNi$_2$B$_2$C [3].

Fig. 2. Gap distribution for the three main directions in YNi$_2$B$_2$C single crystal.

Fig. 3. Temperature dependence of the small and large gap in YNi$_2$B$_2$C. Solid curves represent BCS-like behavior. Inset shows example of $dV/dI$ curves (solid) for the small gap along with fitting curves (dashed).

Fig. 3(inset). We have measured the gap distribution for the different crystallographic directions in YNi$_2$B$_2$C shown in Fig. 2. The anisotropy in the distribution is clearly seen: the small gap is characteristic for the a-axis, while along the c-axis the gap is larger. Also the [110] direction has in average the largest gap. Important is that for many of PCs with different gap we have checked the critical temperature $T_{c,PC}$, which was always close to the bulk $T_c$. This avoids the gap variation due to, i. e., the surface degradation.

The SC gap $\Delta$ and its temperature dependence are established (Fig. 3) from the fit of $dV/dI$. It is seen that $\Delta(T)$ has BCS-type dependence, however the small gap deviates from the BCS curve by approaching $T_c$. Similar (small) gap behavior is characteristic for the multiband superconductor MgB$_2$. For borocarbides, multiband superconductivity has been firstly proposed already in 1998 [4].

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