Point-contact spectroscopy of the antiferromagnetic superconductor HoNi$_2$B$_2$C

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Abstract

The point-contact (PC) spectroscopy study of the electron-phonon (boson) interaction (EP(B)I) spectral function in HoNi$_2$B$_2$C reveals phonon maxima at 16 and 22 meV and 34 meV. For the first time the pronounced high energy maxima at about 50 meV and 100 meV were resolved. Additionally, an admixture of a crystalline-electric-field (CEF) excitation with a maximum near 10 meV and a ‘magnetic’ peak near 3 meV are observed. The contribution of the CEF peak in EP(B)I constant $\lambda_{PC}$ is evaluated as 20-30%, while contribution of the high frequency modes at 50 and 100 meV amounts about 10% for each maxima. PC Andreev reflection measurements below the critical temperature $T_c \simeq 8.5$ K reveals two different superconducting (SC) states separated by $T^*_c \simeq 5.6$ K which is close to the Néel temperature $T_N \simeq 5.3$ K. Below $T^*_c$ the gap $\Delta$ in HoNi$_2$B$_2$C exhibits a standard single-band BCS-like behavior with $2\Delta/k_BT^*_c \simeq 3.9$. Above $T^*_c$ the gap features in PC spectra are strongly suppressed pointing to a peculiar SC state between $T^*_c$ and $T_c$, where incommensurate magnetic order develops.

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

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By point-contact (PC) researches both the superconducting (SC) gap and the PC electron-phonon (boson) interaction (EP(B)I) function $\alpha_{PC}^2 F(\omega)$ can be established from the first and second derivatives of the $I(V)$ characteristic of PC’s [1]. Thus the PC spectroscopy is a powerful method to study both EP(B)I spectra and SC gap behavior.

We have measured [2] PC spectra of HoNi$_2$B$_2$C with pronounced phonon maxima at about 16 and 22 mV, a smeared maximum near 34 mV, and shoulder around 50 mV (Fig. 1). All these features correspond well to the phonon DOS of isostructural LuNi$_2$B$_2$C [3], however the high energy part of the PC spectrum is remarkably smeared. Recently we have also succeed to measure PC spectra with well resolved high energy maxima around 50 and 100 mV (see Fig. 2). The 50-mV maximum corresponds to the maximum in the phonon DOS in Fig. 1, even shoulder at about 60 mV is resolved in the PC spectrum. The phonon maximum at 100-meV was registered forYNi$_2$B$_2$C in [3] and it was attributed to the B-C bond stretching vibrations. The low energy part (< 30 mV) of the PC spectra in Fig. 2 shows less detailed structure of HoNi$_2$B$_2$C phonons as compared to the PC spectra from Fig. 1, likely due to contribution of the Cu phonons between 15-20 mV [1].

The maximum around 10 mV might be connected with CEF excitations, observed in this range by neutron scattering [4], while the maximum around 4 mV we attribute to the magnetic order disturbance (and appearance of spin disorder scattering), since it disappears above the Néel ($\sim$6K) temperature. Most of
Fig. 1. PC spectrum of HoNi$_2$B$_2$C–Cu contact with subtracted background in comparison with the neutron phonon DOS for LuNi$_2$B$_2$C [3]. Arrows mark position of CEF peak and ‘magnetic’ peak at about 4 mV. Vertical dashed lines mark position of the main phonon maxima in PC spectrum.

Fig. 2. PC spectra of HoNi$_2$B$_2$C–Cu contact with well resolved high energy maxima around 50 and 100 mV. The PC spectra (not shown) demonstrate expressed 10-mV peak and completely smeared phonon maxima. This points to the importance of CEF excitations in the charge transport as well as in the SC properties of HoNi$_2$B$_2$C. Thus the contribution of the 10-mV peak in EP(B)I constant $\lambda_{PC}$ is evaluated as 20-30%, while contribution of the high frequency modes at 50 and 100 meV amounts about 10% for each maxima.

The SC gap manifests itself in the $dV/dI$ characteristic 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. 3(inset). The SC gap $\Delta$ and its temperature dependence are obtained (see Fig. 3) from the fit of $dV/dI$ by BTK equations (see [1]). It is seen that $\Delta(T)$ has a BCS-like dependence, however the gap vanishes already at $T_c^* \simeq 5.6$ K, i.e. close to the Néel temperature $T_N \simeq 5.3$ K but well below $T_c \simeq 8.5$ K of the bulk. This can be understood adopting the 'Fermi surface separation' scenario for the coexistence of magnetism and superconductivity in magnetic borocarbides, i.e. a coexistence on different Fermi surface sheets (FSSs), proposed in Refs. [5]. Thus, we suggest that the superconductivity in the commensurate antiferromagnetic phase survives at a special nearly isotropic FSS isolated from the influence of the rare earth magnetism.

Between $T_c^*$ and $T_c$ the SC signal in $dV/dI$ is drastically suppressed, giving no possibility to determine a finite SC gap by fitting the $dV/dI$ data. This shows that the SC state between $T_c^*$ and $T_c$, in the region of peculiar magnetic order, is 'unconventional'. We addressed the specific role of selected FSSs and CEF-excitations in this particular case.

References

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