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Low-energy phonons in $TbNi_2B_2C$ and $HoNi_2B_2C$

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Abstract

We report inelastic neutron-scattering experiments on RNi_2B_2C single crystals (R = Tb and Ho) to investigate the dispersion of low-energy phonons. Both compounds order antiferromagnetically at low temperatures. For superconducting $HoNi_2B_2C$ we observe a strong softening of two phonon branches similar to other superconducting RNi_2B_2C compounds. In contrast, for the non-superconducting $TbNi_2B_2C$ we could not detect significant changes in the phonon spectra as a function of temperature. This correlation between superconductivity and the observed phonon softening indicates a strong electron–phonon interaction and strongly supports the BCS-like description of these compounds.

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The rare-earth nickel borocarbides RNi_2B_2C show interesting physical properties, especially the coexistence of superconductivity and long-range magnetic order [1]. The superconductivity can be explained by a modified BCS theory, where the Cooper pairs are formed due to the electron–phonon interaction. A corresponding strong softening of low-energy phonons was observed for the acoustic and first optical Δ_4 branches by neutron scattering in superconducting RNi_2B_2C single crystals with R = Lu [2,3], Y [4] and Er [5]. Point-contact spectroscopy revealed strong electron–phonon interactions in the superconducting RNi_2B_2C compounds with R = Y and Ho, in contrast to the non-superconducting $LaNi_2B_2C$ [6]. In addition, it was concluded that the magnetism in $HoNi_2B_2C$ further enhances the electron–phonon interaction [6]. Therefore, investigations of these phonons in magnetic RNi_2B_2C compounds with different superconducting behavior are of fundamental importance. Here, we present results of inelastic neutron-scattering experiments for non-superconducting $TbNi_2B_2C$ and superconducting $HoNi_2B_2C$ single crystals.

The isostructural RNi_2B_2C compounds crystallize in the tetragonal $LuNi_2B_2C$ structure with

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space group I4/mmm [7,8]. All crystallographic parameters, i.e., the lattice constants a and c as well as the z position of boron, scale roughly with the ionic radius of the rare earth. $TbNi_2B_2C$ shows no superconductivity down to 7 mK [9], but orders in an incommensurate antiferromagnetic structure below $T_N = 15$ K [8,10]. In contrast, $HoNi_2B_2C$ becomes superconducting below $T_c = 8$ K [11]. Additionally, the Ho^{3+} moments order antiferromagnetically below $T_1 = 5.2$ K in a simple commensurate structure, whereas in the temperature range between T_1 and $T_N = 6.8$ K this antiferromagnetic ground state coexists with two additional incommensurate antiferromagnetic modulations [8,12,13].

Rod-like RNi_2B_2C single crystals of 6 mm diameter were grown by the floating zone method using the ^{11}B isotope to avoid strong neutron absorption [14]. Specimens with a length of 6 mm for R = Tb and 14 mm for R = Ho were cut from the rods. For the inelastic neutron-scattering experiments the samples were oriented in the (ac) scattering plane. The measurements were performed on the three-axis spectrometers 1T1 at the Laboratoire Léon Brillouin, Saclay, and BT2 at the NIST Center for Neutron Research, Gaithersburg. (ξ 0 0) Δ_4 phonons were recorded in the (h 0 8) zone by energy scans using a fixed final energy $E_f = 14.8$ meV at temperatures between $T = 2$ and 100 K.

In Figs. 1 and 2 the dispersion curves of the low-energy phonon branches are shown for RNi_2B_2C with R = Tb and Ho, respectively. The energy scans were fit by sets of peaks with Lorentzian lineshape. The analysis is slightly hampered by the existence of crystal electric field excitations in the range of $\hbar\omega = 3.5$–4.5 and 8.5–10.5 meV for R = Tb, and $\hbar\omega = 10$–12.5 meV for R = Ho. However, the fitted phonon-peak positions are only weakly influenced by these excitations, which have been determined from additional scans at low wave vectors and from regions without peak overlap [15].

For non-superconducting $TbNi_2B_2C$, the dispersion of the two interesting phonon branches at $T = 2$ K is similar to the dispersion measured at $T = 100$ K (not shown in Fig. 1). No softening could be found for the investigated phonon branches. In contrast, for superconducting $HoNi_2B_2C$ a strong softening is observed. The

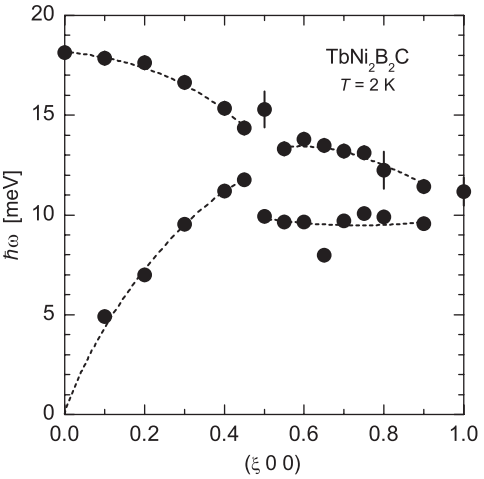

Fig. 1. Low-energy Δ_4 phonons along (ξ 0 0) of $TbNi_2B_2C$ at $T = 2$ K measured on the three-axis neutron spectrometer 1T1 at the Laboratoire Léon Brillouin, Saclay. The dashed lines are guides to the eyes.

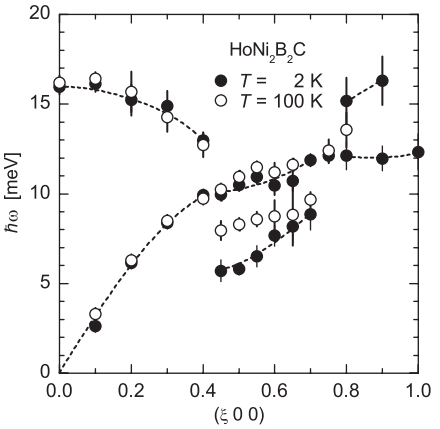

Fig. 2. Low-energy Δ_4 phonons along (ξ 0 0) of $HoNi_2B_2C$ at $T = 2$ and 100 K measured on BT2 at the NIST Center for Neutron Research, Gaithersburg. The dashed lines are guides to the eyes.

softening develops mainly for wave vectors between $q = (0.45\,0\,0)$ and $(0.7\,0\,0)$. Details of the temperature dependence of the low-energy phonons will be described in a forthcoming publication.

In summary, no phonon softening is observed in non-superconducting, magnetic $TbNi_2B_2C$, while superconducting and magnetic $HoNi_2B_2C$ shows a strong phonon softening similar to that in other superconducting RNi_2B_2C compounds. This leads

to the following conclusions. The magnetism in $TbNi_2B_2C$ does not result in a softening of the low-energy Δ_4 phonon branches. Accordingly, the essential electron–phonon interaction is weak in contrast to the predictions in Ref. [6]. For the superconducting RNi_2B_2C compounds a strong phonon softening occurs. This supports the important role of the electron–phonon interaction for the superconductivity and justifies a BCS-like description. Further investigations of the lattice dynamics and the electronic structure are necessary to understand why the strength of the electron–phonon interaction changes dramatically for different isostructural RNi_2B_2C compounds.

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