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# Crystal-field excitations and spin-phonon interactions in DyNi<sub>2</sub>B<sub>2</sub>C: Raman scattering study

## Abstract

We report polarized Raman results of magnetic superconductor DyNi<sub>2</sub>B<sub>2</sub>C ( $T_c=6.2$  K,  $T_N=10.3$  K) to explore crystal-field (CF) excitations and spin-phonon interactions. In addition to the Ni-B<sub>1g</sub> phonon mode at 199 cm<sup>-1</sup>, we observed additional Raman modes at 124, 151, and 221 cm<sup>-1</sup>. By careful analysis of the temperature evolution of these modes, we attribute the 124 cm<sup>-1</sup> excitation to a CF transition. The 151 and 221 cm<sup>-1</sup> modes correspond to zone-folded phonons because they are completely quenched for  $T > T_N$ . With increasing temperature across  $T_N$ , the 124 cm<sup>-1</sup> excitation diminishes rapidly in intensity and, interestingly, an additional mode appears at 119 cm<sup>-1</sup>. This excitation grows in intensity with increasing temperature toward 50 K and gradually decreases with increasing temperature further. We attribute the 119 cm<sup>-1</sup> excitation to an excited CF transition from a low-lying CF level at 5 cm<sup>-1</sup> to the higher CF level at 124 cm<sup>-1</sup>. Anomalous temperature-dependent behavior of the Ni-B<sub>1g</sub> phonon mode was observed in peak energy and in spectral width, i.e., both the phonon energy and the linewidth are enhanced in the vicinity of  $T_N$ , suggesting the presence of strong spin-phonon interactions near the antiferromagnetic ordering temperature in DyNi<sub>2</sub>B<sub>2</sub>C.

## Keywords

Physics and Astronomy

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## Comments

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**Crystal-field excitations and spin-phonon interactions in DyNi<sub>2</sub>B<sub>2</sub>C: Raman scattering study**

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We report polarized Raman results of magnetic superconductor DyNi<sub>2</sub>B<sub>2</sub>C ( $T_c=6.2$  K,  $T_N=10.3$  K) to explore crystal-field (CF) excitations and spin-phonon interactions. In addition to the Ni- $B_{1g}$  phonon mode at  $199\text{ cm}^{-1}$ , we observed additional Raman modes at  $124$ ,  $151$ , and  $221\text{ cm}^{-1}$ . By careful analysis of the temperature evolution of these modes, we attribute the  $124\text{ cm}^{-1}$  excitation to a CF transition. The  $151$  and  $221\text{ cm}^{-1}$  modes correspond to zone-folded phonons because they are completely quenched for  $T > T_N$ . With increasing temperature across  $T_N$ , the  $124\text{ cm}^{-1}$  excitation diminishes rapidly in intensity and, interestingly, an additional mode appears at  $119\text{ cm}^{-1}$ . This excitation grows in intensity with increasing temperature toward  $50$  K and gradually decreases with increasing temperature further. We attribute the  $119\text{ cm}^{-1}$  excitation to an excited CF transition from a low-lying CF level at  $5\text{ cm}^{-1}$  to the higher CF level at  $124\text{ cm}^{-1}$ . Anomalous temperature-dependent behavior of the Ni- $B_{1g}$  phonon mode was observed in peak energy and in spectral width, i.e., both the phonon energy and the linewidth are enhanced in the vicinity of  $T_N$ , suggesting the presence of strong spin-phonon interactions near the antiferromagnetic ordering temperature in DyNi<sub>2</sub>B<sub>2</sub>C.

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**I. INTRODUCTION**

The local order of magnetic moments strongly correlates with superconductivity in rare-earth-bearing compounds, such as  $RMo_5(S,Se)_8$ ,  $RRh_4B_4$ , and  $RNi_2B_2C$  ( $R$  = rare-earth ion).<sup>1</sup> Rare-earth nickel borocarbide compounds  $RNi_2B_2C$  provide a useful means of understanding the interplay between superconductivity and magnetism. For  $R=Dy, Ho, Er,$  and  $Tm$ , superconductivity can coexist with antiferromagnetic (AF) order.<sup>1-5</sup> Among these compounds, DyNi<sub>2</sub>B<sub>2</sub>C exhibits some unique properties in its magnetic structures. For instance, DyNi<sub>2</sub>B<sub>2</sub>C becomes a superconductor ( $T_c=6.2$  K) below the AF ordering temperature ( $T_N=10.3$  K).<sup>2</sup> For  $RNi_2B_2C$  ( $R=Ho, Er, Tm$ ), AF order appears below  $T_c$ .<sup>3-5</sup> The crossover between the  $T_c > T_N$  regime and the  $T_N > T_c$  regime occurs between HoNi<sub>2</sub>B<sub>2</sub>C and DyNi<sub>2</sub>B<sub>2</sub>C. For rare-earth nickel borocarbide compounds, both  $T_N$  and  $T_c$  are scaled by the de Gennes factor, i.e.,  $T_N$  and the suppression of  $T_c$  exhibit linear dependence on the de Gennes factor.<sup>1</sup> Interestingly, detailed study of Ho<sub>1-x</sub>Dy<sub>x</sub>Ni<sub>2</sub>B<sub>2</sub>C has revealed that dependence of  $T_c$  on the de Gennes factor disappears for  $T_c < T_N$ .<sup>6</sup> Unlike  $RNi_2B_2C$  ( $R=Ho, Er, Tm$ ) which exhibit local extrema in the temperature-dependent upper critical field  $H_{c2}(T)$ , DyNi<sub>2</sub>B<sub>2</sub>C exhibits a linear monotonic decrease in  $H_{c2}(T)$  with increasing temperature.<sup>2,4,5,7,8</sup> Magnetic correlations in  $RNi_2B_2C$  manifest themselves as large anisotropic magnetic susceptibilities at low temperature and as Schottky anomalies in specific-heat measurements.<sup>2-5,9</sup> Therefore, rare-earth elements in  $RNi_2B_2C$  play a crucial role in the interplay be-

tween magnetism and superconductivity. The magnetic properties of these compounds are strongly influenced by the rare-earth sublattice and are closely related to the crystal-field (CF) interactions.<sup>10,11</sup> CF energy levels can be used to calculate CF parameters and, as a result, provide useful information on the magnetic properties such as magnetic susceptibility<sup>12</sup> and the Schottky specific heat.<sup>13</sup>

CF excitations can be directly probed using experimental methods such as Raman scattering,<sup>14</sup> inelastic neutron scattering,<sup>13,15-17</sup> and Mössbauer spectroscopy.<sup>11</sup> Among these methods, polarized Raman scattering is unique in that it can probe not only CF excitations but also scattering symmetries of the individual CF excitations. Information on the scattering symmetries enables one to properly assign transition characteristics of the CF excitations.<sup>14</sup> Furthermore, Raman scattering can provide useful information on magnetic correlations to optical phonons. However, only a few papers using the Raman scattering technique have reported optical phonon behaviors in  $RNi_2B_2C$  for  $R=Y, Ho,$  and  $Lu$  (Refs. 18-20), and CF excitations in ErNi<sub>2</sub>B<sub>2</sub>C.<sup>14</sup> In this paper, we investigate CF excitations and optical phonon behaviors related to the AF order in DyNi<sub>2</sub>B<sub>2</sub>C.

**II. EXPERIMENT**

Raman scattering measurements were performed using a single-crystal DyNi<sub>2</sub>B<sub>2</sub>C sample<sup>2</sup> mounted inside a continuous He-flow cryostat. A 647.1-nm Kr-ion laser was focused on the sample in a backscattering geometry along the growth

( $c$  axis) direction of the sample. Various polarization configurations were employed using linearly or circularly polarized light to identify the scattering symmetries for  $\text{DyNi}_2\text{B}_2\text{C}$ :  $(\mathbf{E}_i, \mathbf{E}_s) = (x, x)$ ,  $B_{1g} + A_{1g}$ ;  $(x, y)$ ,  $B_{2g} + A_{2g}$ ;  $(x', x')$ ,  $B_{2g} + A_{1g}$ ;  $(x', y')$ ,  $B_{1g} + A_{2g}$ ;  $(L, L)$ ,  $A_{1g} + A_{2g}$ ; and  $(L, R)$ ,  $B_{1g} + B_{2g}$ , where  $\mathbf{E}_i$  and  $\mathbf{E}_s$  denote the incident and the analyzed polarization directions, respectively, and  $x \parallel [1, 0, 0]$ ,  $y \parallel [0, 1, 0]$ ,  $z \parallel [0, 0, 1]$ ,  $x' \parallel [1, 1, 0]$ , and  $y' \parallel [\bar{1}, 1, 0]$ . Symbols  $L$  and  $R$  denote left and right circularly polarized light, respectively.  $B_{1g}$ ,  $A_{1g}$ ,  $B_{2g}$ , and  $A_{2g}$  are irreducible representations of the space group  $D_{4h}$ . Scattered light was dispersed using a triple-stage spectrometer and recorded using a liquid-nitrogen-cooled charge-coupled device (CCD) detector. After the CCD dark current response was removed from the raw spectra, a calibrated white light source was used to normalize the spectrometer response in order to correct the spectral artifacts due to the collection optics between the sample and the CCD detector. The corrected spectra were divided by the Bose thermal factor  $[1 - \exp(-\hbar\omega/k_B T)]^{-1}$ , giving rise to the Raman response proportional to the imaginary part of the Raman susceptibility.

### III. RESULTS AND DISCUSSION

$\text{DyNi}_2\text{B}_2\text{C}$  single crystals have body-centered-tetragonal structure, belonging to space group  $I4/mmm$  ( $D_{4h}^{17}$ ). The ground state of the nine  $4f$  electrons ( $4f^9$ ) in  $\text{Dy}^{3+}$  is a 16-fold degenerate  ${}^6H_{15/2}$  multiplet. The CF level splits the ground state multiplet into eight Kramers doublets within the  $D_{4h}$  site symmetry at the Dy site. Polarized Raman scattering is useful for identifying scattering symmetries of individual Raman modes. Figure 1(a) shows Raman spectra obtained at  $T=4$  K in various polarization configurations. A strong mode at  $199$   $\text{cm}^{-1}$  can be seen in the  $B_{1g} + A_{2g}$ ,  $B_{1g} + A_{1g}$ , and  $B_{1g} + B_{2g}$  Raman spectra, indicating that this mode has  $B_{1g}$  scattering symmetry. Indeed, the  $199$   $\text{cm}^{-1}$  mode corresponds to the  $B_{1g}$  phonon mode from the  $c$ -axis Ni vibration.<sup>14,18,19</sup> In addition to the Ni- $B_{1g}$  phonon mode, three Raman modes are additionally observed at  $124$ ,  $151$ , and  $221$   $\text{cm}^{-1}$ . The sharp  $124$   $\text{cm}^{-1}$  mode appears strongly in the  $B_{1g} + A_{2g}$ ,  $B_{1g} + A_{1g}$ , and  $B_{1g} + B_{2g}$  Raman spectra. Thus, this mode has mostly  $B_{1g}$  scattering symmetry. The  $124$   $\text{cm}^{-1}$  mode also appears, though weakly, in the  $A_{1g} + A_{2g}$  and the  $B_{2g} + A_{2g}$  scattering symmetries. Consequently, the  $124$   $\text{cm}^{-1}$  mode has a mixed characteristic of the  $B_{1g}$  and the  $A_{2g}$  scattering symmetries. A molecular field of  $B=2.21$  T along the  $(110)$  direction in the commensurate AF state<sup>15</sup> lowers the symmetry from  $D_{4h}$  to  $C_{2h}$ . Note that the twofold axis is along the  $(110)$  direction in  $C_{2h}$ . In this circumstance, the correlation table for  $D_{4h}$  tells us that both the  $B_{1g}$  and the  $A_{2g}$  symmetries become the  $B_g$  symmetry.<sup>21</sup> Thus, the mixed  $B_{1g}$  and  $A_{2g}$  symmetries observed for the  $124$   $\text{cm}^{-1}$  mode are most likely due to the presence of the molecular field in  $\text{DyNi}_2\text{B}_2\text{C}$ . The weak  $151$   $\text{cm}^{-1}$  mode appears in the  $B_{1g} + A_{2g}$  and the  $B_{2g} + A_{2g}$  scattering symmetries. Thus, this mode has  $A_{2g}$  scattering symmetry. Similarly, the  $221$   $\text{cm}^{-1}$  mode appears in the  $B_{1g} + A_{2g}$ ,  $B_{1g} + A_{1g}$ , and  $B_{1g} + B_{2g}$  Raman spectra, indicating that this mode has  $B_{1g}$  scattering symme-

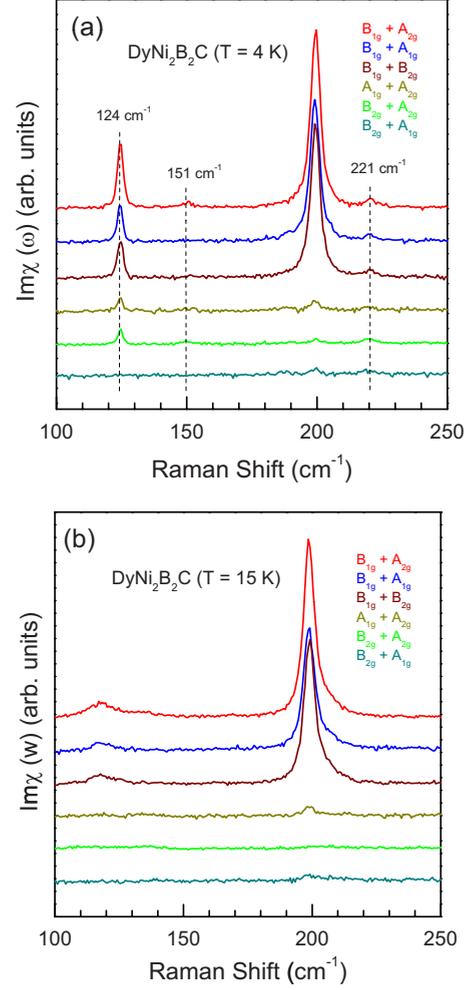


FIG. 1. (Color online) Polarized Raman spectra of  $\text{DyNi}_2\text{B}_2\text{C}$  at (a)  $T=4$  K and (b)  $T=15$  K. From top to bottom,  $(\mathbf{E}_i, \mathbf{E}_s) = (x', y')$ ,  $B_{1g} + A_{2g}$ ;  $(x, x)$ ,  $B_{1g} + A_{1g}$ ;  $(L, R)$ ,  $B_{1g} + B_{2g}$ ;  $(L, L)$ ,  $A_{1g} + A_{2g}$ ;  $(x, y)$ ,  $B_{2g} + A_{2g}$ ; and  $(x', x')$ ,  $B_{2g} + A_{1g}$ , respectively.

Figure 1(b) shows Raman spectra obtained at  $T=15$  K in various polarization configurations. The linewidth of the Ni- $B_{1g}$  phonon mode is broadened mostly due to spin-phonon interactions as well as thermal effect with increasing temperature through the AF ordering temperature. Temperature dependence of the Ni- $B_{1g}$  phonon mode will be discussed in detail later. One noticeable feature in Fig. 1(b) is that the weak responses at  $151$  and  $221$   $\text{cm}^{-1}$ , observed in the low temperature regime for  $T < T_N$ , disappear completely for  $T > T_N = 10.3$  K. Note that, in contrast, the  $124$   $\text{cm}^{-1}$  mode persists even for  $T > T_N$ . The quenching of the  $151$  and  $221$   $\text{cm}^{-1}$  modes above the Néel temperature indicates the correlation of these modes to the commensurate AF order in  $\text{DyNi}_2\text{B}_2\text{C}$ , suggesting that these modes correspond to zone-folded phonons.<sup>22</sup> Zone-folded phonons can appear when zone-boundary phonons are folded into the zone center due to the magnetic periodicity of  $\text{DyNi}_2\text{B}_2\text{C}$  below the AF ordering temperature. The zone-folded phonons quench quickly with a disappearance of the magnetic periodicity above  $T_N$ . Such zone-folded phonons were previously observed in the commensurately ordered AF state in  $\text{CuO}$ .<sup>23</sup>

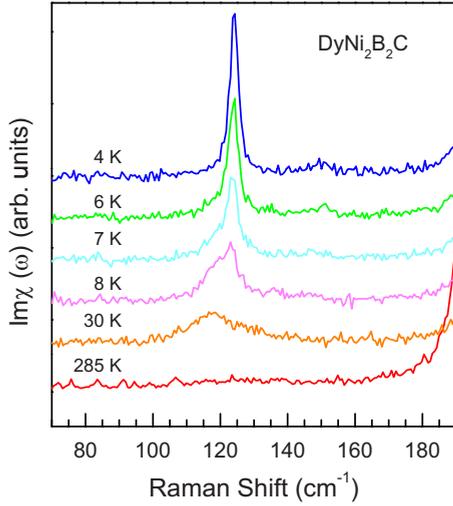


FIG. 2. (Color online) Temperature-dependent Raman spectra of  $\text{DyNi}_2\text{B}_2\text{C}$  in  $(\mathbf{E}_i, \mathbf{E}_s) = (x', y')$  scattering configuration.

The  $124 \text{ cm}^{-1}$  response appears very weakly and its line-width is significantly broadened at  $T=15 \text{ K}$ . Interestingly, in addition to the  $124 \text{ cm}^{-1}$  mode, a broad peak is newly observed at  $119 \text{ cm}^{-1}$ . The  $119 \text{ cm}^{-1}$  response is *not* a consequence of the thermal quenching of the  $124 \text{ cm}^{-1}$  mode with increasing temperature. As clearly shown in Fig. 1(b), the broad  $119 \text{ cm}^{-1}$  mode appears in the  $B_{1g}+A_{2g}$ ,  $B_{1g}+A_{1g}$ , and  $B_{1g}+B_{2g}$  Raman spectra, indicating that this excitation has  $B_{1g}$  scattering symmetry.

In order to identify the origins of the  $124 \text{ cm}^{-1}$  mode and the  $119 \text{ cm}^{-1}$  mode nearby, Raman spectra were carefully obtained as a function of temperature. Figure 2 shows the temperature evolution of the  $124$  and the  $119 \text{ cm}^{-1}$  modes. At very low temperatures ( $T < 5 \text{ K}$ ), only the sharp peak at  $124 \text{ cm}^{-1}$  is observed. With increasing temperature above  $T=5 \text{ K}$ , the  $124 \text{ cm}^{-1}$  response decreases in intensity and broadens in spectral width. Interestingly, a broad response at  $119 \text{ cm}^{-1}$  appears at the lower frequency region of this sharp mode. Figure 3(a) shows a representative Raman spectrum at  $T=8 \text{ K}$ , together with the fitting curves, that clearly exhibits the coexistence of the  $124$  and the  $119 \text{ cm}^{-1}$  modes. The intensity and spectral width changes extracted by fitting the individual Raman spectra to a Lorentzian line shape for the  $119$  and the  $124 \text{ cm}^{-1}$  modes are summarized in Figs. 3(b) and 3(c), respectively. With increasing temperature further above  $T=10 \text{ K}$ , the  $124 \text{ cm}^{-1}$  response decreases rapidly in intensity. Furthermore, spectral width becomes significantly broadened. The rapid decrease in intensity of the sharp response near  $T=10 \text{ K}$  may indicate the correlation of the  $124 \text{ cm}^{-1}$  mode to the commensurate AF order in  $\text{DyNi}_2\text{B}_2\text{C}$ , suggesting that the  $124 \text{ cm}^{-1}$  mode can be related to a zone-folded optical phonon. However, this assumption is unlikely to be correct. The temperature-dependent behaviors, i.e., thermal quenching and linewidth broadening upon raising temperature, of the  $124 \text{ cm}^{-1}$  response suggest that this mode corresponds to a CF excitation.<sup>14</sup> Indeed, inelastic neutron scattering from  $\text{DyNi}_2\text{B}_2\text{C}$  revealed a CF transition around  $15 \text{ meV}$  ( $121 \text{ cm}^{-1}$ ),<sup>15</sup> which is very close to the peak energy ( $124 \text{ cm}^{-1}$ ) of the sharp mode observed

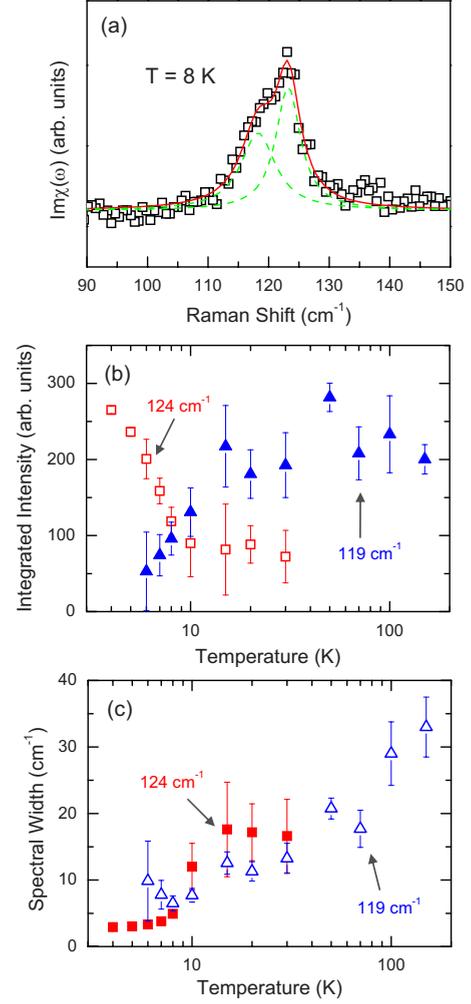


FIG. 3. (Color online) (a) A representative Raman spectrum (open squares) at  $T=8 \text{ K}$  with individual fitting results (dashed lines) for the  $119$  and the  $124 \text{ cm}^{-1}$  modes. A solid line indicates a fitted result to a Lorentzian line shape. (b) Intensity and (c) spectral width changes as a function of temperature for the  $119$  and the  $124 \text{ cm}^{-1}$  modes.

in our results. Thus, we attribute the peak at  $124 \text{ cm}^{-1}$  to a CF excitation. The  $119$  and the  $124 \text{ cm}^{-1}$  responses coexist in the temperature regime for  $6 \text{ K} \leq T \leq 30 \text{ K}$ . Figure 2 shows that the  $124 \text{ cm}^{-1}$  response at  $30 \text{ K}$ , on the high-frequency side of the  $119 \text{ cm}^{-1}$  mode, is significantly weakened and exhibits significantly broadened line shape. When the temperature is higher than  $30 \text{ K}$ , only the broad response at  $119 \text{ cm}^{-1}$  appears in the Raman spectrum. While the  $124 \text{ cm}^{-1}$  mode rapidly diminishes in intensity with increasing temperature, the broad  $119 \text{ cm}^{-1}$  mode grows in intensity as temperature is further increased from  $6$  to  $50 \text{ K}$ . The  $119 \text{ cm}^{-1}$  mode gradually diminishes in intensity with increasing temperature further above  $T=50 \text{ K}$ , and is hardly observable for  $T > 150 \text{ K}$ . Both the  $119$  and the  $124 \text{ cm}^{-1}$  modes are broadened systematically in spectral width with increasing temperature.

Using the CF Hamiltonian and CF parameters for  $\text{DyNi}_2\text{B}_2\text{C}$ , Gasser *et al.*<sup>13,15</sup> calculated a low-lying Kramers doublet at about  $0.3 \text{ meV}$  ( $2.4 \text{ cm}^{-1}$ ). In addition, an inelas-

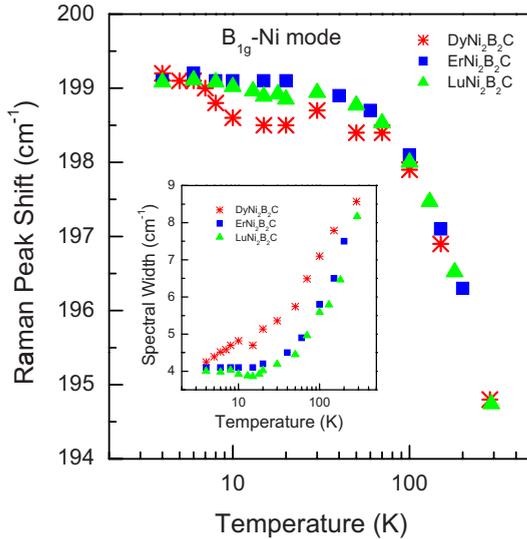


FIG. 4. (Color online) Temperature evolution of the Raman peak energies of the Ni- $B_{1g}$  phonons for DyNi $_2$ B $_2$ C (asterisks), ErNi $_2$ B $_2$ C (solid squares), and LuNi $_2$ B $_2$ C (solid triangles). The inset shows spectral width changes as a function of temperature of the Ni- $B_{1g}$  phonons for DyNi $_2$ B $_2$ C (asterisks), ErNi $_2$ B $_2$ C (solid squares), and LuNi $_2$ B $_2$ C (solid triangles).

tic neutron scattering study of Dy $_{0.05}$ Lu $_{0.95}$ Ni $_{11}$ B $_2$ C revealed a low-lying CF transition at 0.2 meV (1.6 cm $^{-1}$ ) at  $T = 1.8$  K.<sup>24</sup> The intensity of the low-lying CF transition at 0.2 meV diminishes rapidly with increasing temperature due to a line broadening caused by thermal population of this energy level.<sup>24</sup> Thus, if we assume that a low-lying CF transition exists at 5 cm $^{-1}$  in DyNi $_2$ B $_2$ C and that this CF level is rapidly thermally saturated at higher temperatures, similar to the case of Dy $_{0.05}$ Lu $_{0.95}$ Ni $_{11}$ B $_2$ C, the 119 cm $^{-1}$  mode can be attributed to the excited CF transition from the low-lying level at 5 cm $^{-1}$  to the CF level at 124 cm $^{-1}$ . Indeed, as described previously, the temperature dependence of the 119 cm $^{-1}$  response in both intensity and linewidth strongly suggests that this mode corresponds to an excited CF transition. Thermal saturation of the ground-state low-lying level ( $\sim 5$  cm $^{-1}$ ) probably initiates an excited CF transition from this low-lying level to the higher level at 124 cm $^{-1}$ . Activation of the 119 cm $^{-1}$  excitation at higher temperatures may suppress the CF level transition at 124 cm $^{-1}$ , giving rise to a rapid diminishment in intensity with increasing temperature, as shown in the intensity changes illustrated in Fig. 3(b). This scenario also validates the assignment of the 124 cm $^{-1}$  mode as a CF excitation. Inelastic neutron-scattering studies revealed similar behaviors of the excited CF transitions in Pr $_2$ CuO $_4$  (Ref. 16) and PrNi $_2$ B $_2$ C.<sup>17</sup>

Now we focus on the Ni- $B_{1g}$  mode at 199 cm $^{-1}$ . As summarized in Fig. 4, this mode exhibits anomalous temperature-dependent behaviors both in peak shift and in spectral width, i.e., with increasing  $T$  toward  $T_N$ , both a downward shift of the peak energy and a broadening of the

spectral width are enhanced in the vicinity of  $T_N$ . Furthermore, the spectral widths of the Ni- $B_{1g}$  modes in DyNi $_2$ B $_2$ C are much broader in all temperature ranges than those in both LuNi $_2$ B $_2$ C and ErNi $_2$ B $_2$ C. The anomalous temperature dependence of the Ni- $B_{1g}$  mode near  $T_N$  suggests that this phonon mode strongly couples to the AF order in DyNi $_2$ B $_2$ C. In contrast, as shown in Fig. 4, we did not observe any temperature-dependent phonon anomalies in nonmagnetic LuNi $_2$ B $_2$ C ( $T_c = 16.6$  K) nor in magnetic ErNi $_2$ B $_2$ C ( $T_N = 6$  K,  $T_c = 10$  K). Similar anomalous phonon-energy changes in the vicinity of the AF ordering temperature were previously reported for several AF compounds such as MnTe ( $T_N \sim 307$  K),<sup>25</sup> YCrO $_3$  ( $T_N \sim 141$  K), and GdCrO $_3$  ( $T_N \sim 170$  K).<sup>26</sup> In nonsuperconducting GdSr $_2$ RuCu $_2$ O $_8$ , an enhancement of the phonon energies below the magnetic ordering temperature ( $\sim 140$  K) was attributed to the presence of strong spin-phonon interactions in this compound.<sup>27</sup> Recently, Raman scattering from magnetic superconductor RuSr $_2$ (Eu $_{1.5}$ Ce $_{0.5}$ )Cu $_2$ O $_{10}$  revealed that some phonon modes exhibited anomalous softening and spectral width broadening below 100 K.<sup>28</sup> This anomalous phonon-mode behavior is attributed to spin-phonon interactions.<sup>28</sup> All of these results unambiguously demonstrate that the onset of magnetic order can strongly couple to phonons. Thus, the anomalous temperature-dependent behavior of the Ni- $B_{1g}$  mode near  $T_N$  in DyNi $_2$ B $_2$ C is most likely due to the spin-phonon correlation in the vicinity of  $T_N$ .<sup>29</sup>

#### IV. CONCLUSIONS

In conclusion, polarized Raman spectra from DyNi $_2$ B $_2$ C revealed a Ni- $B_{1g}$  mode at 199 cm $^{-1}$  and additional modes at 124, 151, and 221 cm $^{-1}$ . The 124 cm $^{-1}$  mode exhibits mostly  $B_{1g}$  scattering symmetry. The 151 and 221 cm $^{-1}$  modes exhibit  $A_{2g}$  and  $B_{1g}$  scattering symmetries, respectively. Rapid quenching of both the 151 and 221 cm $^{-1}$  modes below the AF ordering temperature suggests that these modes correspond to zone-folded phonons. The 124 cm $^{-1}$  mode is attributed to CF excitation, as evidenced by temperature-dependent behaviors in its intensities and spectral widths. The 119 cm $^{-1}$  mode observed at higher temperatures corresponds to an excited CF transition. The enhancement in both the linewidth broadening and the peak-energy decrease in the Ni- $B_{1g}$  mode at 199 cm $^{-1}$  in the vicinity of  $T_N$  indicates that strong spin-phonon interactions are present in DyNi $_2$ B $_2$ C. Our results demonstrate that Raman scattering studies can provide rich information on the CF excitations, optical phonons, and their spin correlations.

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