



# Raman spectroscopy studies of the $\text{HoFe}_3(\text{BO}_3)_4$ single crystal

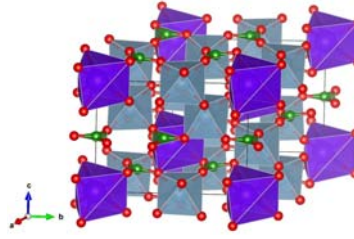
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In recent years, the physical properties of the rare-earth ferroborate multiferroic family,  $\text{ReFe}_3(\text{BO}_3)_4$  (where  $\text{Re} = \text{La} - \text{Lu}$ ), have been under intensive study. This interest is caused by the observation of a large magnetoelectric effect, which enables the control of electrical properties via an external magnetic field. While Raman scattering spectra for a number of crystals ( $\text{Re} = \text{Sm}, \text{Gd}, \text{Nd}, \text{Tb}, \text{Er}, \text{and Y}$ ) have been investigated over a wide temperature range covering various structural and magnetic phases, such studies for the  $\text{HoFe}_3(\text{BO}_3)_4$  single crystal (the crystal structure is presented in Fig. 1) in the low-temperature range have not yet been conducted.

In this work, we investigated the polarized Raman spectra of a  $\text{HoFe}_3(\text{BO}_3)_4$  single crystal in the frequency range of 3–1500  $\text{cm}^{-1}$  and at temperatures from 10 to 300 K. Figure 2 shows the spectra obtained at 10 K with 532 nm laser excitation. The Raman-active modes are identified as follows:  $A_1 - (\text{ZZ})$  and  $E - (\text{YX}, \text{ZX}, \text{and YZ})$ .



$T_C = 366 \text{ K}$   $R32 (z=1) \rightarrow P3_121 (z=3)$ .  
 $T_N = 38 \text{ K}$ .

At high temperature phase:

$$\Gamma_{\text{vib}} = 7A_1 + 12A_2 + 19E$$

At low temperature phase:

$$\Gamma_{\text{vib}} = 27A_1 + 32A_2 + 59E$$

$A_1$  and  $E$  modes are active in Raman spectra.

$A_1 - \text{XX}, \text{YY}, \text{ZZ}; E - \text{XX}, \text{YY}, \text{YZ}, \text{ZY}, \text{XY}, \text{YX}, \text{XZ}, \text{ZX}$

Fig. 1. Structure of  $\text{HoFe}_3(\text{BO}_3)_4$ .

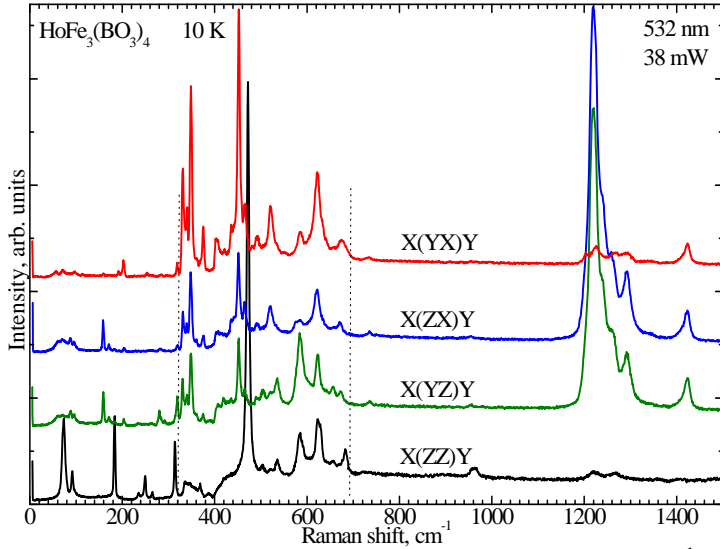


Fig. 2. Polarized Raman spectra carried out at 10 K. Spectral resolution is 3.0  $\text{cm}^{-1}$ .

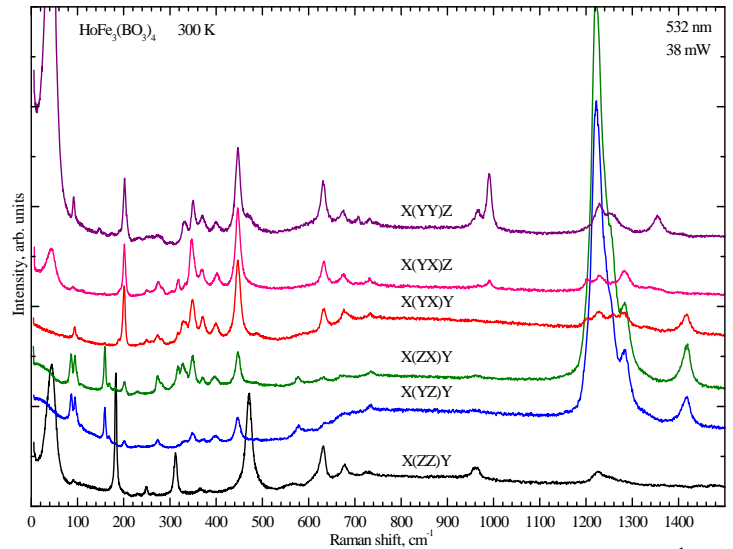


Fig. 3. Polarized Raman spectra carried out at 300 K. Spectral resolution 3.0  $\text{cm}^{-1}$ .

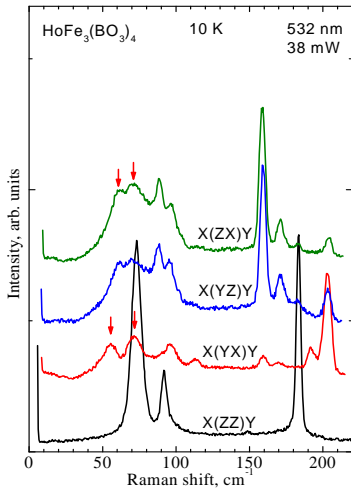


Fig. 4. Comparison of polarized Raman spectra taken in low-frequency region..

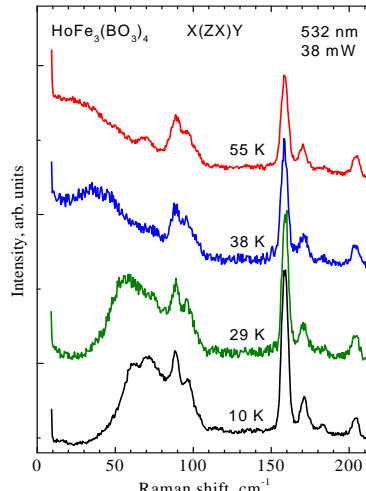


Fig. 5. Temperature dependent polarized Raman spectra obtained in  $\text{X(ZX)Y}$  polarization configuration.

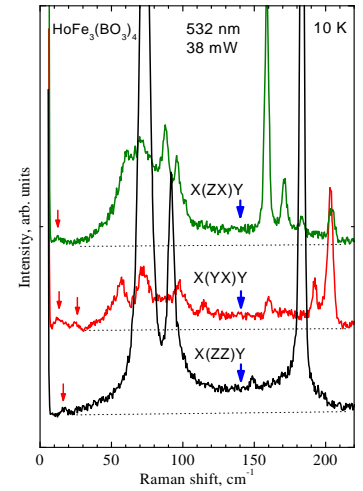


Fig. 6. Polarized Raman spectra of  $\text{HoFe}_3(\text{BO}_3)_4$  taken with 2.0  $\text{cm}^{-1}$  spectral resolution

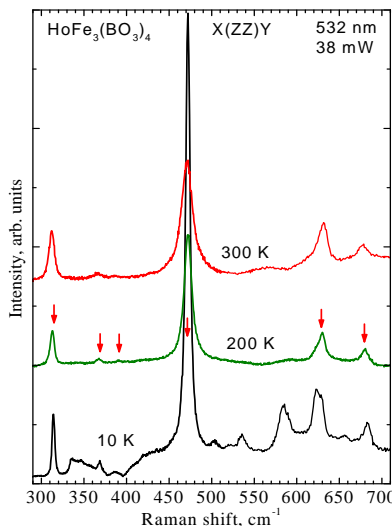


Fig. 7. Temperature dependent polarized Raman spectra obtained in  $\text{X(ZZ)Y}$  polarization configuration. .

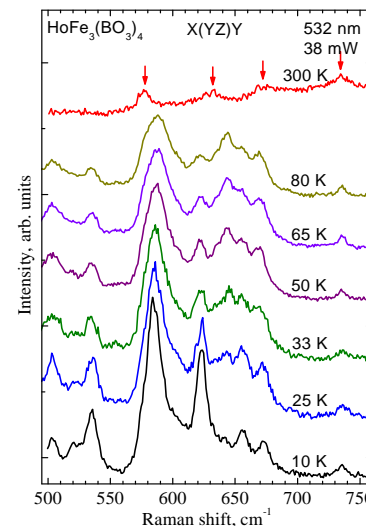


Fig. 8. Temperature evolution of polarized Raman spectra.

## Conclusions

Polarized phonon and magnon spectra of the  $\text{HoFe}_3(\text{BO}_3)_4$  single crystal at low temperatures were studied for the first time. It was shown, the low-temperature Raman spectrum of two-magnon excitations in  $\text{HoFe}_3(\text{BO}_3)_4$  has a complex shape, reflecting features in the density of states of the magnon branches.

At low temperatures, Raman spectrum (Fig. 2) exhibits phonon modes characteristic of both high-temperature and low-temperature phases ( $T_C = 366 \text{ K}$ ). Below the Neel temperature ( $T_N = 38 \text{ K}$ ), two-magnon scattering is observed in the low-frequency region of the spectrum. Additionally, in the range of 330 – 680  $\text{cm}^{-1}$ , the phonon spectrum and the luminescence spectrum overlap. To identify and extract these excitations, we have studied the temperature evolution of the spectra and carried out a comparative analysis with the spectra of  $\text{TbFe}_3(\text{BO}_3)_4$  [1] and  $\text{SmFe}_3(\text{BO}_3)_4$  [2], the latter of which does not undergo a structural phase transition.

## Literature

- [1] A. V. Peschanskii, A. V. Yeremenko, V. I. Fomin, L. N. Bezmaternykh, I. A. Gudim, *Low Temp. Phys.* **40**, 171 (2014).
- [2] A. V. Peschanskii, V. I. Fomin, I. A. Gudim., *Low Temp. Phys.* **42**, 475 (2016).

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