Elastic properties of terbium

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The temperature dependence of the Young modulus along the crystallographic axes b and c (E_b and E_c), and the internal friction of a terbium single crystal have been measured. At 4.2 K, E_b and E_c are equal to 38 and 84.5 GPa, respectively. The lattice part of the Young modulus and the Debye temperature has been calculated. The origin of the Young modulus anomalies arising at the transition to the magnetically ordered state is discussed. [S0163-1829(96)00729-1]

The rare-earth metal terbium has a hexagonal structure, and a magnetocrystalline anisotropy characteristically for heavy rare-earth metals with nonzero orbital moments.[1] Terbium undergoes two magnetic phase transitions: from paramagnetism to a helical spin structure at Θ_N, and from the helical spin structure to a ferromagnetic state at Θ_c.[2–4] An external magnetic field destroys the helical spin structure at a critical value H_{cr} of the field. According to various investigations, the value of Θ_c lies in the range of 210–220 K, Θ_N in the range of 223.3–231 K, and H_{cr}=100–1000 Oe.[5–7]

The Young modulus (E), elastic constants (c_{ij}), ultrasonic attenuation, and internal friction (Q^{-1}) have been investigated on polycrystalline and single-crystal samples of terbium.[6–16] Anomalies connected with the change of magnetic order were found in the temperature dependence of E and c_{ij} at the phase transitions. Most of the studies were done with the help of ultrasonic methods at frequencies about 10 Mhz. Due to the relaxation character of the Young modulus and the internal friction at such a high frequency, important information can be lost. At lower frequencies measurements were done on a single crystal above the liquid-nitrogen temperature.[13,14]

In this work, the measurements of the Young modules and the internal friction of the terbium single crystals were made in the temperature range 4.2–390 K and at the frequency 1.5 kHz. The Young modulus (E) and internal friction (Q^{-1}) of the terbium single crystals were measured along the crystallographic c and b axes. The elastic properties were determined by the method of flexural autovibrations of a cantilevered thin rod as described in Ref. 17.

The sample purity was 99.9 at. %. The crystal was oriented using a diffractometer. The sample was cut by the electrospark method to the rod with dimensions of 7×2×0.2 mm^3. After cutting, the sample was etched in a HNO_3-C_2H_5OH solution in order to remove the destroyed layer. The long edge of the sample was parallel to the crystallographic b axis for E_b measurements, and parallel to the c axis for E_c measurements.

The temperature dependence of the Young modulus and the internal friction measured along the crystallographic c and b axes are shown in Figs. 1 and 2, respectively. In Fig. 1, E_c shows a general trend to decrease with heating, displaying minima in the vicinity of the magnetic phase transitions. The phase-transition temperatures were determined from the positions of the minima on $E_c(T)$ as Θ_c=220 K and Θ_N=229 K. At 4.2 K, E_c is equal to 84.5 GPa. In the temperature dependence of Q^{-1} along the c axis (Fig. 1) there are two maxima corresponding to Θ_c and Θ_N. The temperature dependence of $E_b(T)$ as shown in Fig. 2 differs significantly from that of $E_c(T)$. The Young modulus decreases upon heating from 4.2 until about 150 K, and in the region of Θ_c and Θ_N a sharp increase of E_b is observed. In the paramagnetic phase, E_b decreases monotonously with heating. At T=228 K there is an anomaly which can be connected with the transition at Θ_N. The temperature Θ_c was determined as the point of the most rapid change in E_b to be 220 K.

Take notice of the considerable rise in internal friction in the low-temperature region, which was observed in measurements along the b axis (Fig. 2). Earlier, a significant low-

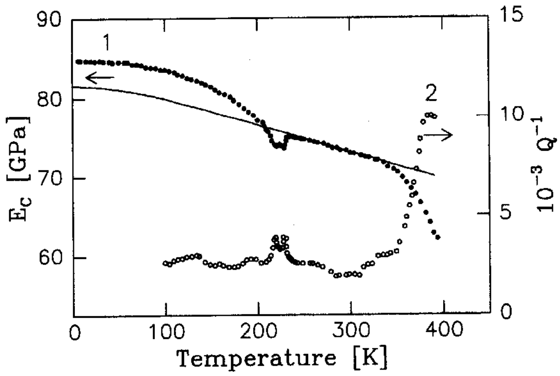

FIG. 1. Temperature dependence of the Young modulus E_c (curve 1) and internal friction Q^{-1} (curve 2) measured along the crystallographic axis c. The lattice part of E_c is shown by the solid line.

