

phys. stat. sol. (b) **182**, K91 (1994)

Subject classification: 78.20; S11.2

*Fachbereich Physik der Universität Osnabrück<sup>1)</sup>*

## Refractive Index of Terbium Gallium Garnet

By

U. SCHLARB and B. SUGG

**Introduction** Terbium gallium garnet (TGG) exhibits a high Verdet constant and a low absorption coefficient in the visible and infrared spectral range. Since TGG can be grown in very good optical quality it is a suitable material for constructing Faraday effect devices such as rotators or optical isolators [1]. Furthermore, rare earth garnets are appropriate materials for optical waveguides and substrates, since their lattice constants can be adjusted over a wide range by using different rare earth ions [2] and the refractive index can be tuned by using Ga, Fe, or Al as further cation in the garnet structure. However, refractive index data have only been reported for  $\lambda = 600$  nm ( $n = 1.978$ ) and  $\lambda = 1060$  nm ( $n = 1.954$ ) in [1] and for  $\lambda = 1523$  nm ( $n = 1.94 \pm 0.02$ ) in [2]. In the absence of more numerous and more precise data the determination of the refractive index of TGG was performed in the visible and near infrared spectral region.

**Experimental** The sample was grown by the Czochralski method. Calcium was added as dopant to the melt since it is known to be conducive to the growth of the crystal. Furthermore, cerium was added to guarantee the overall charge neutrality and to prevent the formation of color centers. A concentration of 25 ppm each of Ca and Ce is present in the crystal under investigation. The crystal is strain free and of perfect optical quality.

The refractive indices were measured by an interferometric technique using a monochromatically illuminated Michelson-type interferometer [3]. In one arm of the interferometer the parallel-plate sample is rotated around an axis parallel to the  $c$ -axis of the crystal and perpendicular to the incident beam, causing a rotation-angle-dependent shift in the optical path-length difference. The resulting interferogram is measured with a computer-controlled setup and evaluated with appropriate numerical fit procedures, yielding an accuracy of about  $\Delta n = 2 \times 10^{-3}$  (see [4, 5]). Using a helium–neon laser tunable in the visible and infrared region or a mercury vapor lamp combined with a 0.2 m monochromator several wavelengths in the range from 400 to 1200 nm are available. The measurements were carried out at room temperature ( $T \approx 20$  °C).

**Results** The measured refractive indices are summarized in Table 1 and plotted in Fig. 1 as full dots. The dispersive behavior can be well described using a single oscillator Sellmeier equation,

$$n^2 - 1 = \frac{E_d E_0}{E_0^2 - (hc/\lambda)^2}, \quad (1)$$

<sup>1)</sup> Barbarastr. 7, D-49069 Osnabrück, Federal Republic of Germany.

Table 1  
Refractive index data of TGG for various wavelengths  $\lambda$

$\lambda$ (nm)	$n$
404.66	2.0178
435.83	2.0057
546.07	1.9765
633.00	1.9656
1079.81	1.9434
1084.45	1.9432
1140.91	1.9420
1152.28	1.9421
1176.68	1.9415

where  $E_d$  and  $E_0$  represent fitting parameters and  $h$  and  $c$  are Planck's constant and the speed of light, respectively. The oscillator energy  $E_0$  can be regarded as average "energy gap" and the dispersion energy  $E_d$  is a measure of the optical transition strength [6]. For the sake of completeness the data reported in [1] and [2] are also plotted in Fig. 1 as open circles and a triangle, respectively, but were not considered for the determination of the parameters  $E_0 = 9.223$  eV and  $E_d = 25.208$  eV.

**Discussion** As stated in [2] rare earth gallium garnets  $R_3Ga_5O_{12}$  ( $R = Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Y, Er, Tm, Yb, Lu$ ) have the same refractive index, at least at  $\lambda = 1523$  nm. Indeed the dispersion parameters  $E_0 = 9.223$  eV and  $E_d = 25.208$  eV found for  $Tb_3Ga_5O_{12}$  are similar to those for  $Gd_3Ga_5O_{12}$  reported in [7], namely 9.4 and 25.7 eV. The dispersive behavior of the refractive index can be well described by a single oscillator Sellmeier equation.

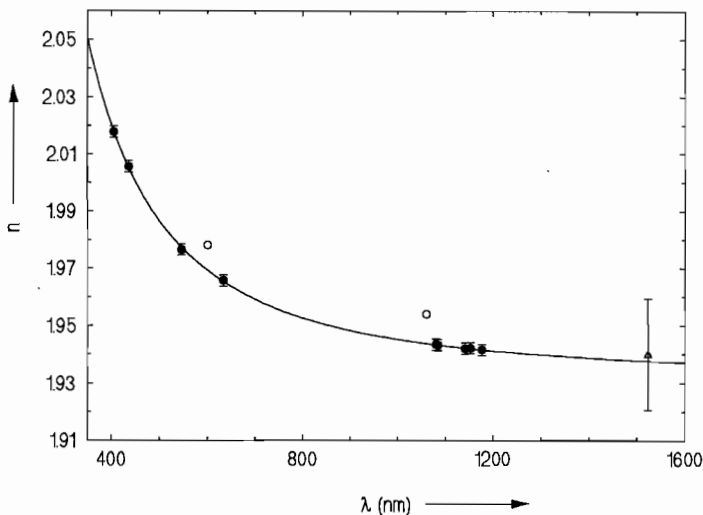


Fig. 1. Spectral dependence of the refractive index. Full dots represent our experimental results. The solid line is a curve fitted to these data using a single oscillator Sellmeier equation. The open circles and the triangle are data reported by Dentz et al. [1] and Tien et al. [2], respectively

A three-term Sellmeier formula as used for  $\text{Gd}_3\text{Ga}_5\text{O}_{12}$  in [8] may be only necessary to describe the infrared dispersion. Compared to the refractive indices of TGG determined by Dentz et al. [1] our values are systematically lower. However, the value of Tien et al. [2] can be confirmed within the limits of accuracy by extrapolation of our Sellmeier curve to 1523 nm.

The authors wish to thank L. Ackermann, Forschungsinstitut für mineralische und metallische Werkstoffe, Idar-Oberstein, Germany, for providing the crystals.

### *References*

- [1] D. J. DENTZ, R. C. PUTTBACH, and R. F. BELT, AIP Conf. Proc. **18**, 954 (1974).
- [2] P. K. TIEN, R. J. MARTIN, S. L. BLANK, S. H. WEMPLE, and L. J. VARNERIN, Appl. Phys. Letters **21**, 207 (1972).
- [3] M. S. SHUMATE, Appl. Optics **5**, 327 (1966).
- [4] K. BETZLER, A. GRÖNE, N. SCHMIDT, and P. VOIGT, Rev. sci. Instrum. **59**, 652 (1988).
- [5] U. SCHLARB and K. BETZLER, Ferroelectrics **126**, 39 (1992).
- [6] S. H. WEMPLE and M. DiDOMENICO JR., Phys. Rev. B **3**, 1338 (1971).
- [7] S. H. WEMPLE and W. J. TABOR, J. appl. Phys. **44**, 1395 (1973).
- [8] D. L. WOOD and K. NASSAU, Appl. Optics **29**, 3704 (1990).

*(Received February 11, 1994)*