Quantum Electronics **30** (4) 283 – 284 (2000)

LETTERS TO THE EDITOR

PACS numbers: 42.55.Rz; 42.55.Xi; 78.20.Ls
DOI: 10.1070/QE2000v030n04ABEH001723

Polarisation magneto-optical effects in a diode-pumped cw $Nd^{3+}:Bi_4Ge_3O_{12}$ laser oscillating at 1.06425 and 1.3418 μm

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Abstract. The characteristics of a cw $Nd^{3+}:Bi_4Ge_3O_{12}$ laser oscillating at 1.06425 μm are studied as functions of the strength of a longitudinal magnetic field. The laser was found to be highly sensitive to the action of an alternating magnetic field with a frequency equal to the frequency of relaxation oscillations. The cw lasing was also obtained at 1.3418 μm.

1. Introduction

The existence of magnetooptical effects in the active media of solid-state lasers opens up new opportunities for studying polarisation effects in these lasers and is also of interest for controlling their output characteristics.

Investigations in this field have been limited over many years owing to the difficulties associated with the use of flash-lamp pumping to excite solid-state lasers and due to a relatively low magnetooptical activity of the traditionally used active media ($Nd^{3+}:Y_3Al_5O_{12}$, $Nd^{3+}:YLiF_4$, glasses doped with Nd^{3+} ions, etc.). The passage to diode pumping and the use of new active media stimulated active magneto-optical studies of solid-state lasers [1 – 3].

We study in this paper magnetooptical effects in a neodymium-doped bismuth germanate laser ($Nd^{3+}:Bi_4Ge_3O_{12}$). The $Nd^{3+}:Bi_4Ge_3O_{12}$ crystal possesses both high magnetooptical activity and good lasing characteristics. The $Nd^{3+}:Bi_4Ge_3O_{12}$ crystal (the atomic concentration of the Nd^{3+} ions was ~1%) with a eulytine structure (the $T_d^6 - \bar{4}3d$ space group) was grown by the Czochralski method in a platinum crucible. The Nd^{3+} ions, which impart laser properties to the crystal, replace the Bi^{3+} ions in the site of the C_3 local symmetry. The thermal conductivity of the $Nd^{3+}:Bi_4Ge_3O_{12}$ crystal is ~0.06 W (cm K)$^{-1}$ and the hardness is 315 kg mm^{-2}.

The effective cross sections for the $^4F_{3/2} \rightarrow {^4I_{11/2}}$ (1.06425 μm) and $^4F_{3/2} \rightarrow {^4I_{13/2}}$ (1.3418 μm) laser transitions in the $Nd^{3+}:Bi_4Ge_3O_{12}$ crystal are large and amount to $\sigma = 1.34 \times 10^{-19}$ and 0.5×10^{-19} cm^{-2}, respectively. The relaxation time of the metastable level T_1 (at 300 K and a concentration of Nd^{3+} ions of about 1%) is 200 μs [4]. The absorption spectrum has strong lines in the region of 0.810 μm with an absorption coefficient of about 6 cm^{-1} [5].

The active element of the laser was a cylinder 20 mm long and 5 mm in diameter. A selective mirror was deposited on one of its end faces. The mirror had a high (~99%) reflectivity at 1.06425 and 1.3418 μm and a high transmission for the pump radiation at 0.81 μm. The second end face of the crystal had an antireflection coating for the wavelengths specified above. The laser cavity ($L = 200$ mm) was formed by a spherical mirror ($R = 200$ mm) and the mirror deposited on the crystal end.

The crystal was located in a solenoid which induced a constant or an alternating (with frequencies up to 90 Hz) magnetic field with an intensity $H \leqslant 0.08$ T. For maximum laser stability, precautions were taken to ensure that the active element did not come into mechanical contact with the solenoid (the crystal and the solenoid were mounted independently, and the crystal diameter was smaller than the internal diameter of the solenoid). A Brewster plate was introduced into the cavity to set the polarisation of the laser radiation. All structural elements of the laser were made of nonmagnetic alloys.

The laser was pumped according to the longitudinal scheme, employing the focused linearly polarised radiation of a laser diode ($\lambda = 0.81$ μm) with an output power up to 500 mW. The recording system made it possible to study the time, spectral, energy, and polarisation characteristics of laser radiation.

We have obtained the following results:

— The laser can generate cw radiation at the wavelengths 1.06425 (the $^4F_{3/2} \rightarrow {^4I_{11/2}}$ transition) and 1.3418 μm (the $^4F_{3/2} \rightarrow {^4I_{13/2}}$ transition). In the latter case, selective losses at $\lambda = 1.064250$ μm had to be introduced into the cavity, which was accomplished by employing an output mirror with a high transmission at this wavelength.

— The threshold pump power for lasing at 1.3418 μm was only 1.5 times higher than that for lasing at 1.06425 μm (about 100 mW), whereas for a $Nd^{3+}:Y_3Al_5O_{12}$ laser these pump powers differ by more than a factor of four.

— In the absence of a magnetic field, the laser radiation is linearly polarised (even in the absence of the Brewster plate) for pumping slightly above the threshold ($\eta < 1.2$). This is probably caused by the weak intrinsic anisotropy (birefringence) of the $Nd^{3+}:Bi_4Ge_3O_{12}$ crystal.

— The imposition of a longitudinal magnetic field on the active medium results in a rotation of the polarisation direction through an angle which may be as high as 2° for

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Received 27 January 2000
Kvantovaya Elektronika **30** (4) 283 – 284 (2000)
Translated by E N Ragozin; edited by M N Sapozhnikov

$H = 0.08$ T; the presence of a linear intracavity polariser (a Brewster plate) results in the change in the output laser power.

— The imposition of an alternating magnetic field gives rise to a harmonic modulation of the output power, which proves to be especially strong when the frequency of the alternating field coincides with the relaxation laser frequency $\omega_r = (\omega\eta/QT_1)^{1/2}$ (ω is the laser radiation frequency and Q the cavity quality factor).

— The resonant build-up at the relaxation frequency (as found earlier in Ref. [6]) permits precision measurements of the Verdet constant V and the birefringence coefficients of intracavity elements.

— Our measurements have yielded a value of the Verdet constant of 340 angular min (cm T)$^{-1}$ for the $Nd^{3+} : Bi_4Ge_3O_{12}$ crystal, which will agree with the results [5] and far exceeds the Verdet V constant for $Nd^{3+} : Y_3Al_5O_{12}$ equal to 80 angular min (cm T)$^{-1}$ [7].

— The Verdet constant for the $Nd^{3+} : Bi_4Ge_3O_{12}$ crystal exhibits a strong dispersion near the absorption line at 0.81 μm, where it changes from 400 to 700 angular min (cm T)$^{-1}$ as the wavelength changes only by 4 nm.

— The birefringence of the active element was nonuniform over the cross section and varied between 10^{-6} and 5×10^{-8}.

Thus, stable CW lasing at 1.06425 and 1.3418 μm has been obtained in a laser on a magnetic $Nd^{3+} : Bi_4Ge_3O_{12}$ crystal. The polarisation and energy characteristics of the laser can be controlled by applying a longitudinal magnetic field. The Verdet constant and the birefringence of the optical elements in the laser cavity can be measured precisely by using the modulation technique.

Acknowledgements. This work was supported by the Russian Foundation for Basic Research (Project No. 99-02-16054), the 'Fundamental Metrology' Programme, and the Educational and Scientific Centre 'Laser Physics and New Materials.' The authors acknowledge that the study was significantly facilitated by their cooperation in the Joint Open Laboratory for Laser Crystals and Precision Laser Systems.

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