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Short-wavelength ($\lambda = 914$ nm) microlaser operating on an Nd^{3+} : YVO_4 crystal

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Abstract. Conditions for lasing at $\lambda = 914$ nm in a diode-pumped Nd^{3+} : YVO_4 crystal were determined. The possibility of intracavity frequency doubling of the microlaser emission with the aid of an $LiIO_3$ crystal was demonstrated.

Nd^{3+} : YVO_4 crystals are nowadays used extensively in diode-pumped lasers, including the use for frequency doubling ($\lambda = 530$ nm) [1]. A fairly wide absorption line of the Nd^{3+} ions ($\lambda = 808$ nm), the feasibility of varying the Nd^{3+} concentration between wide limits, and a large cross section of the laser transition with $\lambda = 1064$ nm make this material attractive for diode-pumped lasers. The use of thin (~ 1 mm) Nd^{3+} : YVO_4 samples makes it possible to obtain an output power of several watts (in the green region) from a diode-pumped laser [2].

Advertising information on the use of Nd^{3+} : YVO_4 crystals in lasers with the emission wavelength in the blue spectral region ($\lambda = 457$ nm) has appeared recently. However, we are unaware of any scientific reports of lasing with $\lambda = 914$ nm on the ${}^4F_{3/2} \to {}^4I_{9/2}$ transition of neodymium in this crystal under diode pumping or reports of frequency doubling. The aim of the present investigation was to fill this gap.

We used Nd^{3+} : YVO_4 crystals (with the Nd^{3+} atomic concentration $C = 1\%$), 0.5 mm long and 4 mm in diameter. An optical diagram of the pumping scheme and of the laser is shown in Fig. 1. To produce an inverted population of the levels, we used a diode pump system (made by APhS GmbH), which had a fibre output (core diameter of 100 μm and a numerical aperture of 0.22) and delivered radiation powers of up to 2.5 W at $\lambda = 808$ nm. The pump radiation was focused by a three-lens objective, which transformed the image of the fibre end-face into a pumped spot 60 μm in diameter. This diameter of the pumped spot was found to be optimal under the conditions of our experiments and it made it possible to achieve a twofold excess of power over the laser threshold.

We recall that lasing at $\lambda = 914$ nm is described by a three-level diagram. It is known that the lower laser level in the Nd^{3+} : YVO_4 crystal is offset from the ground state by a spacing as small as 433 cm^{-1}, and that it is strongly populated at room temperature (and even more so at the operating temperature). Consequently, population inversion for the lasing transition requires a large number of neodymium ions in the excited state. To avoid absorption by the lasing transition, this excited state of the ions should be maintained throughout the length of the laser crystal. This means that the pump radiation intensity at the output crystal face should represent a significant proportion of the pump radiation intensity at the input face.

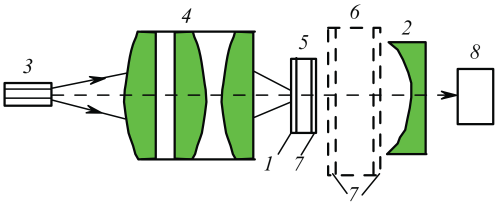

Figure 1. Schematic diagram of the investigated diode-pumped microlaser with an intracavity frequency doubler: (*1*; *2*) cavity mirrors; (*3*) fibre output of the pumping system; (*4*) objective; (*5*) Nd : YVO_4 active element; (*6*) $LiIO_3$ nonlinear element; (*7*) antireflection coatings; (*8*) photodetector.

The efficiency of the utilisation of the diode pumping was increased by depositing, on the output crystal face, a dielectric coating which reflected totally the pump radiation and transmitted the radiation with $\lambda = 914$, 1064, and 1340 nm. The fabrication of this dielectric mirror required a standard technological procedure, which cannot be said about the fabrication of the dielectric mirror on the input crystal face. Because of a small difference between the laser and pump wavelengths ($\Delta\lambda \sim 100$ nm), the synthesis of a multilayer dielectric structure was a difficult task.

We managed to perform this task by using a special computer program to optimise a structure with a large number of layers ($N \sim 40$) having variable parameters [3]. The results of this optimisation are presented in Fig. 2. Fig. 2a shows the dependence of the optical thickness of a layer on its serial number in the structure, and Fig. 2b gives the spectral characteristic of the structure. One can see that the largest changes in the optical thickness of the layer, required to obtain the desired result, occur at the beginning and at the end of the evaporation process, which was carried out using Balzers computer-controlled vacuum evaporators. The mirror produced with the aid of our program provided a low reflectivity ($R < 1\%$) for the radiation with $\lambda = 1064$ and 1340 nm, which was required to eliminate lasing at these wavelengths.

In the experiments on lasing at $\lambda = 914$ nm, we used an external outcoupling mirror (a plane mirror or a spherical one with the radius of curvature $r = 15$ mm). The mirror reflectivity was $R = 97.5$ or 100% in the experiments on frequency doubling.

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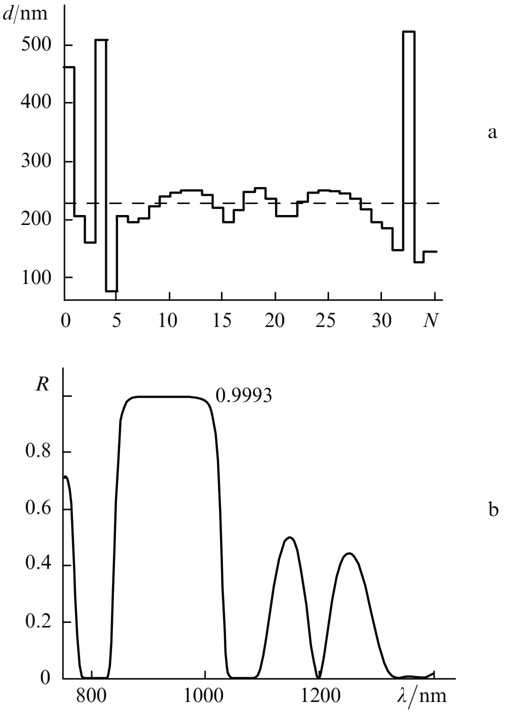

Figure 2. Optical thickness d of a dielectric layer, deposited on mirror *1*, plotted as a function of the layer number N (the even layer numbers correspond to SiO_2 and the odd numbers correspond to Ta_2O_5 (a) and the spectral dependence of the reflectivity of mirror *1* (b). The dashed line in Fig. 2a corresponds to the change of the optical thickness of layers of the shared dielectric mirror.

First, we determined the dependence of the output laser radiation intensity on the cavity length for a given pump power (Fig. 3). We used the plane mirror with $R = 97.5\%$ as an outcoupling reflector. One can see that the intensity decreased sharply with increasing cavity length, which was evidence of a strong effect of a thermal lens induced in the active element by the pump radiation. It was possible to maintain stable lasing at $\lambda = 914$ nm only for the cavity length down to 3 – 4 mm. We managed to increase somewhat the cavity length (required, in particular, to accommodate an intracavity frequency doubler) by using a spherical mirror with $r = 15$ mm. Therefore, in the experiments on second-harmonic generation, we used only a spherical mirror totally reflecting at $\lambda = 914$ nm.

Fig. 4 gives the dependence of the output radiation power on the pump power for the cavity with the plane mirror and the minimum operating length. This dependence is complex and it is determined, in particular, by the formation of a thermal lens. The output radiation power increases with increasing pump power much faster than linearly. This suggests that it should be possible to achieve a considerably higher laser efficiency on increasing the excess of the pump power over the threshold value.

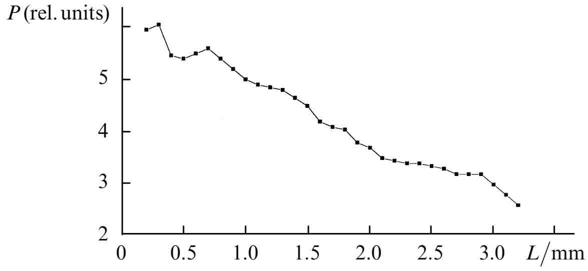

Figure 3. Dependence of the microlaser output power P (at $\lambda = 914$ nm) on the cavity length L for the pump power exceeding the threshold by a factor of two.

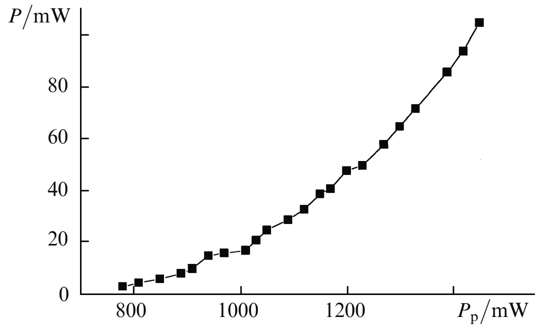

Figure 4. Dependence of the microlaser output power P (at $\lambda = 914$ nm) on the pump power P_p for the minimum cavity length and the output mirror reflectivity $R = 97.5\%$.

Our estimates of the intracavity radiation density (on the basis of the data presented in Fig. 4) show that it is possible to achieve efficient second-harmonic generation by using an $LiIO_3$ crystal 2 mm long with antireflection coatings (for $\lambda = 914$ and 457 nm) on both faces. The blue radiation was outcoupled through the spherical mirror. We achieved stable generation of the blue radiation. The radiation power at the laser output reached ~6 mW.

Our studies thus showed that the $Nd^{3+} : YVO_4$ crystals can be sufficiently efficient for the generation of radiation with $\lambda = 914$ and 457 nm in lasers with a relatively simple cavity configuration. Optimisation of our laser system should make it possible to generate blue radiation with a power of at least several tens of milliwatt.

References

1. Shen D, Liu A, Song Y, Ueda K *Appl. Opt.* **37** 7785 (1998)
2. Chen Y F, Huang T M, Wang C L, Lee L L *Appl. Opt.* **37** 5727 (1998)
3. Lyndin N M, Sychugov V A, Usievich B A *Kvantovaya Elektron. (Moscow)* **22** 503 (1995) [*Quantum Electron.* **25** 478 (1995)]