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Intracavity quasi-phase matched frequency summing in a laser based on a periodically poled active nonlinear Nd : Mg : LiNbO$_3$ crystal

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***Abstract*.** **The intracavity summing of the frequencies of lasing ($\lambda = 1.084$ μm) and pump radiation from a 0.81-μm diode laser is performed in a periodically poled active nonlinear Nd : Mg : LiNbO$_3$ crystal.**

Keywords: *active nonlinear crystal, periodically poled structure, self-frequency conversion, quasi-phase matched interaction.*

The study of active nonlinear crystals doped with rare-earth ions and combining active (lasing) and nonlinear properties began at the end of 1960s [1 – 3]. The latest advances in this field of laser physics were associated with the application of diode lasers for pumping [4, 5] and with the synthesis of new active nonlinear crystals with good optical properties and high optical damage thresholds [6 – 8]. The use of periodically poled active nonlinear crystals opens new possibilities for the efficient self-frequency conversion, when the lasing at a fixed frequency appears and quasi-phase matched nonlinear conversion of the laser frequency occurs in the crystal (generation of harmonics, frequency summing, SRS transformation, etc.) [9 – 12].

In this paper, we present the first results of the experimental study of the summing of the lasing frequency in a periodically poled active nonlinear Nd : Mg : LiNbO$_3$ crystal and the radiation frequency of a diode laser used for pumping. The crystal was grown from the melt with a nearly congruent composition by the Czochralski method along the normal to the closely packed face $\{01\bar{1}2\}$. Such a crystal is usually referred to as a 'face-type' crystal [13]. The diameter of the face at the growth front was 10 – 15 mm, while the crystal boule diameter was 20 mm, and the domain walls in the central part of the boule were parallel to the $\{01\bar{1}2\}$ face. This face formed plane domain walls and rendered the domain structure stable to temperature variations.

The periodicity of the domain structure and the concentrations of Nd$_2$O$_3$ and MgO impurities were studied by the methods of selective chemical etching and X-ray microscopic analysis [13]. Average weight concentrations of Nd$_2$O$_3$ and MgO used for growing a periodically poled Nd : Mg : LiNbO$_3$ crystal were (0.5 ± 0.2)% and (0.8 ± 0.04)%, respectively. The domain structure period determined by the ratio of the pulling rate to the rate of rotation of the crystal during its growth over a crystal length of 14 mm was (4 ± 0.1) μm.

Fig. 1 shows the scheme of the experimental setup. A periodically poled active nonlinear Nd : Mg : LiNbO$_3$ crystal with a domain structure period approximately equal to 4 μm and a length of 7 mm was placed in a semiconcentric cavity of length 20 cm near a plane mirror. The crystal was pumped by two thermally stabilised 0.81-μm diode lasers (ATC-C1000-100-AMO and ATC-C1000-150-AMO). The laser beams were combined with the help of a polarisation cube. Continuous wave lasing was observed at 1.084 μm. The plane mirror had a high reflectivity at the lasing wavelength ($R_{1.084} = 99.9$ %) and a high transmission at the pump wavelength ($T_{0.81} = 85$ %). The emission wavelengths emerging through the spherical mirror ($R_{1.084} = 99.9$ %, $T_{0.464} = 90$ %, $T_{0.81} = 90$ %) were measured with a monochromator, and their power was measured with a power meter.

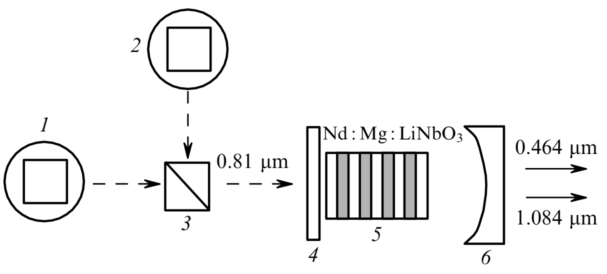

Figure 1. Schematic of the experimental setup: (*1*, *2*) laser diodes, (*3*) mixing cube, (*4*) plane mirror, (*5*) active nonlinear crystal, (*6*) spherical mirror.

A periodically poled active nonlinear Nd : Mg : LiNbO$_3$ crystal absorbed approximately 60 % of the pump radiation at 0.81 μm. This part of the pump radiation created a population inversion in the active element resulting in lasing at 1.084 μm. The remaining unabsorbed part of the pump radiation interacted nonlinearly with laser radiation. As a

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result, radiation at the sum frequency was produced, which was extracted from the cavity.

The wavelength corresponding to the sum frequency was 0.464 μm, in good agreement with the theoretical value. The dependences of powers of laser radiation and the sum-frequency wave (at 0.464 μm) on the absorbed pump power are presented in Fig. 2. One can see that the lasing power at the fundamental wavelength 1.084 μm increases linearly with the pump power, while the power at the sum frequency $\nu_{\text{las}} + \nu_{\text{p}}$ increases almost quadratically.

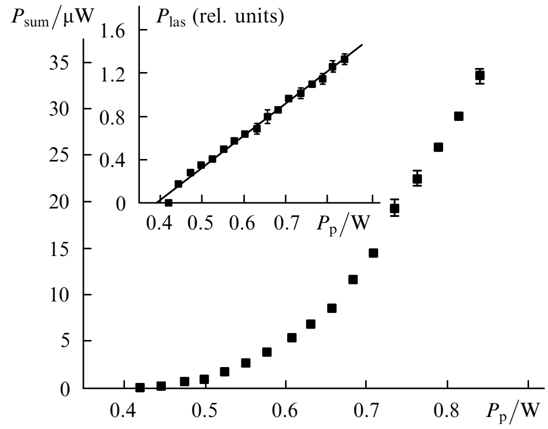

Figure 2. Dependence of the lasing power P_{las} at 1.084 μm and the power P_{sum} of sum-frequency wave at 0.464 μm on the pump power P_{p} absorbed in the crystal.

Thus, we have performed intracavity quasi-phase matched summing of lasing and pump frequencies in a periodically poled active nonlinear Nd : Mg : LiNbO$_3$ crystal.

We can expect that optimisation of parameters of periodically poled active nonlinear crystals, in particular, the periodicity of the domain structure (note that deviations from the calculated period amounted to 0.1 μm in our experiments) and the optical quality of the active nonlinear crystal itself will allow us not only to increase the efficiency of frequency summing, but also to implement other schemes of self-frequency conversion in periodically poled active nonlinear crystals [12].

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References

1. Evlanova N.F., Kovalev A.S., Koptsik V.A., Kornienko L.S., Prokhorov A.M., Rashkovich L.N. *Pis'ma Zh. Eksp. Teor. Fiz.*, **5**, 351 (1967).
2. Johnson L.F., Ballman A.A. *J. Appl. Phys.*, **40**, 297 (1969).
3. Dmitriev V.G., Raevskii E.V., Rubinina N.M., Rashkovich L.N., Silichev O.O., Fomichev A.A. *Pis'ma Zh. Tekh. Fiz.*, **5**, 1400 (1979).
4. Wang C.Q., Chow Y.T., Gambling W.A., Zhang S.J., Cheng Z.X., Shao Z.S., Chen H.C. *Opt. Commun.*, **174**, 471 (2000).
5. Dekker P., Dawes J.M., Piper J.A., Liu Y., Wang J. *Opt. Commun.*, **195**, 431 (2001).
6. Ye Q., Shah L., Eichenhold J., Hammons D., Peale R., Richardson M., Chin A., Chai B.H.T. *Opt. Commun.*, **164**, 33 (1999).
7. Lu J., Li G., Liu J., Zhang S., Chen H., Jiang M., Shao Z. *Opt. Commun.*, **168**, 405 (1999).
8. Kaminskii A.A., Jaque D., Bagaev S.N., Ueda K., Garcia-Sole J., Capmany J. *Kvantovaya Elektron.*, **26**, 95 (1999) [*Quantum Electron.*, **29**, 95 (1999)].
9. Kravtsov N.V., Laptev G.D., Morozov E.Yu., Naumova I.I., Firsov V.V. *Kvantovaya Elektron.*, **29**, 95 (1999) [*Quantum Electron.*, **29**, 933 (1999)].
10. Sohler W. *Techni. Dig. of the Pacific Rim Conf. on Lasers and Electro-Optics* (Seoul, 1999) p. 1265.
11. Capmany J., Callejo D., Bermudez V., Dieguez E., Artigas D., Torner L. *Appl. Phys. Lett.*, **79**, 293 (2001).
12. Laptev G.D., Novikov A.A., Chirkin A.S. *J. Russian Laser Research*, **23**, 183 (2002).
13. Naumova I.I., Evlanova N.F., Blokhin S.A., Lavrishchev S.V. *J. Crystal Growth*, **187**, 102 (1998).