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DUAL-POLARIZATION GENERATION IN THE ND:YAG LASER

Introduction

Dual-polarization laser generation in dynamic mode is currently used for some interesting applications [1, 2]. We propose using it for passive cavity dumping by the second harmonic generation in the mode locked laser. In this case it is important to have the same radiation intensity at both polarizations.

In this paper, we investigate the effect of the difference between inactive loss coefficients and cavity optical lengths for simultaneously generated polarizations on their intensities.

1. Theoretical model

Dual-polarization generation in dynamic regime is simulated with the use of simple scalar model. The main approximations used in the model are as follows:

a) The pump source (a lamp) produces unpolarized radiation.

b) The *Nd: YAG* active laser medium properties are independent of the optical field polarization: stimulated emission cross-section σ_e and refractive index n of the medium are equal for both polarizations, anisotropic properties of the Nd^{3+} ions are not considered.

c) The cavity anisotropies consist in different coefficients of losses γ and optical cavity lengths L_{opt} for radiation with different polarizations.

Our model may be used to investigate quantitative behavior of the described system, although it may be not enough for more complicated cases. To describe the laser generation in more detaled and correct way, the corresponding vector models should be used [3]. Such models allow to take into account the polarization of the pump laser and other factors besides the cavity anisotropies that may influence the polarization states of lasers, as well as consider crystal symmetry and anisotropic properties of the ions at different sites.

The proposed model is based on the rate equations for the point model of active medium [4]. The 4-level generation scheme is considered.

$$\frac{dS'}{dt} = \frac{nL_{LC}}{L_{opt}'} v_c \sigma_e S'(n_2 - n_1) - \frac{c\gamma' L_{LC}}{L_{opt}'} S'$$

$$\frac{dS''}{dt} = \frac{nL_{LC}}{L_{opt}''} v_c \sigma_e S''(n_2 - n_1) - \frac{c\gamma'' L_{LC}}{L_{opt}''} S''$$

$$\frac{dn_1}{dt} = \sigma_e (S' + S'')(n_2 - n_1) - \frac{n_1}{\tau_1} + \frac{n_2}{\tau_2}$$

$$\frac{dn_2}{dt} = \sigma_e (S' + S'')(n_1 - n_2) + \frac{n_3}{\tau_3} - \frac{n_2}{\tau_2}$$

$$\frac{dn_3}{dt} = \frac{P}{s_{LC} h \nu_a} \sigma_a (N_s - n_1 - n_2 - n_3) - \frac{n_3}{\tau_3} \quad . \qquad (1)$$

Here *S'* and *S''* correspond to the photon flux densities of the radiation with different polarizations, n_i describe the carrier densities at different energy levels. Other *Nd:YAG* crystal parameters used in the calculations: pump wavelength λ_a = 808 nm, emission wavelength λ_e = 1064 nm, ab- sorbtion cross-section $\sigma_a = 7{,}7 \cdot 10^{-20}$ cm^2, emission cross-section $\sigma_e = 28 \cdot 10^{-20}$ cm^2, refractive index n = 1,82, crystal length L_{LC} = 6 cm, crys- tal surface area s_{LC} = 9,425 cm^2, lifetime at $^4F_{3/2}$ level τ_2 = 230 mcs, lifetime at $^4F_{5/2}$ level τ_3 = 10 ns, lifetime at $^4I_{11/2}$ level τ_1 = 30 ns, total Nd^{3+} ion den- sity (concentration 1%) $N_s = 1{,}38 \cdot 10^{20}$ cm^{-3}.

System (1) is used to calculate time dependence of photon flux densities *S'* and *S''* (and intensities $I = S \cdot h\nu_e$) for the given parameters – pump power *P*, cavity optical lengths L_{opt}', L_{opt}'' and coefficients of losses in the cavity γ', γ'' for different polarizations. Initial values of pump power, cavity optical length and losses used in the calculations are *P = 2 kW*, $L_{opt} = 65$ *cm*, $\gamma = 0{,}003$ *cm*$^{-1}$ respectively. The coefficient of losses γ = 0,003 cm^{-1} and crystal length L_{LC} = 6 cm are equivalent to the output mirror reflectivity of 96,5%.

2. Results

The first important conclusion follows from the first two equations of the system (1). It describes the condition of simultaneous existence of non-zero *S'* and *S''* values in the steady-state: $\gamma' = \gamma''$. This observation is confirmed with the simulations of laser generation in dynamics. Figures 1a, 1b show time dependencies of *I'* and *I''* for $\gamma' \neq \gamma''$ and $L_{opt}' \neq L_{opt}''$.

The intensity of the polarization with bigger γ finally goes to zero independently of the other parameter values. The difference between losses γ'-γ'' and cavity optical lengths L_{opt}'-L_{opt}'' as well as the pump power *P* influence only the dynamics of the generation and time needed to achieve the steady-state.

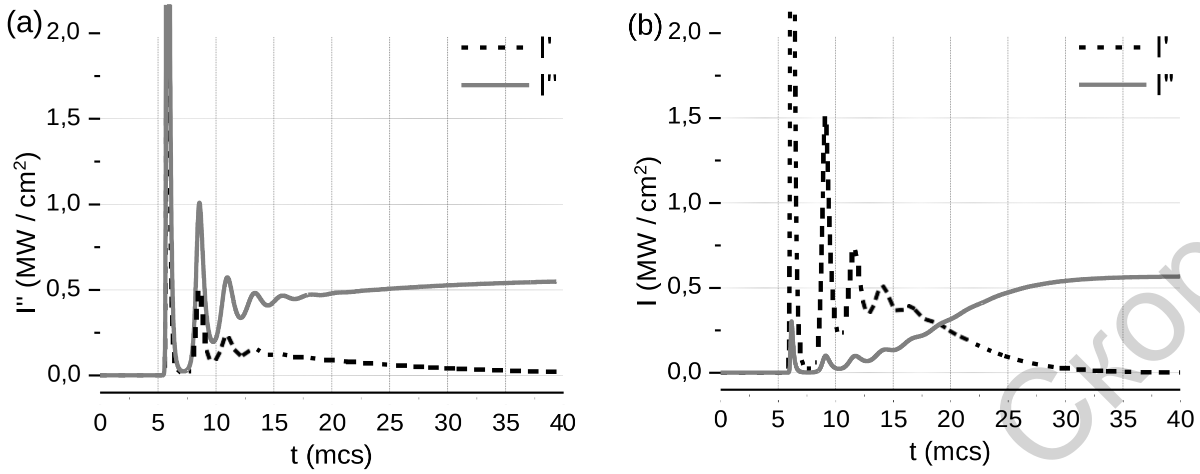

Figure 1 – Time dependence of the *I'* and *I''* for two polarizations for
(a) $P=2kW$, $L_{opt}'=L_{opt}''=65$ *cm*, $\gamma'=0{,}00303$ cm^{-1}, $\gamma''=0{,}003$ cm^{-1} ($\Delta\gamma/\gamma''=1\%$);
(b) $P=2$ kW, $L_{opt}'=60$ *cm*, $L_{opt}''=65$ *cm* ($\Delta L_{opt}/L_{opt}''=-7{,}7\%$), $\gamma'=0{,}0031$ cm^{-1},
$\gamma''=0{,}003$ cm^{-1} ($\Delta\gamma/\gamma''=33\%$)

In the case when the condition γ' = γ'' is fulfilled, the ratio *I'/I''* of the *I'* and *I''* steady-state values are defined by the ratio of the corresponding cavity optical lengths L_{opt}'/L_{opt}'' (Figure 2). The observed dependence *I'/I''* (L_{opt}'/L_{opt}'') is exponential.

In reality the generation is realized at different longitudinal modes, and losses in the cavity are not equal for them (and may be also not constant in time). This situation may be simulated by specifying γ' and γ'' fluctuating in time around the average value. Figure 3 shows an example of the generation dynamics for both polarization modes and their losses time dependence in such case.

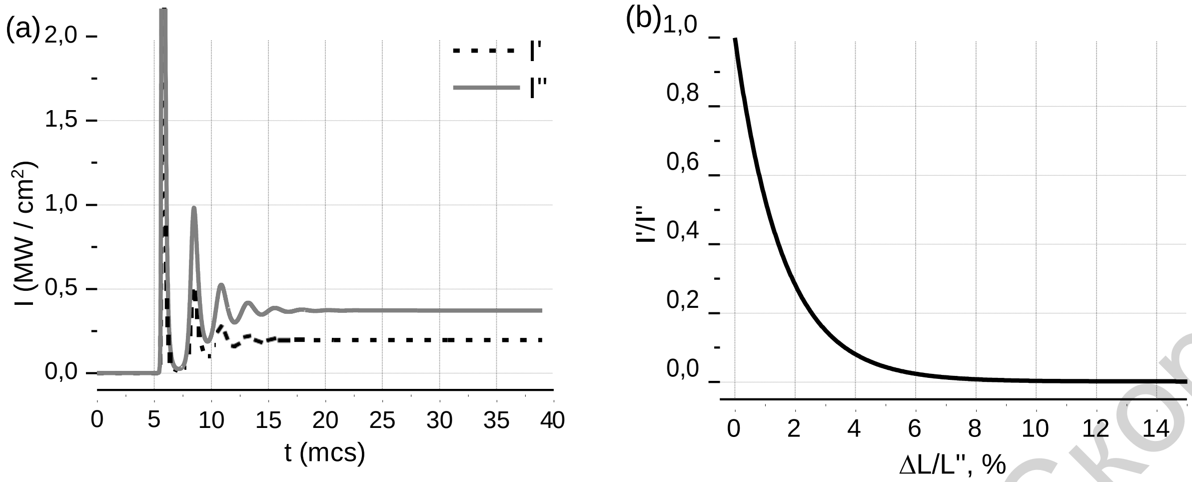

Figure 2 – (a) Time dependence of the I' and I'' for two polarizations for $P=2kW$, $\gamma'=\gamma''=0{,}003\ cm^{-1}$, $L_{opt}'=65{,}65\ cm$, $L_{opt}''=65\ cm$ $(\Delta L_{opt}/L_{opt}''=1\%)$;
(b) Dependence of the intensity ratio I'/I'' on the cavity length ratio L_{opt}'/L_{opt}'' for $P=2\ kW$, $\gamma'=\gamma''=0{,}003\ cm^{-1}$ $(L_{opt}''=65\ cm$, $L_{opt}' > L_{opt}'')$

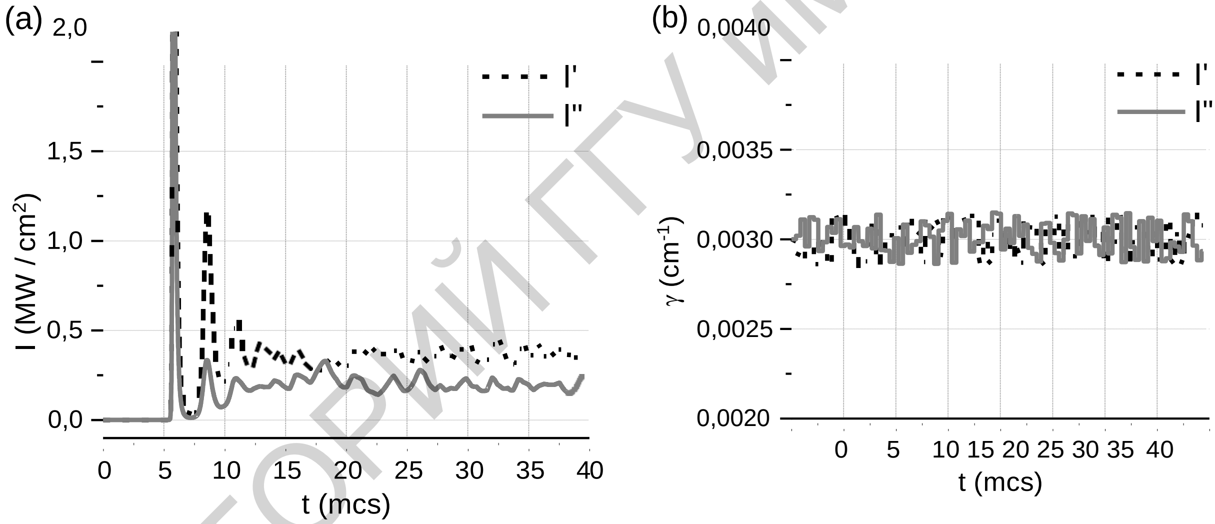

Figure 3 – Time dependence of the I', I'' (a) and γ', γ'' (b); both γ' and γ'' are fluctuating randomly in the range of 5% about the average value of 0,003 cm^{-1} with the period of ~430 *ns* (100 cavity round-trips)

In the described case none of both polarization modes intensities goes to zero with time as the average values of losses for them remain approximately equal.

3. Experiment

The experimental setup sketched in Figure 4 was used to obtain dual-polarization generation in the Nd: YAG laser with lamp pumping.

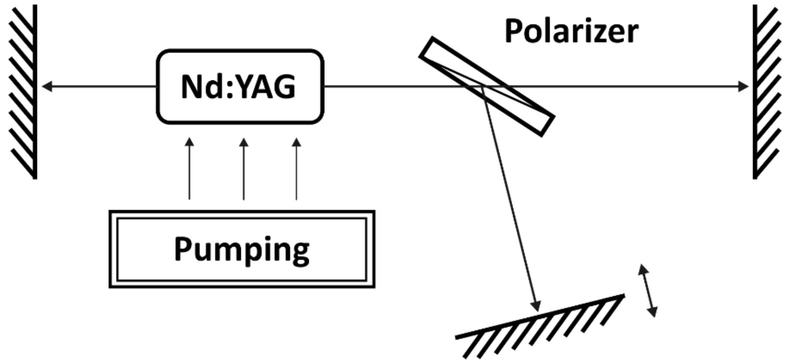

Figure 4 – Experimental setup

The beams with two orthogonal polarizations were separated with the use of a polarizer inclined at Brewster's angle (57° between the normal and beams propagation directions). The output mirror common for two polarization modes had reflectivity of 53%, the other mirrors were highly reflective and equal for both beams. One of the end mirrors was placed on the moving mount, so it was possible to change the cavity length for one of the beams.

We obtained the simultaneous generation on two palarizations for a pulsed laser operation. The pulse shapes for orthogonal polarization modes are shown in Figure 5.

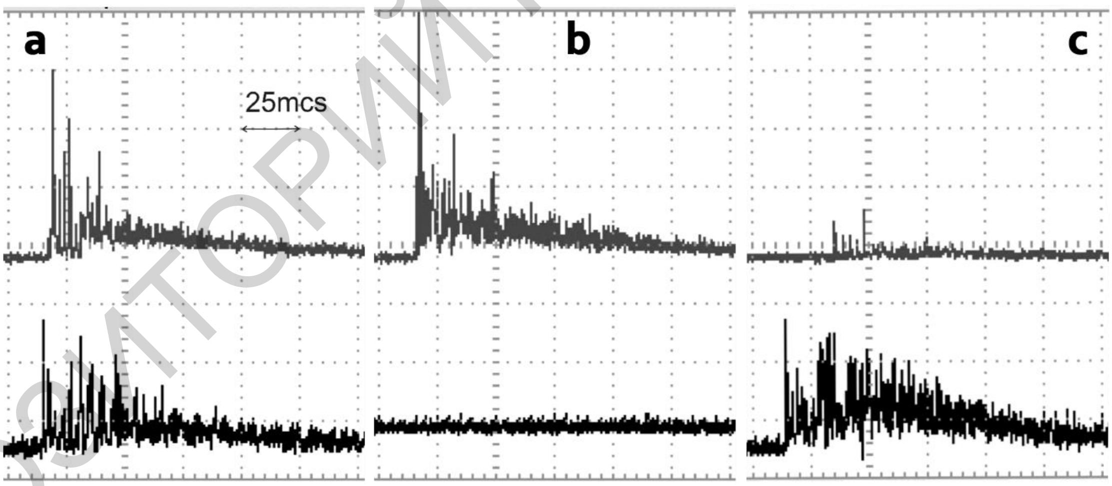

Figure 5 – Pulse profiles for different polarizations: *a* – coefficients of losses in the cavity *γ', γ''* for different polarizations are almost the same (no additional losses), *b* – additional losses for the beam corresponding to the lower curve, *c* – additional losses for the beam corresponding to the upper curve

Figure 5a shows that the pulse profiles for two polarization modes are different. The Figure 5b and 5c show the pulse profiles when additional losses were added into the cavity of one of the polarized beams (we used a glass plate increasing losses by ~16% for the cavity round-trip). This led to a significant decrease of the corresponding beam intensity and relative increase of intensity of the other beam.

4. Conclusions

The effect of the difference in loss coefficients and cavity lengths for different polarizations on the ratio of the intensities of the generated beams was studied. We have shown that generation at different polarizations in the dynamic mode is possible with different loss factors for them. At different optical cavity lengths for different polarizations, generation is possible in continuous mode if the loss coefficients are the same. In this case, the intensity of beams with orthogonal polarizations will be different.

References

1. Khelifa, Naceur-Eddine. Traceability of small forcemeasurements and the future international system of units (SI) / Naceur-Eddine Khelifa, Philippe Averlant, Marc Himbert Int. J. Metrol. Qual. Eng. – 2016. – Vol.7. – P. 306–313.
2. M. Brunel Dual-polarization microchip laser at 1,53 μm. / M. Bru- nel, A. Amon, M Valet. – 2005. – Opt. Lett. – Vol. 30. – P. 2418–2420.
3. Dalgliesh, R. Polarization States of a Single-Mode (Microchip) Nd:YAG Laser – Part I: Theory / R. Dalgliesh, A. D. May, and G. Stephan. – 1998. – IEEE Journal of quantum electronics. – Vol. 34 – P. 1485–1492.
4. Stashkevich, I.V. Cavity Dumping by the Second Harmonic Genera- tion / I.V.Stashkevich, R.I.Navitskaya, A.S Gorbacevich. – BSU Journal. Physics. – 2017. – № 2. – C. 57–62.