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COMPARISON OF PARAMETERS OF RUBY AND NEODYMIUM QUANTUM GENERATORS WITH PULSE HIGH QUALITY

by

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ABSTRACT: An investigation was made of a ruby laser operating in a pulsed Q-switching mode. Q-switching was controlled by rotating the prism of total internal reflection. The giant pulses obtained from the ruby laser differed from the pulses of the neodymium laser by their parameters. A neodymium laser generates a single pulse at a prism rotation speed of 25,500 rpm and a pumping energy of 2020 joules, while the ruby laser with the same rotation speed and a smaller pumping energy (1520 joules) generates 2—3 pulses which diminish in power. The parameters of ruby and neodymium lasers operating under similar conditions were compared. Neodymium glass rods and ruby rods with identical dimensions were used The illuminator, the rotating prism, and the electrical and measuring parts of the installation in both cases were the same. The prism rotated at 24,000 rpm. The optimum mirror from the emergence side in the neodymium laser had a reflection coefficient of 60% and in the ruby laser, 42%. The investigations showed that the rate of resonator Q-switching, which determines the character of the laser emission, depends not only on the rotation speed of the prism but also on the optical properties of the active substance.
Original article has: 4 figures. English translation: 8 pages.

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	А а	A, a	Р р	Р р	R, r
Б б	Б б	B, b	С с	С с	S, s
В в	В в	V, v	Т т	Т т	T, t
Г г	Г г	G, g	У у	У у	U, u
Д д	Д д	D, d	Ф ф	Ф ф	F, f
Е е	Е е	Ye, ye; E, e*	Х х	Х х	Kh, kh
Ж ж	Ж ж	Zh, zh	Ц ц	Ц ц	Ts, ts
З з	З з	Z, z	Ч ч	Ч ч	Ch, ch
И и	И и	I, i	Ш ш	Ш ш	Sh, sh
Й й	Й й	Y, y	Щ щ	Щ щ	Shch, shch
К к	К к	K, k	Ъ ъ	Ъ ъ	"
Л л	Л л	L, l	Ы ы	Ы ы	Y, y
М м	М м	M, m	Ь ь	Ь ь	'
Н н	Н н	N, n	Э э	Э э	E, e
О о	О о	O, o	Ю ю	Ю ю	Yu, yu
П п	П п	P, p	Я я	Я я	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

COMPARISON OF PARAMETERS OF RUBY AND NEODYMIUM QUANTUM GENERATORS WITH PULSE HIGH QUALITY

Yu. F. Morgun and V. A. Pilipovich

It is shown that speed of introduction of high quality of resonator determining character of radiation of optical quantum generator depends not only on speed of rotation of prism but also on optical properties of active material.

Earlier we carried out work for the study of a neodymium optical quantum generator in conditions of pulse inclusion of high quality [1]. Control of high quality was carried out by rotating a prism of total internal reflection. Satisfactory coincidence of parameters calculated by analytic formulas with parameters found from experiments indicates that in the case of a neodymium [OKG] (ОКГ) [optical quantum generator], there was attained practically instantaneous inclusion of high quality.

This work gives the results of investigations of ruby OKG working in conditions of pulse high quality with the same method of modulation of high quality as in the first work. Measurements showed that the gigantic pulses obtained from ruby OKG essentially differ in parameters from pulses of neodymium OKG. Whereas neodymium OKG at a speed of rotation of prism of 25,500 r/min at a pumping energy of 2020 joules generated a monopulse; the ruby OKG with that same speed of rotation and smaller pumping energy (1520 joules) generates 2-3 pulses which diminish in power. Therefore, it is of interest to conduct an experimental comparison of parameters of neodymium and ruby quantum generators working in close conditions.

For this purpose there were used rods of neodymium glass and ruby of identical dimensions. The electrical illuminator rotating the prism and also the measuring part of the installation in both cases were the same. Speed of rotation of the prism was 24,000 r/min. The optimum mirror from the side of output in the neodymium OKG had a factor of 60% and in ruby it has a reflection factor of 42%.

From works on quantum generators with pulse high quality [2-5] it follows that the distinction obtained by us in pulses of generation can be explained during calculation of speed of change cf high quality of resonator from threshold value $Q_{\text{пор}}$ up to maximum $Q_{\max}$. Naturally it is assumed that from source of pumping, there is brought to working substance of generator the power necessary for creation in it of threshold inverse population density $n_{\text{пор}}$. Magnitude $n_{\text{пор}}$ during a considerable range of energy possibilities of the pumping system will be changed in a large interval, which is determined by limits of change of high quality of resonator.

A qualitative illustration of picture of formation of radiation pulses, different in character, (their number, energy, and time parameters) is given below. Since during rotation of prism, high quality of resonator changes from $Q_{\min}$ to $Q_{\max}$, magnitude of threshold inverse population density will constantly change, dropping from $n_{\text{пор}}^{\max}$ to $n_{\text{пор}}^{\min}$. To describe the operation of quantum generators with pulse high quality there is usually considered time of inclusion of high quality t_Q and rise time of pulse $t_{\text{И}}$. For a modulator on revolving prism, time of inclusion of high quality should be defined as the time to turn the prism at an angle from magnitude $\phi_{\text{пор}}$, which corresponds to the threshold value of high quality $Q_{\text{пор}}$ at a given pumping power to angle $\phi = 0$, which corresponds to the maximum value of high quality of resonator $Q_{\max}$. Here ϕ is the angle of unparallelism of resonator reflectors. Rise time of pulse $t_{\text{И}}$ should be counted off from the moment of achievement by the prism of angle $\phi_{\text{пор}}$ to the moment which corresponds to the maximum of the monopulse (or the maximum of the first pulse). The number of pulses and their power will depend on the ratio between magnitudes t_Q and $t_{\text{И}}$. For those cases when $t_Q \overset{\sim}{<} t_{\text{И}}$, it is possible to consider that there is carried out the instantaneous inclusion of high quality and during generation there will be observed one pulse of great power.

It is obvious that at $t_Q > t_{\text{И}}$ and $Q_{\text{пор}} < Q_{\max}$ the threshold value of inverse population density cannot reach a minimum value after generation of the first pulse and therefore, increasing the high quality of the resonator further will lead to appearance of the following pulses of generation. Since $\phi_{\text{пор}}$ increases with increase of pumping power, then at a given rotary speed of the prism, the number of pulses increases with increase of energy brought into the illuminator tubes. Therefore, at high energies of pumping, a pulse of great power can be obtained only at considerable rotary speeds of the prism. The modulator with a rotating reflector turns out to be more effective for a plane-parallel resonator, which (spherical, confocal, etc.) is more critical than others to adjustment.

The results expounded below of measurements of parameters of pulses of generation of ruby and neodymium OKG agree well with the circuit considered of work of generators in conditions of pulse high quality.

In Fig. 1 there are represented oscillograms of pulses of neodymium and ruby OKG. From comparison of oscillograms it follows that in spite of identical speed of rotation of prism and the same exceeding of the threshold by energy of pumping for both samples, parameters of pulses are essentially different. The first assumption about the nature of this distinction should originate, obviously, from the distinction of speed of introduction of high quality for these generators. One of the possible checks of this assumption consisted of obtaining generation on neodymium OKG at a small rotary of the prism.

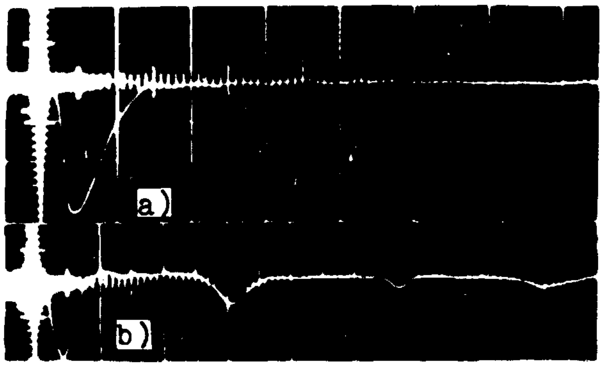

Fig. 1. Oscillograms of gigantic pulses of neodymium a) and ruby b) OKG during speed of rotation of prism of 24,000 r/min. Energy of pumping is 1520 joules (neodymium) and 2020 joules (ruby), threshold values of energy of pumping are 1000 and 1400 joules, respectively, and speed of scanning is 50 and 100 ns/div.

At a speed of rotation of 25,500 r/min (Fig. 2a) on output of generator there is observed a single pulse lasting on the order of 30 ns and having a pulse energy of 1 joule. Deceleration of rotation of the prism to 5500 r/min (Fig. 2b) essentially changes the parameters of the generated signal. Instead of one pulse in this case on the output of the generator, there are observed two pulses which are divided by an interval of time of about 500 ns. The duration of the first pulse is 55, and the duration of the second pulse is 65 ns, which considerably exceeds the duration of the monopulse obtained at a high speed of rotation of the prism. Since energy of pumping and, consequently, $t_{\text{пор}}$ in both cases remained constant, then the only cause of variation of parameters of pulses can only be change of speed of inclusion of resonator, which in the second case was almost five times less than in the first. In light of this experiment, the explanation of results of measurements represented in Fig. 1 of different speed of inclusion of high quality (small for ruby OKG and great for neodymium) is convincing. Inasmuch as for both generators, speed of rotation of prism, conditions of pumping and geometric parameters of resonator were identical, the difference in speed of inclusion of high quality could be caused only by the influence of the working substance.

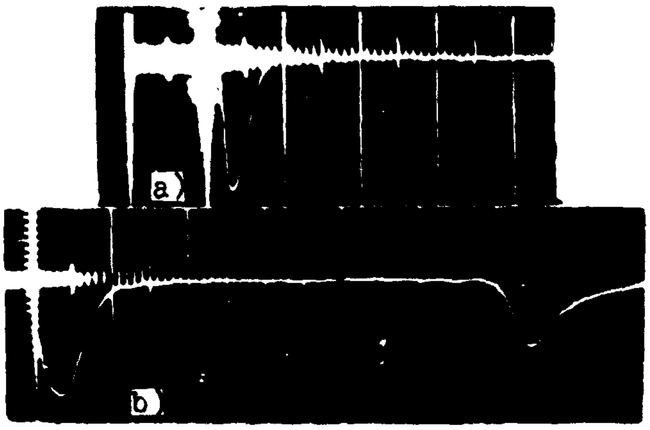

Fig. 2. Oscillograms of gigantic pulses of a neodymium OKG at different speeds of rotation of prism: a) is 25,500 r/min, b) is 5500. Pumping energy in both cases is equal to 1520 joules; scanning speed is 100 ns/div.

The measurements mentioned below testify about the essential influence of optical heterogeneity of active material on speed of inclusion of high quality in OKG with a rotating prism. Qualitatively the speed of inclusion of high quality can be estimated by the dependence of threshold energy of pumping on the adjustment of the rotating reflector. Taking additionally the dependence of threshold energy of pumping on losses on reflectors of resonator, it is possible to determine speed of turning off losses numerically. For this, on the basis of two taken dependences of the threshold energy of pumping - on angle of adjustment and on losses on reflectors of resonator - losses are plotted as a function of adjustment. The scale of angles of adjustment can be translated to a time scale for any rotary speed of the reflector. As a result there was obtained a graph of change of losses in time, by which speed of change of losses was numerically determined.

In Fig. 3a u_{Hax}^{nop} is plotted as a function of ♦. The length of the resonator was 40 cm. One branch is given of each of the curves (the second branch is symmetrical). As follows from form of curves, speed of inclusion of high quality in neodymium and ruby OKG is essentially different. Dependence of threshold energy of pumping on losses on reflectors of resonator is represented in Fig. 3b. Inasmuch as Fig. 3a and 3b are obtained during the same conditions, on the basis of them, there can be plotted the characterizing change of losses during adjustment of reflector (Fig. 4). For a speed of rotation of prism of 25,500 r/min along the axis of abscissas is plotted also time of change of losses of resonator t (ns). The curves of Fig. 4 confirm qualitatively the presented diagram of work of generator in conditions of pulse high quality.

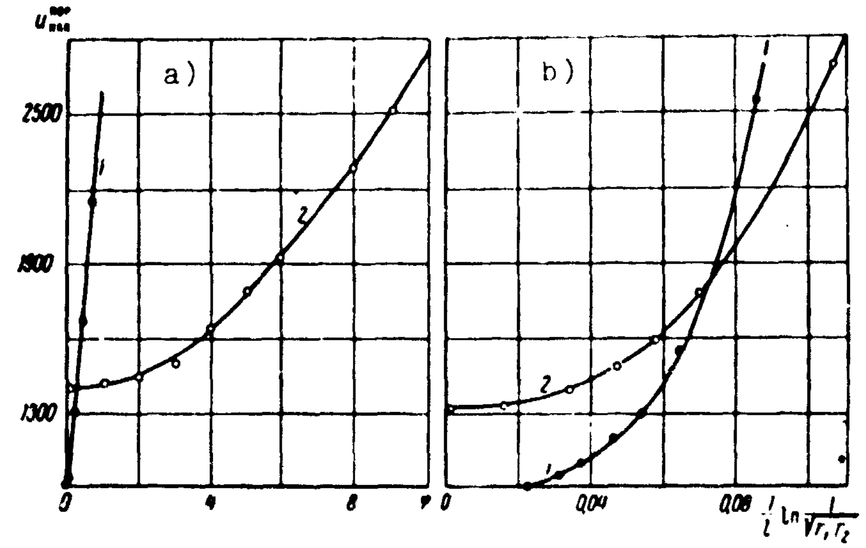

Fig. 3. Dependence of threshold energy of $u_{\text{нак}}^{\text{пор}}$ (joules) on angle of adjustment of ϕ (min) of a prism of total internal reflection a) and on losses on reflectors of resonator $\frac{1}{l}\ln\frac{1}{\sqrt{r_1 r_2}}$, cm^{-1} b) for neodymium (1) and ruby (2) OKG.

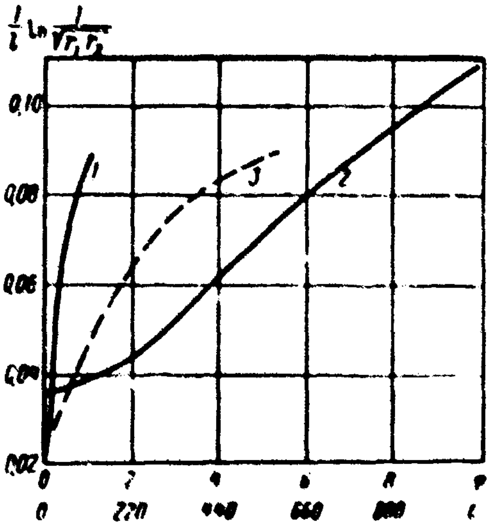

Fig. 4. Dependence of resonator reflector losses $\frac{1}{l}\ln\frac{1}{\sqrt{r_1 r_2}}$ (cm^{-1}) on angle of rotation of prism of total internal reflection ϕ (min): 1 and 2 – for neodymium and ruby OKG at a speed of rotation of prism of 25,500 r/min; 3 – neodymium at a speed of 5500 r/min.

To a threshold pumping energy of a neodymium OKG of 1520 joules, there corresponds (on curve 1, Fig. 3b) a magnitude of losses of 0.064 cm^{-1}. On curve 1, Fig. 4, we determine that a change of magnitude of losses from 0.064 cm^{-1} to a minimum value of 0.022 cm^{-1}

cm^{-1} occurs each 44 ns (at a speed of rotation of the prism of 25,500 r/min). At such a fast change of losses, speed of inclusion of high quality is close to instantaneous. The neodymium laser generates a monopulse (Fig. 2a). At a speed of prism rotation of 5500 r/min, time of turning off losses is about 200 ns (curve 3, Fig. 4). With such a speed of introduction of high quality, the neodymium laser radiates 2 pulses (Fig. 2b).

In case of a ruby laser during a threshold pumping of 2020 joules, the change of losses from magnitude 0.081 cm^{-1} (curve 2, Fig. 3b) to minimum value 0.036 cm^{-1} occurs during the time near 700 ns (at a speed of prism rotation of 24,000 r/min). With such a speed of turning off losses, there are radiated several pulses (Fig. 2b). Duration of sequence of pulses is also about 700 ns. In order to obtain, during use of this ruby crystal, a gigantic single pulse, it is necessary to increase speed of turning off losses approximately 10 times i. e., to apply a reflector revolving with an effective speed of 240,000 r/min.

Thus, constructing on two threshold dependences $u^{\text{пор}}_{\text{нак}} = f(\phi)$ and $u^{\text{пор}}_{\text{нак}} = f\left(\frac{1}{l}\ln\frac{1}{\sqrt{r_1r_2}}\right)$ a curve of losses as a function of angle of adjustment $\frac{1}{l}\ln\frac{1}{\sqrt{r_1r_2}} = f(\varphi)$, it is possible to predict the fitness of a given sample of active material for work in a generator with a revolving prism and to determine for a given OKG the speed of rotation of reflector necessary to generate a monopulse.

The strong dependence of threshold energy of pumping on unparallelism of reflectors of resonator for neodymium OKG (curve 1, Fig. 3a) indicates that optical heterogeneity of neodymium glass turns out to be too small to essentially disturb the plane-parallelness of the resonator. For a generator with a ruby rod (curve 2), dependence of threshold pumping energy on angle ϕ turns out to be weak enough, especially within angular limits up to 1'. If for a neodymium OKG in this interval, the threshold pumping energy is changed more than twice, then for a ruby this change is only a few percent. Placing an optically nonuniform ruby rod into a plane-parallel resonator, we transform the latter into a resonator with reflectors with a curvilinear surface [6]. If the optical heterogeneity of the ruby rod is such that it can be represented in the form of a lens, then the resonator should be considered spherical. It is obvious that this is the cause of divergence of theoretical [7-8] and experimental [9] results on study of dependence of power of generation on angle of adjustment of reflectors of plane-parallel resonator. In Fig. 5 there is represented such a dependence. Theoretical curve 1 was calculated for a resonator with flat mirrors inside which there is placed an optically uniform rod of active material with a matted lateral surface (open resonator).

The difference of the curves shown in the figure indicates considerable idealization of model accepted by authors as compared to practically existing solid generators. This especially pertains to generators on ruby for which model of plane-parallel resonator, during calculation of considered dependence, turns out to be of little use. In a somewhat better approach to this model, there is a generator with a neodymium glass, the optical homogeneity of which is considerably better than that of ruby. It is possible to consider that the coincidence of experimental and theoretical results for solid generators will be more satisfactory if analogous calculation is carried out for a spherical resonator.

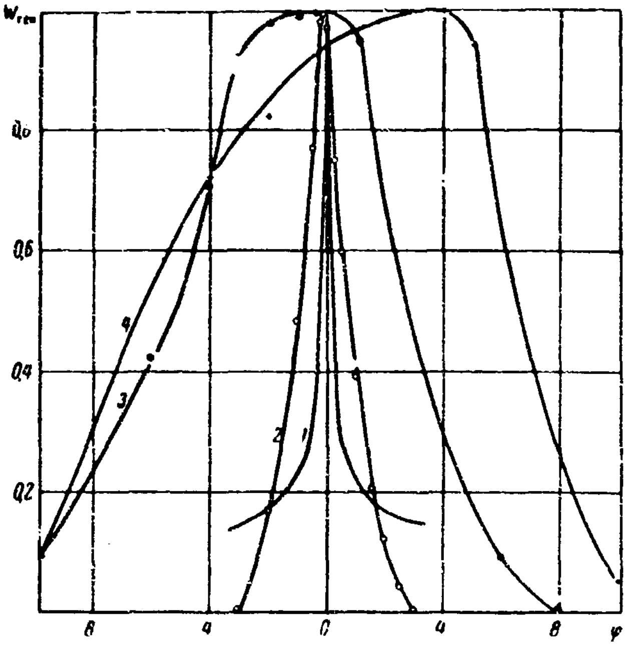

Fig. 5. Dependence of standardized power of generation $W_{ген}$ (relative to one) on the angle between reflectors of resonator ϕ (min): 1 - theoretically calculated [8]; 2, 3, and 4 - experimental correspondingly for neodymium and two ruby OKG.

Summary

It has been shown that the rate of the resonator Q-switching determinating the character of the laser radiation depends not only on the prism rotation velocity but also on the optical properties of the active substance.

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