TWO-COLOUR COAXIAL ACTIVE MEDIA ND^{3+}:YAG-RUBY FLASH LAMP PUMPED AND Q-SWITCHED OPTICAL QUANTUM GENERATOR

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Based on patented principle we develop a laser that oscillates in controllable manner simultaneously or consequently in two different spectral ranges (1.06μm, 0.694 μm). The emissions are in coaxial or/and in separated beams. In the solution two coaxially disposed Nd:YAG and Ruby crystals with different absorption spectra are pumped by a single flashlamp, thus exploiting better the pump radiation. The focusing effects by the enveloped Nd:YAG increased the pump energy density (~ 2 times) in the Ruby. We Q-switching both operations using a single frustrated total reflection Q-switcher in the common part for the two beams in the resonator. The laser construction is essentially simpler and chipper than this one of two separate lasers due to the use common pump and elements. The laser action is modeled by a rate differential equations system. The conditions for simultaneous or consequent operation with comparable output characteristics of both media are carried out.

Keywords: solid-state optical quantum generator, flashlamp pumping, simultaneous two colors operation, Q-switching

1. INTRODUCTION

Many practical applications of the lasers need of a laser light at two wavelengths, in particular, in two different colors – e.g. in differential absorption spectroscopy – in LIDAR aerosols and pollutants monitoring, in holography, in metrology, in generation of sum or difference frequencies in nonlinear optics [1]. The usefulness of such emission is essentially higher if it is in nanosecond, high power, pulses. In addition, the interest increases if the pulses can be emitted in controlled manner consequently in nanosecond intervals or simultaneously (depending on the applications). The trivial and traditional way to solve this question is to use two separate quantum generators (lasers) each producing one of needed emissions. However such realization, evidently, is expensive and complicated, especially in the case of flash lamp pumped lasers. It is necessary also to synchronize the two-excitation subsystems and to use and synchronized two nanosecond action Q-switchers. The frequently used two-wavelength emission from a single medium, especially from the dye, F-color centers, semiconductors etc. is limited in a single color range [2-4].

In the report we present further development of our previously patented [5] technique for nontraditional and effective solution of the question to produce in a simple and chipper manner two laser emissions with different colors and with independent spectral and temporal control of each of them.

The principle [5] of our original system relates to use a complex active element composed by two closely coaxially disposed active media with different absorption spectra that overlap the emission spectrum of the pumping lamp. We describe here a realization that uses as active medium a coaxial combination of Nd:YAG (absorption around 0.81 um) and Ruby (absorption around 0.48 nm and 0.53 nm) crystals . The system presents few main advantage in comparison with the use of two separate lasers: i) the laser construction is essentially simple and cheaper using a single flashlamp-electrical supply pump system and mechanics ii) the efficiency is increased due to the more effective use of the pump lamp radiation iii) the two color emissions with nanosecond duration can be emitted temporally in all optical controlled manner – simultaneously or consequently. The laser output can be taken in a single beam (closely coaxial beams) or/and in spatially separated beams.

The laser action is modeled by a rate differential equations system. By numerical investigations we have studied the action of the systems and have carried out the conditions for effective operation, including all optical controlled consequent or simultaneous emissions in Q-switched mode at the two colors with comparable output energies and powers. Our investigations prove a statement true and give the conditions of practical realization of such very useful quantum generator.

2. BASIC LASER CONSTRUCTION –SCHEME AND PRINCIPLE OF THE ACTION

The schematic of our system is plotted in Fig.1. The construction is clear from the given notation in the figure. The 10 cm long Ruby crystal, cut in one end at a Bruster's angle, with diameter **2a** of 0.3 cm is placed in the convenient 0.3 cm bore diameter hole in Nd:YAG laser crystal with external diameter **2A** of 0.8 cm and length *l* also of 10 cm. The active media operate in flat-flat mirrors complex resonator (in practice two coaxially disposed resonators). They have a common coaxial part for both beams from the perpendicular cut side of both crystals, with placed frustrated total reflection Q-switcher with switching time of 0.4 μs. From the end side, due to the Brewster's end of the Ruby crystal and the perpendicular end of the Nd:YAG the axes of the two resonators are completely separated in the space. Each is closed by proper end mirror – M_2 (Nd:YAG) and M_3 (Ruby) respectively with an

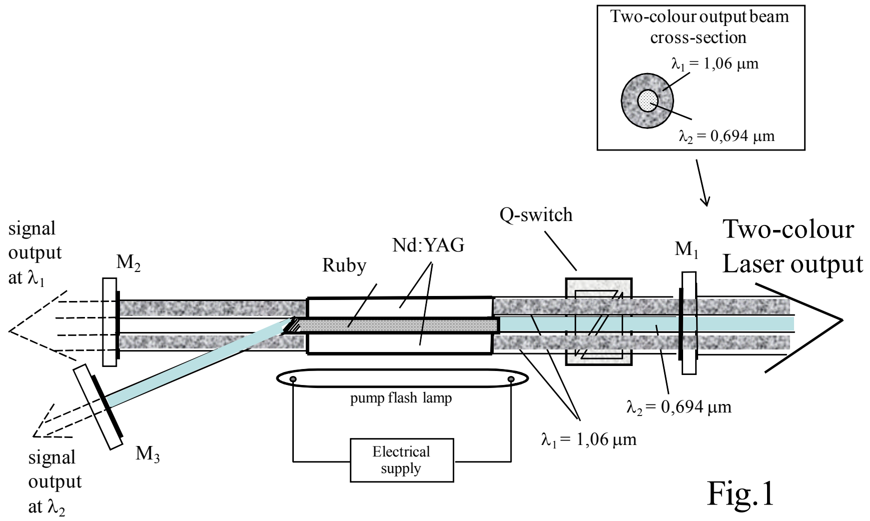

Fig.1

approximately 5 % transmission to produce a separate signal output at each wavelength. These two mirrors, with conveniently chosen transmission can be used also to form two spatially different outputs for the two wavelengths. The coaxial front part is closed by the common flat mirror– M_1 which can be with different chosen reflectivity for each emission (0.6 for Ruby and 0.75 for Nd:YAG). From this mirror is taken the two-wavelength laser output in closely coaxial beams for the two wavelengths. This construction of the complex bi-channel resonator is naturally very useful, permitting the effective independent control of each generation by varying the mirrors reflectivity, the losses and the length of each channel (L_1 –Nd:YAG and L_2 - Ruby). The complex laser element and the single pump flashlamp are disposed in the focal lines of the elliptical pump chamber. The lamp is connected with electrical supply and electronic control-synchronizing subsystem with the Q-switcher. The optical pump pulse shape is approximated well with trapezium with leading front of 100 μs, plateau of 100 μs and failing front of 300 μs. The Q-switch opening is at 520 μs after the starting of the pump pulse.

Focusing effect and improvement of the Ruby crystal pumping

Firstly, following Ref. 6, we must take into account the focusing effect in our complex cylindrical laser element. From this Reference we can take the pump energy density *ρ(r)* as a function of distance *r* from the active road axis. In our case the external Nd:YAG part of the element does not absorb the pump light for the Ruby. In this condition, the dependence *ρ(r)* that is valuable for the considered by us element, taken from Ref. 6, are shown in Fig. 2. We have found that the shown curve can be very closely approximated by the exponential curve. The found by us approximation is:

$$\rho(r) = 3\rho_o\, e^{-\frac{r^2}{A^2}\cdot \ln 3} \qquad (1)$$

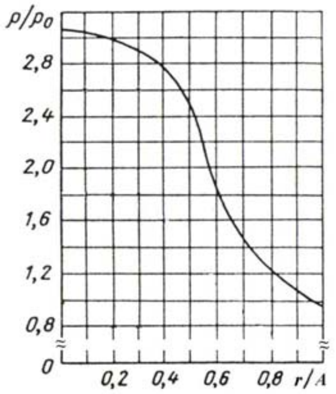

Fig.2 (from Ref. 6)

Using (3) we can calculate the parts of the absorbed energy in the Ruby and in the Nd:YAG volume respectively. The absorbed in the Ruby volume part E_{Cr} is given by the integral (φ is the angle in the active medium cross section):

$$E_{Cr} = \int_0^a \int_0^{2\pi} \int_0^l \rho(r)\, r\, dr\, d\varphi\, dl \qquad (2)$$

The total incident pump energy E_{tot} for the Ruby is given by:

$$E_{tot} = \int_0^A \int_0^{2\pi} \int_0^l \rho(r)\, r\, dr\, d\varphi\, dl \qquad (3)$$

Using (1), (2) and (3) we can found the energy in the Ruby volume:

$$E_{Cr} = E_{tot} \cdot \frac{3}{2}\left[1 - \exp\left(-\ln 3 \cdot a^2 \cdot A^{-2}\right)\right] \tag{4}$$

In our consideration we can accept that the diameter of the flash-lamp and of the Nd:YAD road are conveniently chosen that all pumped light is focused into the crystal diameter [6]. Using (4) we can calculate for the our experimental conditions that the pump energy density increases in Ruby of about two times by the focusing effect of the enveloped Nd:YAG crystal. We can calculate also the fraction of the energy at the absorption wavelengths in Nd:YAG volume as total pump energy at the absorption band of the Nd:YAG minus the energy, losses in the hole for the Ruby . The pump energy for E_{Nd} is given by : $E_{Nd} = E_{tot} - E_{Cr}$.

Using E_{Cr} and E_{Nd} and the given above pump pulse shape we can calculate the pumping rates [7] for the Ruby $R_p^{Cr}(t)$ and for the Nd:YAG $R_p^{Nd}(t)$ as a function of the time *t*. Thus we are able to analyze the proposed laser output parameters as a function of the pump parameters, active laser elements and laser resonator parameters. For the treated by us case (electrical pump energy of ~150 J) we use a typical spectral distribution for flashlamp pump energy, given in Ref. 6. Taken into account the coefficients of transformation and transmission of the energy that pump the complex element, we have estimated that the optical pump energies are approximately $E_{Cr} = 6$ J and $E_{Nd} = 8.5\ J$.

3. INVESTIGATION OF THE LASER ACTION. COMPUTER SIMULATION AND CONDITIONS FOR DESIRED SYSTEM OPERATION

We modeled the action of the proposed complex laser by adapting the set of the differential rate equations for describing the laser operation [7]. The Nd:YAG laser is treated as a four-level system and the Ruby –as a tree levels. We can write:

For Nd:YAG part

$$\begin{aligned}
&\frac{dN_2^{Nd}}{dt} = R_p^{Nd}(t) - B_e^{Nd} \cdot N_2^{Nd} \cdot q^{Nd} - \frac{N_2^{Nd}}{\tau^{Nd}} \\
&\frac{dq^{Nd}}{dt} = B_e^{Nd} \cdot N_2^{Nd} \cdot q^{Nd} \cdot V_a^{Nd} - \frac{q^{Nd}}{\tau_c^{Nd}} \\
&N_t^{Nd} = N_2^{Nd} + N_g^{Nd}
\end{aligned} \tag{5}$$

For Ruby part

$$\begin{aligned}
&\frac{dN_2^{Cr}}{dt} = R_p^{Cr}(t) - B_e^{Cr} \cdot N_2^{Cr} \cdot q^{Cr} + B_a^{Cr} \cdot N_2^{Cr} \cdot q^{Cr} - \frac{N_2^{Cr}}{\tau^{Cr}} \\
&\frac{dN_g^{Cr}}{dt} = -R_p^{Cr}(t) + B_e^{Cr} \cdot N_2^{Cr} \cdot q^{Cr} - B_a^{Cr} \cdot N_2^{Cr} \cdot q^{Cr} + \frac{N_2^{Cr}}{\tau^{Cr}} \\
&\frac{dq^{Nd,Cr}}{dt} = \left(B_e^{Cr} \cdot N_2^{Cr} \cdot V_a^{Cr} - B_a^{Cr} \cdot N_2^{Cr} \cdot V_a^{Cr} - \frac{1}{\tau_c^{Cr}} \right) \cdot q^{Cr}
\end{aligned} \tag{6}$$

$$N_t^{Cr} = N_2^{Cr} + N_g^{Cr}$$

Here the exponent indices *Nd* and Cr are for Nd:YAG and for the Ruby ($Cr^{3+}Al_2O_3$), respectively. In the systems is noted : with $N_2^{Nd,Cr}$ - the population of the upper laser level per unit volume in both media, with $q^{Nd,Cr}$ – the generated photons, $B_e^{Nd,Cr} = \left(\sigma_e^{Nd,Cr}.l.c\right)/\left(V_a^{Nd,Cr}.L'^{\,Nd,Cr}\right)$ and $B_a^{Cr} = \left(\sigma_a^{Cr}.l.c\right)/\left(V_a^{Cr}.L'^{\,Cr}\right)$ [s^{-1}], where $\sigma_e^{Nd,Cr}$, σ_a^{Cr} are the emission and absorption cross-sections, respectively (2,8.10^{-19} cm^2 - Nd; em. 2,5.10^{-20} cm^2 – Cr^{3+}, abs. 1,22.10^{-20} cm^2 – Cr^{3+}); $V_a^{Nd,Cr}$ - the working volumes (4,3 cm^3 - Nd, 0,7 cm^3 - Cr); c=3x10^{10} cm/s is the light velocity; $L'^{Nd,Cr} = L^{Nd,Cr} + (n^{Nd,Cr} - 1)\cdot l$ - the optical length of the Nd:YAG and Ruby resonators, *l=10 cm* is the length of the active media, $n^{Nd,Cr}$ - the corresponding refractive indices and $L'^{Nd,Cr}$ are respectively 26 cm – Nd and 28 cm – Cr (the specially chosen values, see below; variable in the investigations) The time members $\tau^{Nd,Cr}$ of 0,23 ms and 3 ms, respectively are the lifetimes of the upper laser level for Nd:YAG and the Ruby. The dumping time of a photon in the resonator is $\tau_c^{Nd,Cr} = L'^{\,Nd,Cr} / \left(c.\gamma^{Nd,Cr}\right)$, where $\gamma^{N,dCr}$ [7] describes the loss in the resonators for the two media, respectively - variable in the investigations, depending on the reflectivity of the resonator mirrors and cavity lengths [7].

From the given two equation systems, by varying the two resonators parameters and the pump energy we have show that all declared useful possibilities of the system proposed can be completely realized with very realistic in practice construction. The given parameters in the description above of our quantum electronics devices are specially chosen after series of calculations. These group of parameters assure a completely time overlapping of both generated nanosecond pulses and as addition - with near equal peak powers. We considered only the common coaxial-beam two-wavelength output. In Fig. 3 is shown the two computed giant pulses, generated by both media for the described case. For other pear of resonator lengths – L_1=45 cm and L_2= 26 and the slowly decreased pump energies (7 J – Nd, 5 J - Cr) and Q-switch opening after 400 us the pulses are emitted in nanosecond consequences as it is shown in Fig 4. The parts, emitted from the other end outputs are quiet different and not considered here (the treatment is in completely similar manner, if this outputs are of interest).

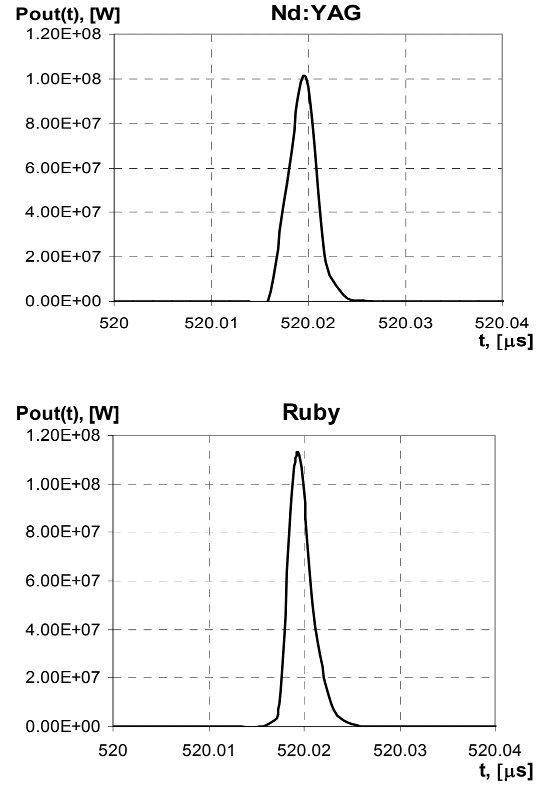

Fig.3

4. CONCLUSION

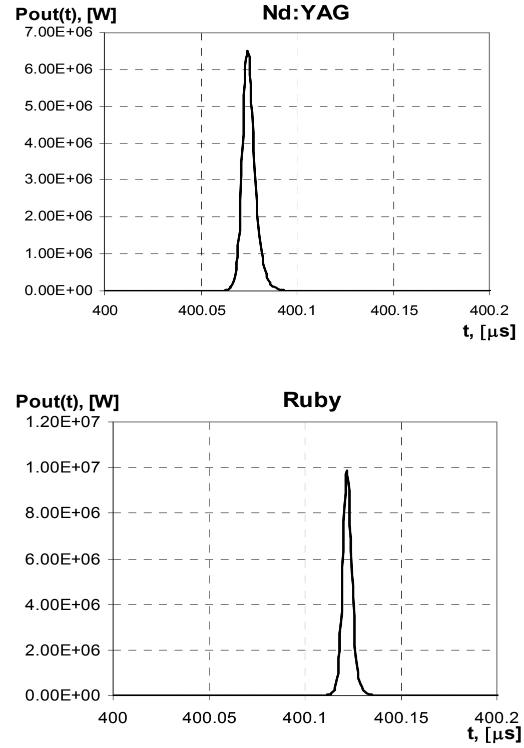

Fig.4

In this work we have described an original quantum electronics system that can emits in all optical controlled manners – simultaneously or consequently, nanosecond laser pulses at two different colors – in IR - 1.06 µm (or 1.33 µm) and in Visible - 0.6943 µm (or 0.6929 µm). The special solution, based on the coaxial constructed elements that combined Nd:YAG and Ruby Crystals permits to obtain the two color emissions in single output beams (coaxially disposed) or/and in completely spatially separated beams. The resonator permits, using a non-spectrally dependent single Q-switcher (e.g. frustrate total reflection type) to modulate both media operation and by independently chosen resonator parameters to obtain all optically the noted control. Except, that our solution present the essential technical advantages – more simple and chipper that two separate lasers, the elimination of complex synchronization in the nanosecond range, the system uses more effectively the flashlamp pump energy and increases the pump energy density in the internal active media. In our investigations, presented here we have shown the feasibility of the device and the realistic system parameters for obtaining all noted advantages. The system proposed can be very useful when the combination of two lasers light is necessary (marked in the Introduction).

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