A NEW FLASH LAMP PUMPED AND Q-SWITCHED ND:YAG OPTICAL QUANTUM GENERATOR WITH SIMULTANEOUS LASING AT TWO COLOURS (1.06 μM AND 0.94 μM)

Plamena Tihomirova Todorova[1], **Margarita Angelova Deneva**[1],
Marin Nenchev Nenchev[1, 2]

[1]Department of "Optoelectronics and Laser engineering", Technical University-Sofia, Branch Plovdiv, "St.Peterburg" 61, 4000 Plovdiv, Bulgaria, e-mail: deneva@tu-plovdiv.bg

[2] Institute of electronics, Bulgarian Academy of Sciences, "Tcarigradsko shausse" 72, 1784 Sofia, Bulgaria

We develop a Nd:YAG laser that oscillates in controllable manner simultaneously or consequently in two different spectral ranges (1.06μm, 0.94 μm) and without the wavelength competition problem. The emissions are in coaxial or/and in separated beams. In our solution two different, coaxially disposed parts of Nd:YAG crystal, operating in convenient resonator arshitecture produce both emission. The focusing effects in Nd:YAG increased the pump energy density (~ 2 times) in the central part which emits at 0.94 μm. Both operations are Q-switched 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 flashlamp, electrical supply , Q-switcher and mechanical 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, Nd:YAG, flashlamp pumping, simultaneous two colors operation, 1.06 μm and 0.94 μm, Q-switching

1. INTRODUCTION

Many practical applications of the lasers need of a radiation 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 reported and 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 of the proposed in the work original quantum-electronics generator relates to use a two closely coaxially disposed parts of the single Nd:YAG laser crystal in a single laser system and in convenient resonator architecture to operate at the two most interesting wavelength - 1.06 um and 0.94 um (after frequency doubling – green and bleu colors). The Q-switching is achieved using a convenient Q-switcher, operating simultaneously for both colors – based on frustrate total reflection. The laser proposed 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 use of a single, convenient, Q-switcher, avoiding a very complex synchronizations for the separate lasers 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

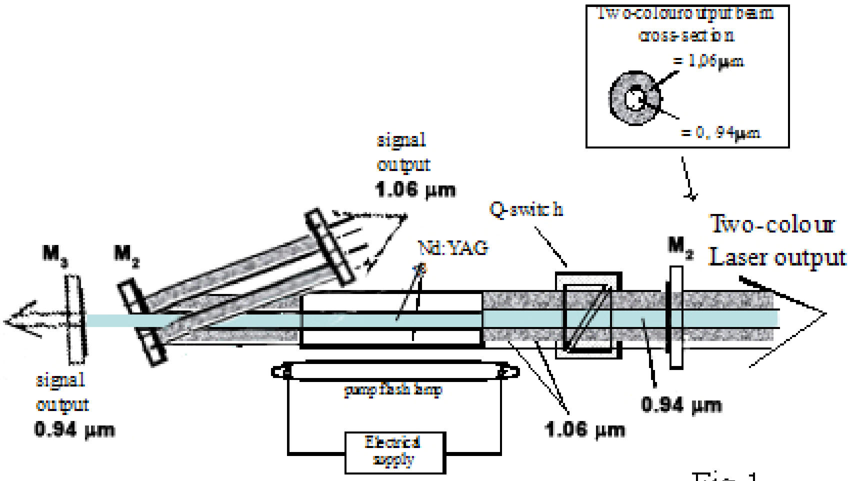

Fig.1

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 Nd:YAG crystal with diameter of 6 mm, is placed in the pump chamber and pumped by a flashlamp and traditional electrical supply. The active media operate in the optical resonator architecture that in special manner combined two laser resonators. In the given variant we use a flat-flat mirrors complex resonator (in practice two coaxially disposed resonators). The resonator part (1-st partial resonator for generation at 1.06 um) is formed by the front mirror M_1, the intermediate totally reflecting mirror M_2 with hole of 3 mm , centered at the Nd:YAG crystal axis and end mirror M_4 (R ~ 0.98). The second resonator part for generation at 0.94 μm– a simple falt-flat resonator, consists of the common for both resonator mirror M1 (with different reflectivity for the two colors; the more appropriated can be calculated below) and the mirror M_3 with a reflectivity of ~ 99 % . The two resonators have a common coaxial part for the two beams from the output side (to common mirror M_1), with placed there frustrated total reflection Q-switcher with switching time of ~ 0.1 – 0.5 μs. From the end side, the axes of the two resonators are completely separated in the space. The mirrors M_3 and M_4, with conveniently chosen transmission, can be used also to form two spatially different outputs for the two wavelengths. The two-wavelength laser output in closely coaxial beams for the two emissions is taken from the common mirror M_1. 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 –for 1.06 um and L_2 - for 0.94 um). The Nd:YAG laser crystal and the 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 200 μs and failing front of 300 μs. The Q-switch opening is at 500 μs after the starting of the pump pulse.

Focusing effect and increasing the crystal central part 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 typical condition for the Nd:YAG lasr crystal [6], the dependence *ρ(r)/ ρ*$_0$*(r)* that is valuable for the considered by us element, taken from Ref. 6, are shown in Fig. 2. (the curve with the points). We have found that the most convenient approximation (thick line in the figure) of this curve is by:

$$\Rightarrow \rho\left(\frac{r}{R}\right)=\left[0.3\cdot\left(\frac{r}{R}\right)^{8}-1.7\cdot\left(\frac{r}{R}\right)^{2}+1.9\right]\cdot\rho_0 \qquad (1)$$

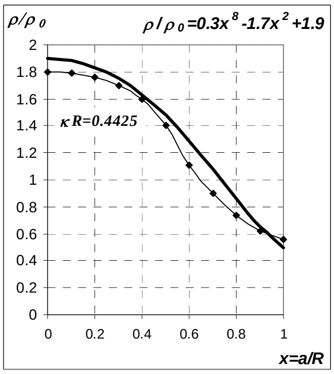

Fig.2

Using (1) we can calculate the parts of the pump energy in the central part of the crystal with a radius r that is generate the emission at λ = 0.94 μm and in the all Nd:YAG volume respectively –with radius R . We accept that all the incident energy is absorbed. The absorbed in the central part energy $E_{0.94\,um}$ (noted as E_{Cr}) is given by the integral (φ is the angle in the active medium cross section, l –the length of the crystal, a – the current value of the radius):

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

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

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

Using (1), (2) and (3) we can found the energy in central part of the crystal-in the volume for generation at λ = 0.94 μm:

$$\Rightarrow\ E(0 \div r) = 2\pi l \cdot \rho_0 \cdot \left(0.03 \cdot \frac{r^{10}}{R^8} - 0.425 \cdot \frac{r^4}{R^2} + 0.95 \cdot r^2 \right) \tag{4}$$

with E_{tot} given by: $$E(0 \div R) = 1.11 \cdot \pi l \cdot R^2 \cdot \rho_0 \tag{5}$$

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 increased of about two times by the focusing effect of the enveloped Nd:YAG part. We can calculate also the fraction of the pump energy in Nd:YAG part for generation at λ = 1.06 μm ($E_{1.06\ um}$) as a total pump energy at the absorption band of the Nd:YAG minus the pump energy that is absorbed in the volume for generation at λ = 0.94 μm: $E_{1.06\ um} = E_{tot\bullet} - E_{0.94um}$

Using $E_{1.06\ um}$ and $E_{0.94um}$ and the given above pump pulse shape we can calculate the pumping rates [7] for the generation at each wavelength 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.

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]. For the generation at

1.06 um the Nd:YAG laser is treated as a four-level system and for the generation at 0.94 um – as a tree levels. We can write:

For λ = 0.94 μm part

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

For λ = 0.94 μm part

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

Here the exponent indices *Nd* and Cr are for generation at λ = 1.06 μm and for at λ = 0.94 μm, 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. At λ =1.06 um, and abs. 4.10^{-20} cm^2 for λ = 0.94 um); $V_a^{Nd,Cr}$ - the working volumes; 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 resonators for generation at 1.06 um and for 0.94 um – variable in the investigations, *l=10 cm* is the length of the active media, $n^{Nd,Cr}$ - the corresponding refractive indices a. The time members $\tau^{Nd,Cr}$ of 0.23 ms is the lifetimes of the upper laser level for Nd:YAG. 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.

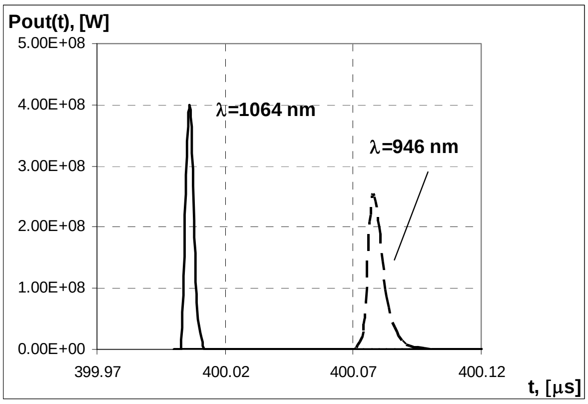

Fig.3. Generation in sequence

($E_{1.06um}$=7.2 J, $E_{0.94\ um}$=22.8 J, 2R/2r = 8/6 mm $L_{1.06}$ um/L0.94 um =60/40 cm)

We found that for the total optical pump energy of 30 J (~150 J electrical energy) ,the optical length of the resonator for generation at 0.94 um of 20 cm and of the resonator length of 1.5 m for generation at 1.06 um and 0.98 and 0.8 reflectivity of the otput mirror for each wavelength respectively, we can obtain the giant pulses with a comparable power for the two wavelengths. In this case the pulses are in sequence with a delay (for 0.94 um generation) of ~ 100 ns.This case is shown in Fig. 3. By varying the resonator length for generation at 1.06 um around the given value we can obtain different delay between the pulses. When the resonator lengths for 1.06 um is chosen to be 2 m the two generated giant pulses overlap in time as it is shown in Fig. 4.

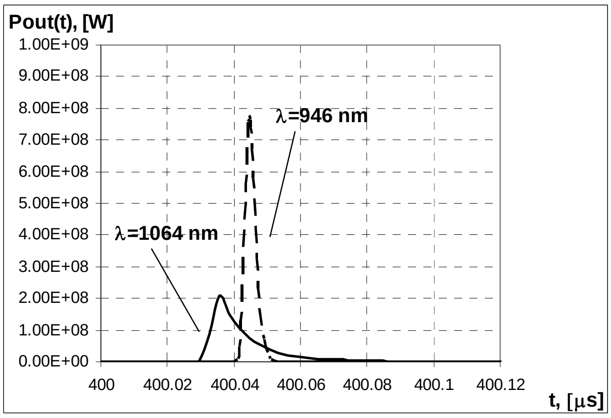

Fig.4. Simultaneous generation

($E_{1.06um}$=7.2 J, $E_{0.94\ um}$=22.8 J, 2R/2r = 8/6 mm $L_{1.06}$ um/L0.94 um =300/20 cm)

4. CONCLUSION

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 and in - 0.0.94 μm (after doubling – green ,0.53 um and bleu – 0.47 um). The special solution, based on the coaxial used parts of the Nd:YAG 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 produce high power (~ MW) laser pulses. Our solution presents the essential technical advantages – more simple and chipper that two separate lasers, the elimination of complex synchronization in the nanosecond range. 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).

The work is supported by Technical University-Sofia, Br. Plovdiv (Cont. n 08029i- ни -17 2007)

5. REFERENCES

[1] Demtreder W., *Laser spectroscopy: Basic concepts and instrumentation*, New York, 1982.

[2] Nenchev M., M. Meyer, *Two-wavelength Dye-Laser Operation Using a Reflecting Fizeau Interferometer,* Appl. Phys. 24, 1981, pp. 7-9

[3] Gorris-Neveux M., M. Nenchev, R. Barbe and J. Keller, *A two-wavelength, passively self-injection locked, CW Ti:Al_2O_3 laser*, IEEE J. Quantum Electron**,** USA Vol.31, 7, 1995, pp. 1253-1260.

[4] Louyer Y., J. P. Wallerand, M. Himbert, M. Deneva and M. Nenchev, *Two-wavelength passive self-injection-controlled operation of diode-pumped cw Yb-doped crystal lasers*, Appl. Optics**,** USA Vol. 42, Sept. Issue, 2003, pp. 4301-4315.

[5] Nenchev M., *Multicolor laser*, Bulg. Patent No 25954/1978 (reg.06.01.1976).

[6] Mikaelian A., M. Ter-Mikaelian and K. Turkov**,** *Solid-State Optical Generators*, Moscow, ed.Sovetskoe Radio, 1967.

[7] Svelto O., *Principles of lasers*, 4^{-th} ed., Plenum Press, New York and London, 2002