A SIMPLE TWO-WAVELENGTH LASER EMITTING IN SUCCESSIVE NANOSECOND PULSES

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We have shown that the laser, emitting at two independently tunable wavelengths in sequent nanosecond pulses can be created using a passive technique with a bleaching absorber. We have modeled the action of such oscillator and have shown that for conveniently chosen conditions such operation can be obtained. The operation is in original simple and high efficient two-channel resonator. The technique considered simplifies essentially the laser construction. The lasers of such type are of interest for application in simplified differential absorption systems for ecological control and in scientific investigations.

1. INTRODUCTION.

In the present work we propose and investigate an original and very simple for realization solution of two-wavelength laser that produces successive emissions at both wavelengths in nanosecond pulses during a single pump pulse. The wavelengths are independently tuned. The two-wavelength lasers [1-2] are the base for realization of ecological monitoring systems (detection of SO_2, NO_2 etc.), for isotope separation techniques, for scientific applications. The possibility of our laser to emits of both wavelengths in successive nanosecond pulses makes it very useful for applications in the noted fields in the cases where the space under investigation change quickly in times e.g. for explosion processes, for high speed motion of the part of space under investigation. The pulse generation in successive pulses permits to simplify essentially the receiver and computer – treatment system using single devices for acceptance and treatment of both pulses. In the use actually are the system of this type with active switching of the two wavelengths what, taken into account the nanosecond time for the control, makes them very complex and expensive.

2. TWO-WAVELENGTH LASER DESIGN.

The two-wavelength laser proposed is based on the use in an original two-channel cavity switching of the lasing in both channels automatically, by passive filter that its transmission is changed by the firstly started generation in one of the channels. The initial conditions are chosen so that the lasing start firstly in the channel without the

filter and this lasing provides itself bleaching of the filter. The bleaching of the filter leads to more favorable conditions for generation in the channel with the filter. Due to the strong wavelength competition and appropriately chosen initial conditions this generation provides stop of the lasing in the other first channel, thus assuring the switching of the wavelength in nanosecond time scale. The laser uses an original two-channel resonator (Fig.1) in which a single interference wedge IW_1 [1-2] is element both for frequency selection and for resonator channels coupling. The flat common output mirror M_1 (R_1=0.1, variable), IW_1 and the mirror M_2 (R_2=0.9, variable) compose the first resonator channel tuned at λ_1. The second channel (tuned at λ_2) uses

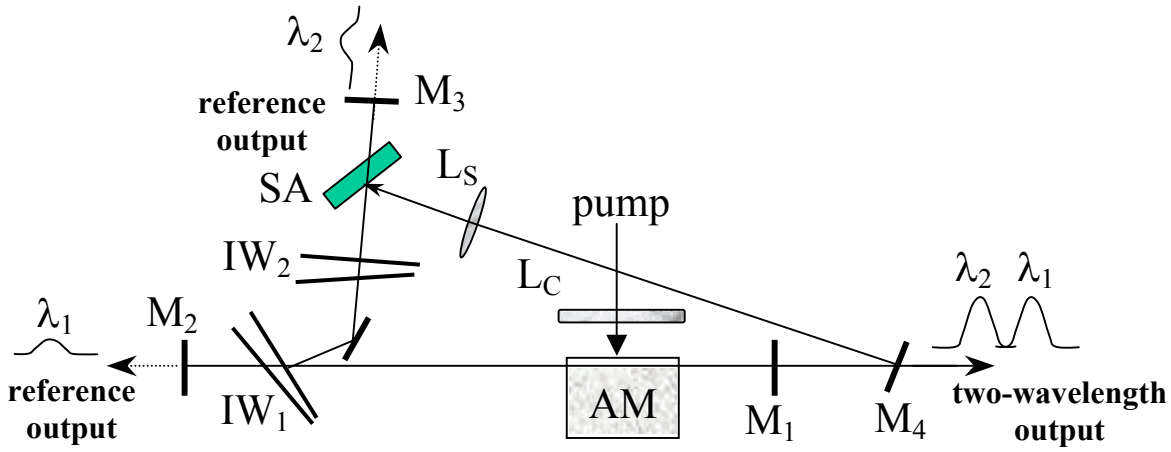

Fig. 1. Optical set-up for producing of two wavelengths in successive pulses.

M_1, IW_1 as an intermediate mirror, IW_2 as a tunable selector and the end mirror M_3 (R_3=0.9, variable). The resonance transmission maximums at the used wedges are at ~ 30 nm with bandwidth of the transmission of ~ 0.3 nm and maximal transmission of ~ 0.8 (IW_1, variable) and 0.85 (IW_2). In the example under consideration the laser active medium is the ethanol solution of Rhodamine 6G (5.10^{-3} mol/l) filled in the cell with length of 1 cm and is placed in the comment part of the channel. The transversal pumping is by the 532 nm harmonic of a standard Q-switched Nd:YAG laser with length of ~ 20 ns and energy of ~ 0.2 - 0.4 mJ (variable), focalized in the AM by the cylindrical lens L_C with focal length of 5 cm. The standard saturable absorber SA for the Rh6G laser (with initial transmission of e.g.~ 15% and saturation intensity I_s=1MW/cm^2) is placed in the second channel as a commutation element. The Q-factor of the first channel is chosen (by mirror alignment, or by mirror and IW_1 reflectivity variation) to be initially higher than this one in the second channel with non-saturated SA. The part of the output laser beam (trough the mirror M_1) is directed by a partially transmissive mirror M_4 to bleaching SA. This beam is focused into SA approximately at the direction of resonator axes by the spherical lens L_E with focal length of 6 cm in spot area S_e (~ $4x10^{-4}$cm^2). As we have shown, in the typical case with arbitrary chosen laser and pump parameters, the laser produces emission only in one of the channels, i.e. at a single wavelength or two generations in every

channel respectively at different wavelength, given by IW_1 and IW_2 adjustment, but at superimposed pulses. Contrary, by appropriately chosen conditions from the theoretical consideration the laser can operate exactly at the desired mode – to produces emissions at two wavelengths in successive nanosecond pulses. In the last case a few nanoseconds after the start of the generation at λ_1 the SA is bleached and the emission in the second channel appears and completely suppresses the emission at λ_1. Both wavelengths are emitted in a completely superimposed beam trough the M_1 as a main laser output and separately as a reference outputs trough M_2 and M_3, respectively.

3. INVESTIGATION OF THE LASER ACTION.

Modeling and theoretical description

The laser operation is treated on the base of differential rate equation system [2,3] that is conveniently adapted to describe our experimental condition. The adapted system is:

$$\left|\begin{array}{l} \dfrac{dN}{dt} = W_P(t)\cdot N_t - (B_1\cdot q_1 + B_2\cdot q_2)\cdot N - \left[W_P(t) + \dfrac{1}{\tau}\right]\cdot N \\ \dfrac{dq_1}{dt} = \left[B_1\cdot V_a\cdot N - \dfrac{1}{\tau_{c_1}}\right]\cdot q_1 + \dfrac{k_1 N}{\tau} \\ \dfrac{dq_2}{dt} = \left[B_2\cdot V_{a_2}\cdot N - \dfrac{1}{\tau_{c_2}}\right]\cdot q_2 + \dfrac{k_2 N}{\tau} \end{array}\right.$$

$$\tau_{c_2} = \frac{L_2}{c}\cdot\left[\left(\gamma_1 - \ln\left(R_3\cdot T_{IW_2}^2\cdot\exp\left(-(\alpha_0 l_a)/(1+\frac{I}{I_s})\right)\right)\right)/2 + \gamma_i\right]^{-1}$$

$$I = \frac{R_4\cdot\gamma_1\cdot c^2\cdot h}{2L_1\cdot\lambda_1\cdot S_e}\cdot q_1(t) + \frac{c^2\cdot h}{2L_2\cdot\lambda_2}\left(\frac{R_4\cdot\gamma_1}{S_e} + \frac{1}{S_i}\right)\cdot q_2(t)$$

Here $N(t)$ is the population inversion per unit volume for the active medium. N_t is the total number of the dye molecules per unit volume, which in our computation is equal to $6\text{x}10^{17}$ cm^{-3}, $B_{l,2}=\sigma_{1,2}(l_{1,2}).l_{1,2}.c_0/V_a.L'_{1,2}$, $\sigma_{21}(\lambda_{1,2})$ - the emission cross-sections, corresponding to λ_1 and λ_2, respectively ($1.85\text{x}10^{-16}$ and $1.71\text{x}10^{-16}$); $V_a = 2.7\text{x}10^{-4}$ cm^3 is the working volume of the active medium (here and below we give the values used in our experiment); c_0 is the speed of light in vacuum, τ=3 ns and $\tau_{c1,c2} = L'_{1,2}/c_0.\gamma_{1,2}$ are respectively the lifetimes of the upper laser level and of photon in the ring cavity, where $\gamma_{1,2}$ describes losses in the cavity channels. The terms k_iN_i/τ give for i=1,2 the rates of photons produced in the laser mode volume by the spontaneous emission with $k_i=6\text{x}10^{-16}$ in our case. In the system $W_P(t)$ is the pumping rate in the pulse that pumps AM. The cross section of the intracavity

generated beam in SA is S_i=4.x10^{-4}cm^2. $T_{IW1,2}$ are the transmission of the interference wedges.

Results of numerical calculation.

The system is solved numerically by the Runge-Kuta-4 method. From the solution we obtain $q_1(t)$ and $q_2(t)$ and respectively the laser output powers at λ_1 and λ_2. The calculations are made for λ_1 and λ_2 variable around 585 nm, where the dye absorption is negligible. From $q_1(t)$ and $q_2(t)$ one can determine also the length of the pulses, the pulse powers and the average output powers. In some cases, the results of the numerical solution are compared with the analytical solution of the system. The solution of the system for the described experimental condition gives an essential dependence of the moment of the switching of the wavelength by the length of the channels, the initial losses and the delay time of the optical line that can be used to obtain an optimal its value for desired laser operation. In Fig. 2 are plotted some typical calculated dependence of the output powers for both generations, obtained for non-optimized conditions for successive emission –

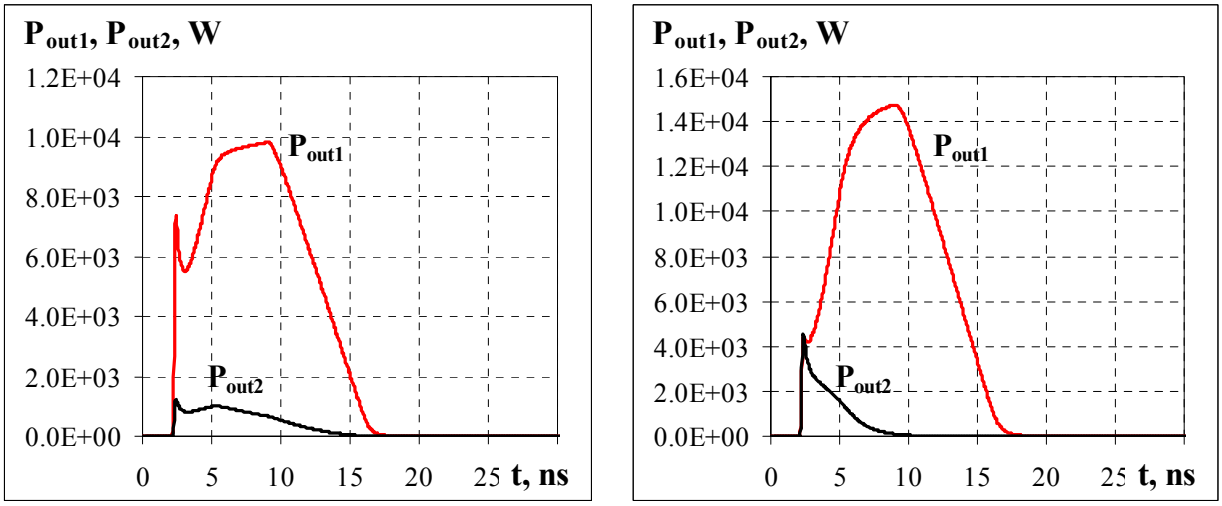

Fig. 2. Two typical cases of arbitrary chosen (non-optimized) parameters of the laser and the pumping.

i.e. for arbitrary chosen parameters of the laser and pumping. P_{out1} and P_{out2} correspond to the two wavelengths, respectively, as it is shown in Fig.1. In the calculations λ_1 =585 nm and λ_2 =583 nm. For Fig.2 (left) the channel lengths are L_1=L_2=5 cm. The pumping energy is 0.2 mJ, T_{iw1}=T_{iw2}=0.85, R_1=0.8, R_2=0.9, R_3=0.95. For Fig.2 (right) the R_1=0.7, R_3=0.9, T_{iw1}=0.75, L_1=L_2=6 cm. The generation is in overlapped pulses what limits the use a single system for treatment of the laser signals in differential absorption spectroscopy applications, including LIDAR atmospheric pollution measurement. By varying the laser parameters we have obtained the cases when the two pulses are generated well sequently, i.e. in desired mode. The curves that are shown in Fig.3 and Fig.4 illustrate these cases. The parameters for Fig.3 are: R_1=0.1, R_2=0.4, R_3=0.95, L_1=2.5 cm, L_2=4.8 cm, T_{iw1}=0.8, T_{iw2}=0.85. For Fig.3 (left) E_p = 0.2 mJ. Fig3 (right) is calculated for E_p = 0.3 mJ.

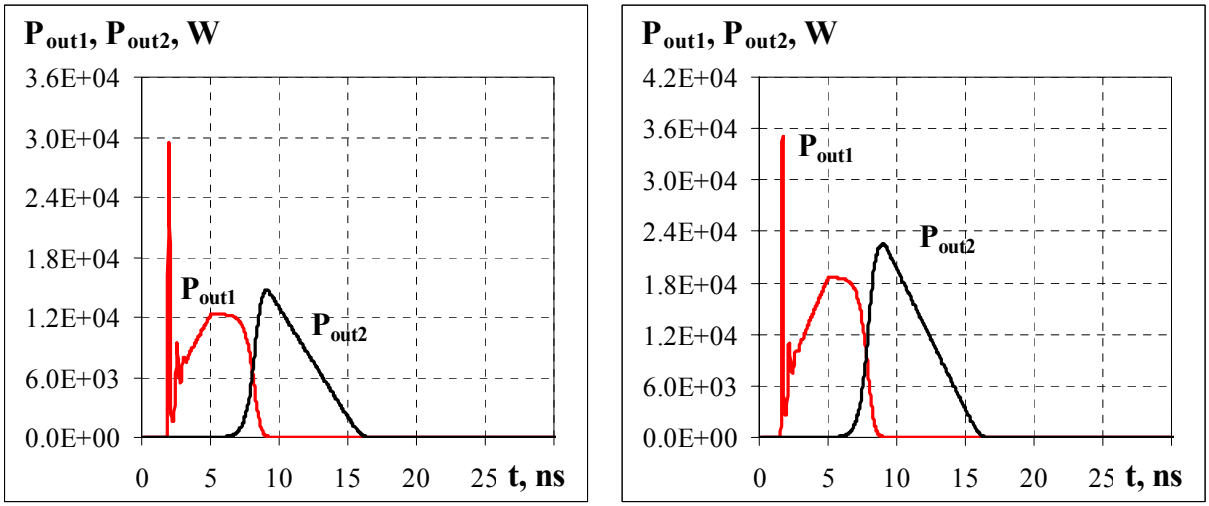

Fig. 3. The cases with conveniently chosen parameters of the channels that permit real sequent pulses operation (see the text).

The comparison of the two figures shows that for an essential fluctuation of the pump energy the desired mode of operation is retained. Fig.4 presents other case of ensemble of parameters that assures sequent operation: R_1=0.1, R_2=0.2, R_3=0.95, L_1=2.1 cm, L_2=4.8 cm, T_{iw1}=0.8, T_{iw2}=0.85. For Fig.4 (left) E_p=0.2 mJ, for Fig.4

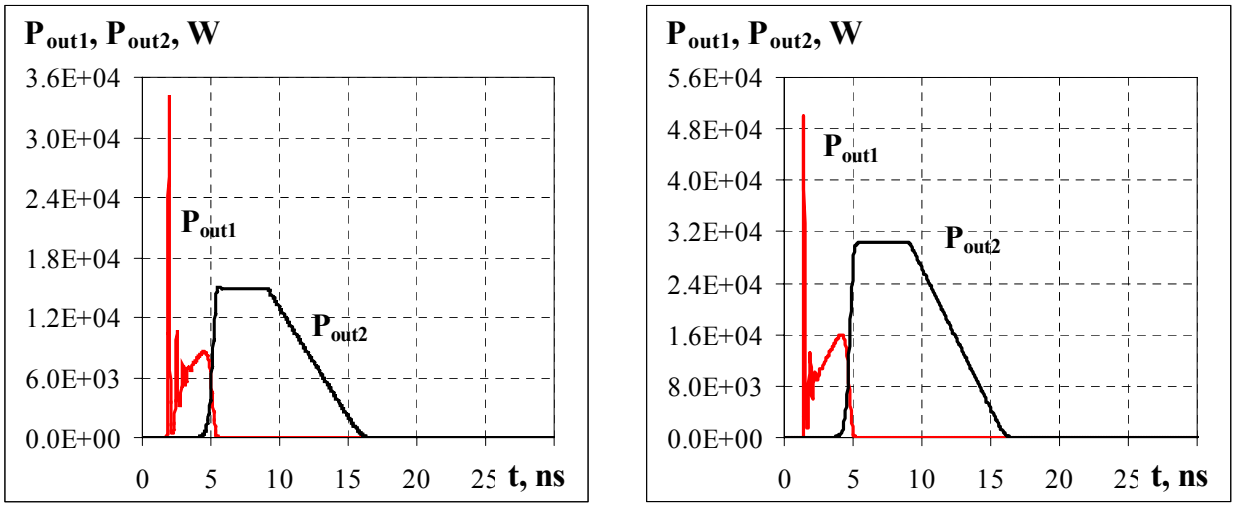

Fig. 4. Other cases of conveniently chosen parameters for sequent generation.

(right) E_p=0.4 mJ, i.e. very good reproducibility of the desired mode of operation is typical for high fluctuation of the pump energy.

The analyses show that for sufficiently large tuning of the pair of the wavelengths the operation in successive pulses can be also retained. In Fig. 5 are shown computed laser output powers (time dependences) for two pairs of wavelengths and the other

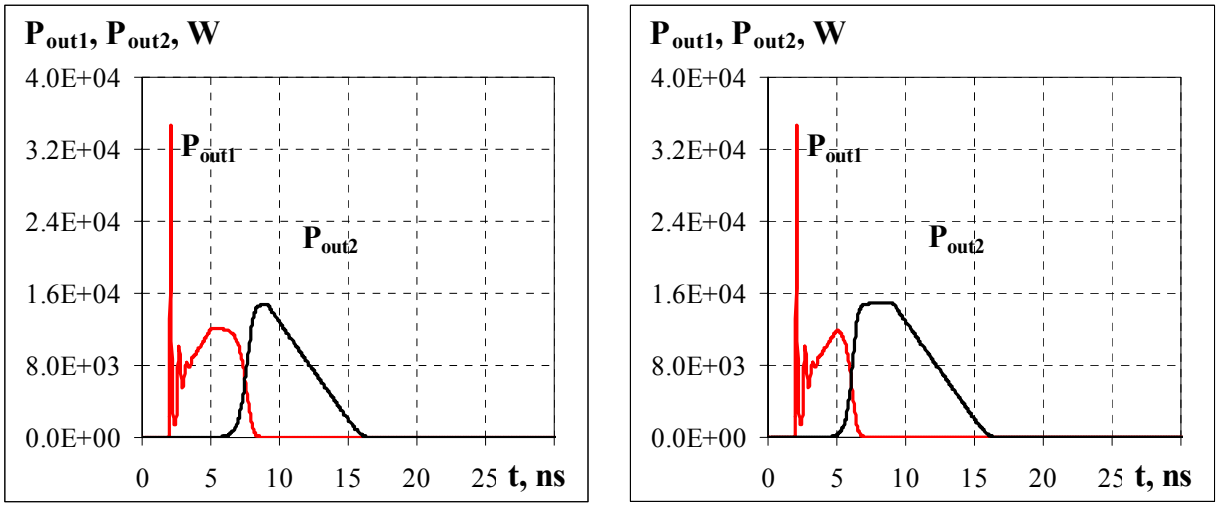

Fig.5. Tuning of the pair of the wavelengths (585 nm and 581 nm – left; 590 nm and 585 nm – right). The conservation of the desired mode of operation can be seen.

conditions: λ_1=585 nm and λ_2=581 nm (Fig.5 left); λ_1=590 nm and λ_2=585 nm (Fig.5 right).

4. CONCLUSION.

In this rapport we have proposed and demonstrate the possibility of realization of very simple and chipper two-wavelength tunable laser that emits sequent nanosecond pulses at two independently tunable wavelengths. The laser use en original two channel cavity with auto-switching of the lasing channel by use of saturable absorber. It was shown that for the appropriately chosen parameters of each channel the desired mode of operation can be obtained. The generation is in sequent pulses that permit the use a single system for treatment of the laser signals in differential absorption spectroscopy applications, including LIDAR atmospheric pollution measurement.

5. ACKNOWLEDGEMENTS

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