New Two-wavelength, Transversally Laser- pumped Laser with Improved Spatial Structure

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***Abstract* – We propose a new solution of transversal, one-side laser pumped two-wavelength laser. The proposed laser solution has as main and essential advantage the assurance of natural intensity symmetry in generated beam cross section and the facilitation of strong low-transversal mode emission – for the case of strongly non-homogeneous pumping. We present the principle, the theoretically treatment with computer analysis and also carry out basic experimental tests of our proposal.**

Keywords – two-wavelength laser, side pumped, radial homogeneous generated beams

I. INTRODUCTION

Laser light with two independently tunable wavelengths is basis for many practical methods and devices. The most important of them are: the differential absorption spectral technique for study the presence and concentration of a given substance in complex mixtures; in nonlinear mixing of two wavelengths to produce their sum and difference wavelengths; in metrology; in holography. Essential practical application is the LIDAR technique for remote sensing and control of atmospheric components, especially of the undesired pollutants such as NO_2, SO_2 [1]. The intuitive way to obtain the two wavelength laser light is to superimpose or to use in different manner the emission of two separated lasers. However, the essential drawback is that such realization needs two lasers – optics, mechanics, pumping and involves the usage of complex systems for synchronization of two nanosecond emissions. The output power P_{out}, being generally proportional to the difference between the maximum P_{pump} and the threshold P_{th} pumping power respectively [3], will decrease if such division is used (following the ratio $P_{out} \sim (P_{out}/P_{th})$-1, e.g. for operation at pumping power three times exceeding the threshold, the decrease of the output power is 2 times).

A well established, cheaper and effective way to obtain laser light at two wavelengths is to use a single laser in regime of generation of two (or more) output beams at different wavelengths, the so called two–wavelength laser [1,2]. The most suitable for this proposal are the wide gain lasers such as Dye, Titan-Sapphire, F-Color Center lasers with laser pumping carried out by additional laser. Typical important practical case of two-wavelength generation is the one-side transversally laser pumped lasers. A well-established examples are the Dye lasers, pumped most frequently by the harmonics of Q-switched Nd:YAG or Ruby lasers [4]. As a rule, the two wavelengths are generated in superimposed or closely disposed, parallel to the axes parts of two spectral-selective resonators. The common linear parts are also parallel to the input wall for the pump light. Thus, for the generation process the pumped volume is used in optimal manner. However, there are also essential drowbacks, related to the progressive decreasing of the pump light intensity in the depth of the pumped region. This leads to strong non-homogeneous amplification distribution in cross section of the generation and respectively to strong transversal non-homogeneity of the laser output beam. Some problems can be partially solved using low-absorption dye solution and by decreasing strongly the beam diameter (~ 0.1-0.2 mm). The latter leads to a very ineffective use of the pump radiation.

In this work we propose a new solution of transversal, one-side laser pumped two-wavelength laser. The consideration is on the example of laser pumped dye laser [4]. The main and essential advantage of the proposed laser solution is to naturally assure the homogeneous radial pumping of the generated beam resulting in natural intensity symmetry in beam cross section. It also strongly facilitates the low-transversal mode emission. We present the principle, the theoretical treatment with computer analysis and carry out basic experimental tests of our proposal.

II. PRINCIPLE OF THE PROPOSAL – DISCUSSION, WHAT ARE THE ADVANTAGES. EXPERIMENTAL AND THEORETICAL TREATMENT.

For simplicity and for clarity of the solution, the case of Rhodamine 6G (Rh6G) dye solution laser, pumped by the second harmonic (0.53 μm) of the Nd:YAG laser was used. The standard arrangement [5] of such laser was utilized - quartz cell with length of 10 mm filled with the Rh6G dye solution ($6x10^{-4}$ mol/l in ethanol). The pump light (~5 mJ/40 ns; 0.5 Hz rep. rate) was focused on the front cell wall with a 5 cm cylindrical lens. The focalization forms the beam in horizontal rectangular form with dimension 0.7 cm x 0.04 cm. Practically, the entire energy (~90 %) was absorbed in parallelepiped-form volume of the solution with approximate dimensions of 0.7 x 0.04 x 0.04 cm.

Following our experimental results, we have noticed a drawback concerning the spatial beam profiles when the traditional solution with the parallel propagation of the two channel axis in the pumped layer is used. That is why in our previous work [5] we have realized Rh6G two-wavelength laser, using an arrangement in which the channels of the two selective resonators are separated, one being parallel and close to the cell wall and the other – passing the active layer under a small angle (~ 10^o) using the internal

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reflection by the input cell wall. By investigating the transversal profile of the generated beams we have noted the strong difference to the common scheme and the advantage to use the declined resonator axis.

Here we will use our observation and in order to propose and develop a two wavelength laser of the described type with essentially improved beam profiles. The basic idea is to use the internal total reflection for the laser operation with conveniently declined axes of the two spectral selective resonators. Thus, as we will show, the two beams are naturally obtained with very good radial symmetry, in contrast to the parallel axes propagation is used.

As a first experimental point in the work we show the two beam profiles in the realization of the laser of the considered new type (with kinked axis). The results and the corresponding curves after computer treatment of the photographed spots are illustrated on the photograph on Fig.1. The bottom spots on Fig.1(a) and the corresponding graph on Fig.1(c) are for the generation in the channel with axis parallel to the input window (that passes through the pumped zone). The top spot and the corresponding curve in Fig.1 (b) are for the resonator with the axis using the total reflection to pass in grazing angle through the pumped volume. The improved beam profile for the second case is evident.

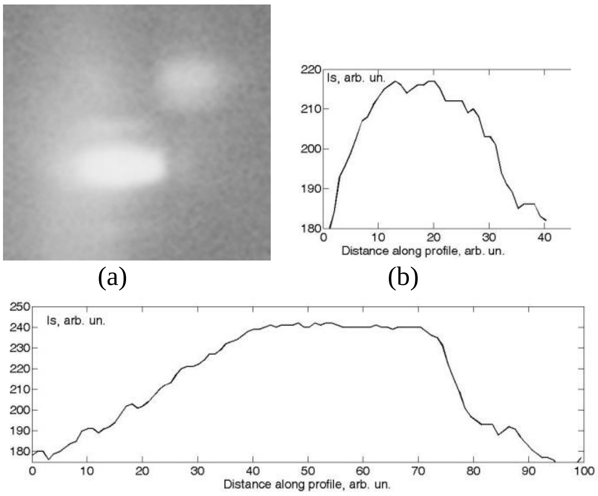


Fig.1. The actual photograph of the beam profiles (a) for generation with resonator axis parallel of the input window (bottom spot) and for grazing axis using total reflection in the wall (angle ~ 10^o , top spot), (b) and (c) gives the corresponding computer treatment - of the top spot (b) and the bottom spot (c). The natural improvement of the profile for the grazing propagation is evident.-

Based on this our two-wavelength laser realization using a grazing trajectory for one of the axes, leads us to the idea to develop the laser of the discussed type with the two axes, both kinked using the total internal reflection was considered. If the axes pass at very small angle (grazing incidence ~ 10^o) by respect to the input wall plane, the used length of the pumped region will be slightly shorter with respect to the full length and the losses will be negligible. However, the beam profiles will be with strongly improved quality. The natural principle of the beam profiles improvement for the grazing axes disposition is clarified by Fig.2.

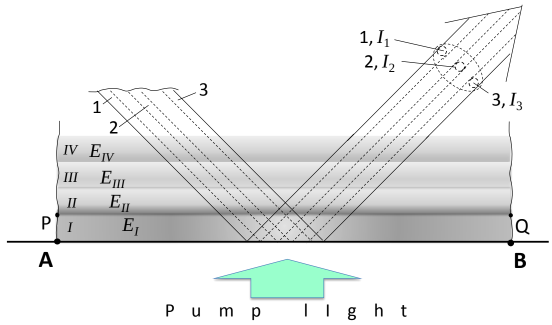


Fig.2 . To the explanation of the beam profile improvement for the grazing axis propagation using the total internal reflection.

The active medium (pumped dye solution) is presented as sequences of zones (I-IV) with different amplifications due to the pump light energy (E*i*) decreasing, due to its absorption in the active medium ($E_1 > E_2 > E_3 > E_4$). The detailed consideration of the picture shows that the arbitrary ray of any part of the formed laser beam (for example 3 rays are shown – (1), (2), (3)) passes exactly the same path. The averaged pumping conditions contribute to the equal amplification through the active medium. Thus we obtain propagation of the beam as in the homogeneously pumped active medium that is completely different in comparison with wall-parallel propagation. The given observation and the physical discussion lead to the proposal of the two wavelength laser with two grazing angle propagation axes in the active laser volume (and formed laser beams). The scheme of such laser solution, based on grazing beam propagation in the active volume, obtained by total internal reflection of the input wall, is shown in Fig.3. The concave mirror M_0 and the end mirrors M_1, M_2 are with parameters, disposition and adjustment suitable to form two optical resonators [3]. The axis of each resonator propagates in kinked manner in the active medium, using the total reflection of the glass laser cell wall (the incident angles are of order of 75^o-80^o). The Interference Wedges $IW_{1,2}$ are used as spectral selectors [6,7] in the cavities, $D_{1,2}$ are diaphragms.

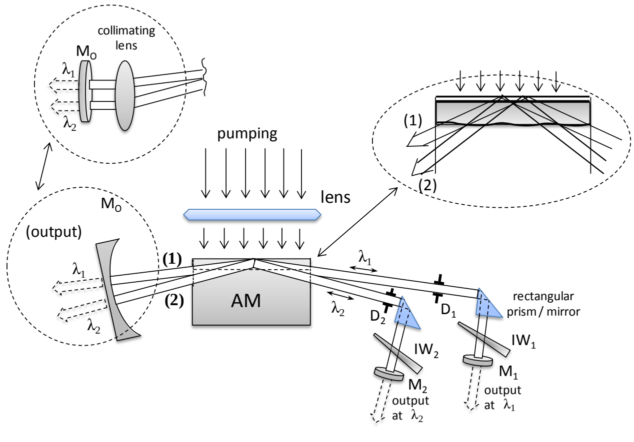


Fig. 3. The scheme of the proposed two-wavelength laser solution. AM is the Active Medium - quartz cell with dye solution. In the left inset - the formation of the output in parallel beams using the lens and a flat mirror and in the right - scheme for the explanation of the laser action.

On Fig.4 are given schematically the parts of the resonator axes and the formed beams around the places of the incident central part of the input wall of the dye cell. The axis and the formed beam are noted as (1) and (2).

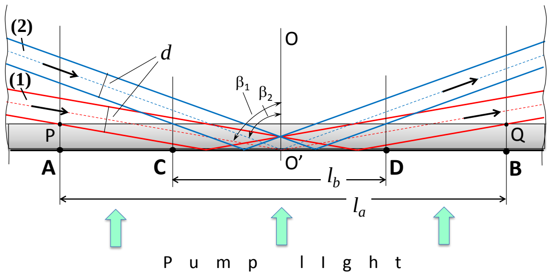


Fig. 4. Scheme of resonator axis and formed beam propagation in the zone of amplification.

On Fig.4. AB is the pumped length in the cell, CD is the zone of beam superposition. The incident angles are β_1= 83.16^o and β_2=74.36^o for the beams (1) and (2), respectively. The lengths of AB and of CD are 1 cm and 0.28 respectively. The depth of the pumped region d is calculated to be 0.04 cm - for used 6.10^{-4} mol/l Rh6G ethanol solution as an active medium.

Using the scheme from Fig. 4 we have estimated the path of each beam outside the competition zone (practically outside the zone CD) and the part with superposition (competition) of the beams – zone CD. We have theoretically investigated the beams behavior - especially tunability, described with two differential equation systems – one for the non-competing parts and second for the superposition and competition of the two beams. Practically, the system that describes the generation in the competition zone is based on the conveniently adapted rate differential equations [4]:

$$\frac{dN_2}{dt} = R_p(t) - \left[B_1 \cdot q_1(t) + B_2 \cdot q_2(t)\right] \cdot N_2(t) - \frac{N_2(t)}{\tau}$$
$$\frac{dq_1}{dt} = B_1 \cdot q_1(t) \cdot V_{a1} \cdot N_2(t) - \frac{q_1(t)}{\tau_{c1}}$$
$$\frac{dq_2}{dt} = B_2 \cdot q_2(t) \cdot V_{a2} \cdot N_2(t) - \frac{q_2(t)}{\tau_{c2}}$$

with $P_{out}^{1,2} = (\gamma_{out}^{(1,2)}.c/2L').h\nu^{(1,2)}.q_{1,2}(t)$ where the output powers are P_{out}^1 and P_{out}^2 , the generated photons in the two channels are denoted as q_1 and q_2 for the two selected wavelengths λ_1 and λ_2. N_2 is the inverse population in the pumped active volume; $B_{1,2} = \sigma_e^{(1,2)}.l_{1,2}.c/(V_{a1,2}.L')$ is calculated in s^{-1}; σ_e^1 is the emission cross-section for λ_1 in the channel (1) (variable); σ_e^2 = 1.8x10^{-16} m^2 is the emission cross-section for λ_2 = 562 nm (fixed at the maximum of the gain curve of the Rh6G [4]); l_1 = 0.34 cm and l_2 = 0.3 cm – lengths of the active medium, corresponding to (1) and (2) channels respectively in overlapped part; c = 3x10^{10} cm/s is the light velocity; V_{a1} = 4.22x10^{-4} cm^3 and V_{a2} = 3.73x10^{-4} cm^3 is the active volumes for the two wavelengths; L' = 6 cm is the optical length of the resonator for both channels. The lifetime of the upper laser level is τ = 3 ns. The term in $h\nu^{(1,2)}$ is the energy of the generated photons for the corresponding wavelength, measured in [J]. The dumping time of the photon in the resonator is $\tau_{c1,2} = L'/c.\gamma^{(1,2)}$, where $\gamma^{(1,2)}$ describes the loss in the corresponding channel resonator, following Ref. [Svelto 2010]. The total number of active dye molecules used in the calculations is 3.61x10^{17} cm^{-3} that corresponds to a solution concentration of $6\cdot10^{-4}$ mol/l. The term $R_p(t) = P_p(t)/(h\nu_p.V_{a1})$ is the pump rate. $R_p(t)$ is related to the temporal shape of pump energy for our oscilloscope observation trapezoid shape with a rise time of 10 ns, near-plateau part of 10 ns and fall time of 20 ns. For the considered case the pump energy is 5 mJ. The concave mirror was taken to be with 99% reflection and the mirrors M_1 and M_2 with reflections of 0.1 and 0.6, respectively; the transitivity of IW_1 is 50 % and of IW_2 – 90 %. For this conditions, we obtain for two selected wavelengths λ_1 = 563 nm and λ_2 = 562 nm for the two beams near equal outputs of 2 mJ and 1.9 mJ respectively.

For the computing of the generation outside the zone of competition CD we take the same system with initial conditions N_2 = 0 and q_1 = 1 and q_2 = 0 (the last acceptance reduces the system to describe the generation only for q_1. Here and below, we take as a pump energy the part of the full pump energy, proportional to the relative length of the considered active medium length. After solving the reduced system we obtain the new value for q_1. We solve again the full system for the range CD taking as initial condition the obtained value of q_1. For q_2 the value 1 is used. As a third step we solve the system for the third zone, taking as initial condition the obtained value for q_2 from the solution for the zone of competition and now we accept q_1 = 0. From the solution of the system, we obtain q_2 as a photon number in the beam (2) and take for the beam (1) q_1 to be equal of the photons number, obtained by solution of the system for zone CD. From obtained photon number for each output beams, we obtain correspondingly the generated output energy for each beam [5].

Using this scheme of calculation with a fixed wavelength λ_2 in the channel (2) at 562 nm and tuning the wavelength λ_1 in the first channel, we obtain the tuning curve of the laser. The last is given in Fig. 5.

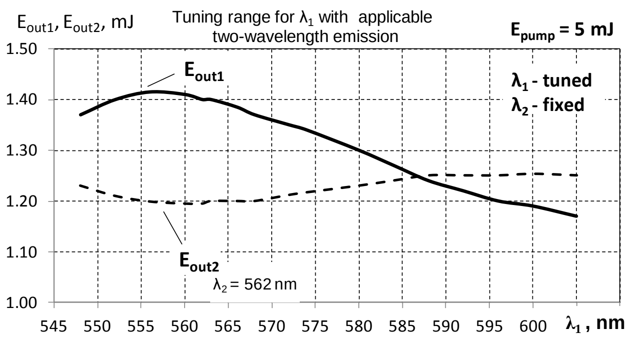
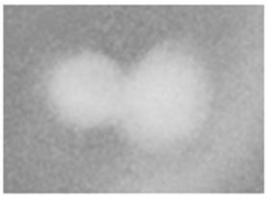


Fig.5. The calculated tuning curve for the output energy of the proposed laser. The wavelength in the second channel (2) is fixed at λ_2=562 nm and the wavelength λ_1 in the first channel (1) is tuned.

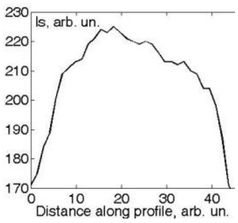
If we compare this tuning curve with the two-wavelength laser for which one of the channel is close and parallel disposed to the input wall and the second one is with grazing propagation [5] it can be seen that in the new laser the tuning curve is essentially broadened. This can be expected, taken into account that the competition zone here is quite shortened. This is one of the advantages of the proposed laser.

However, the main and essential advantage is, as we have discussed already, the generation in the scheme of pumping the two beams with radial symmetry in the cross section. We have already presented the physical argumentation of such phenomena.

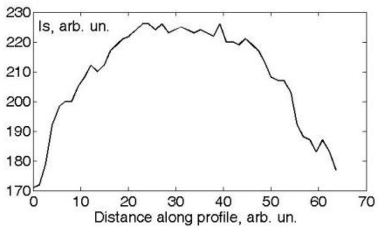
In our preliminary test-experiment we have utilized such laser with discussed construction parameters and have obtained the expected results – the two beams with naturally obtained radial symmetric beam profiles. The actual photograph and the computer treatment to obtain the beam profiles are given in Fig.6. It is clearly seen that the spot profiles are with radial symmetry. Our consideration shows that the spots profiles are nearly composed by superposition of two radial symmetric modes each – of the modes TEM_{00} and TEM_{01*} [7].



(a)



(b)



(c)

Fig. 6. The actual photograph of the beam profiles (a) for generation in the proposed two wavelength laser with grazing resonator axis and beam propagation (incident angles of ~ 70 ^{o}, left spot (b) and ~ 80 ^{o} right spot (c). The obtained natural radial symmetric profile can be seen.

III. Conclusion

In this work we have proposed a new solution of transversal, one-side laser pumped two-wavelength laser. The consideration is for the example of laser pumped dye laser. The proposed laser solution has as main and essential advantage to assure naturally the homogeneous radial pumping of the generated beam. The natural intensity symmetry in beam cross section is assured. Additionally, the strong low-transversal mode emission is facilitated. We have presented the principle of this solution together with the carried out theoretical treatment, computer analysis and basic experimental tests.

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