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RING LASER RESONATOR WITH STIMULATED BRILLOUIN SCATTERING MIRROR

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In acest articol sunt prezentate rezultatele unui studiu teoretic şi experimental privind proprietățile unui rezonator optic de tip inelar folosind un laser cu Nd:YAG care operează la lungimea de undă de 1.06 µm. Sunt prezentate ecuațiile de rată într-un sistem rotativ pentru distribuția câmpului optic şi inversia de populație obținându-se condițiile de oscilație pentru rezonatorul laser. Cu ajutorul acestui altgoritm a fost construit modelul cinetic pentru un rezonator laser inelar folosind împrăştierea stimulată Brillouin (SBS). Un rezonator laser inelar conține patru oglinzi plane şi o bară laser Nd:YAG cu un câştig mic. O oglindă Brillouin care conține o celulă cu CS_2 este plasată în spatele unei lentile în exteriorioru l rezonatorului inelar. Laserul funcționează în regim liber cu un coeficient laser scăzut. Când intensitatea radiației laser creşte în rezonator, bariera difuziei stimulate Brillouin depăşeşeşte pragul maxim obținându-se creşterea reflectivității în celulă, iar coeficientul rezonatorului scade brusc. Folosind o fotodiodă şi un osciloscop digital (2 GHz) au fost măsurate durata pulsului şi energia laserului cu un detector Mollectron. Structura transversală a distribuției intensității radiației a fost monitorizată cu o cameră CCD şi un sistem SPIRICON.

The results of an theoretical and experimental study of the properties of a ring resonator used with a Nd:YAG laser operating at 1.06 µm are presented. The rates equations arepresented in a rotative system for an optical field distribution and inversion population obtaining the oscillation conditions of a ring laser resonator. With this model a kinetic model for a ring laser resonator with stimulated Brillouin scattering mirror (SBS) was developed. The ring laser resonator contains four plane mirrors and a Nd:YAG rod with a small signal single pass gain. A Brillouin mirror contains a cell with CS_2 is put behind of a lens in exterior of ring resonator. The laser works in free regime with a low coefficient laser resonator. When the intensity of laser radiation increases in the resonator, barrier of the stimulated Brillouin diffusion grows out of and the reflectivity of cell increase, so that the coefficient of resonator is switched.

Using a fast photodiode and a digital oscilloscope (2GHz) we measured the duration of the laser pulse and the energy with a Mollectron detector. The transversal structure of output radiation intensity was monitorised usinga CCD camera and a SPIRICON system.

Keywords: stimulated Brillouin scattering, ring laser resonator, SBS mirror

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1. Introduction

Phase conjugation via stimulated Brillouin scattering (SBS) has been demonstrated to be a simple and very efficient method for dynamically correcting the aberrations in solid state lasers [1-5]. First Q-switching of the laser resonator using SBS was applied for ruby lasers and then for Nd:YAG lasers [4].

The approach usually adopted is to include the SBS medium inside a laser cavity with a secondary mirror employed to provide feedback at the beginning of the laser action [7,8]. High intra–cavity intensities experienced by the SBS medium in this configuration can lead to poor spatial beam quality. This limits the repetion rate and peak power of the output.

SBS was extended for Q-switching down to the UV wavelenght range, for excimer laser [9] till the IR domain, for Er lasers [10, 11].

In this article, we investigate experimentally and theoretically the performances of a pulsed Nd:YAG laser system utilising external stimulated Brillouin scattering for Q-swiching and phase conjugation of the cavity radiation for ring laser resonator. In comparison with the linear configurations, where each round trip the laser beam travels within the cavity will generate a downshifted Stokes beam and therefore will increase the bandwidth of the laser emission, the ring configuration allows the potential of single frequency operation from the resonator. In the ring configuration, the Q-swiching regime is obtained in a novel oscillator two-pass amplifier system [11,12]. The ring resonator geometry was used also for a dye laser with SBS Q-swiching mirror.

2. Theoretical model of SBS ring laser

The system describing the Q-swiching regime is the same as in the case of the linear resonator [13].

$$\frac{dq}{dt} = q\left[Bn - \gamma_{nl}(q)\right]$$

$$\frac{dn}{dt} = -qBn \tag{1}$$

$$n(0) = n_{th}(1+\zeta); q(0) = q_{sp}$$

where: q is photon density, n is the population inversion, n_{th} is the inversion at generation threshold, B is Einstein's coefficient and $\gamma_{nl}(q)$ are the losses which depend on intensity due to the dependency of the SBS reflection coefficient, R, on intensity. The initial population inversion, n(0), is assumed above the threshold as the term $1+\zeta$ ($\zeta \sim 2\%$).

The threshold condition for the two intensities I_a and I_c are derived considering an imaginary plane between the polarizer and mirror R_l:

$$I_a R_1 T R_2 R_3 e^{(\gamma_a-\alpha)l_r} R_4 (1-R_{out}) + I_c R R_{out} = I_a$$
$$I_c (1-R_{out}) R_4 e^{(\gamma_c-\alpha)l_r} R_3 R_2 T R_1 = I_c \tag{2}$$

where R_{out} is the reflectivity of the output mirror (polariser), $R_1=R_2=R_3=R_4=100\%$, T is the transmission of the saturable absorber (T=30%), and l_r is the rod length and α are the losses per unit length of the laser rod.

We define: $\delta = \dfrac{I_c}{I_a}$ (3)

Thus, the nonlinear losses $\gamma_{nl}(q)$ have the form:

$$\gamma_{tot} = \gamma_a + \gamma_c = 2\alpha + \frac{1}{l_r} \ln\left\{ \frac{1-R\delta R_{out}}{\left[(1-R_{out})TR_1R_2R_3R_4\right]^2} \right\} \tag{4}$$

where $\tau = l_0/c$ is the round trip time of the resonator. In the expresion of the nonlinear losses we neglect the term reffering to the linear losses $2cl_r\alpha/l_0$, which is very small.

The steady state theory of SBS have been considered again to find the analytical solution for R:

$$\frac{\exp(-G)}{R} = \frac{1-R}{\exp\left[(1-R)g_B L_{eff} I\right] - R} \tag{5}$$

where G~25 is referring to the initial Stokes noise, g_B is the Brillouin gain and L_{eff} is the interaction length which depends on the focal length of the focalizing lens.

Photon density in the laser resonator is:

$$q = \frac{2}{ch\nu}(I_c + I_a) \tag{6}$$

where I_s is Stokes density.

Introduceing the normalised variables:

$$\zeta = t/\tau$$
$$R(\zeta) = I_s/I$$
$$y(\zeta) = n(\zeta)/n(0) \tag{7}$$
$$x(\zeta) = (I + I_s) g_B L_{eff}$$

we obtain the following equation system:

$$\begin{aligned} \frac{dR(\zeta)}{d\zeta} &= [A_0 y - G(R)]C(R) \\ \frac{dy(\zeta)}{d\zeta} &= -B_0 yx \\ \frac{dx(\zeta)}{d\zeta} &= [A_0 y - G(R)]x \end{aligned} \tag{8}$$

The third equation in the system (8) represents the dynamics output pulse equation. The initial conditions are:

$$R(0) \approx e^{-G} y(0) = 1; x(0) \approx e^{-G} \tag{9}$$

and rspectively:

$$\begin{cases} A_o = \tau B n(0) \\ B_0 = \dfrac{2\tau B}{ch\nu g_B L_{eff}} \\ G(R) = \ln\left[\dfrac{1 - R\delta R_{out}}{[(1 - R_{out})TR_1R_2R_3R_4]^2}\right] \\ C(R) = \dfrac{R(1-R^2)}{2R + \dfrac{1-R^2}{\dfrac{1+(1-R)e^G}{1+(1-2R)e^G}\ln\left[R + R(1-R)e^G\right]}} \end{cases} \tag{10}$$

The results of the numerical simulations are presented in Fig. 1.

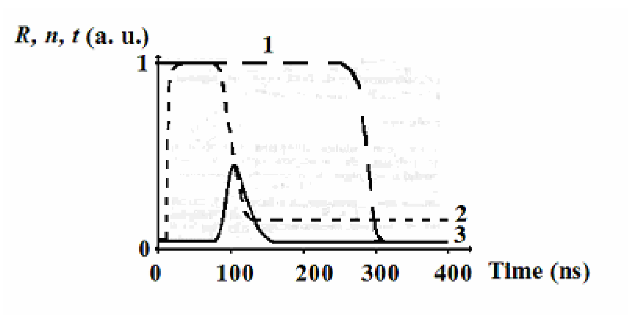

Fig 1. Brillouin reflexion coefficient R (curve 1), population inversion (curve 2), output pulse (curve 3) versus time, for R_{out}=0,5

3. Experimental set-up

The experimental set-up is depicted schematically in Fig. 2 [1]:

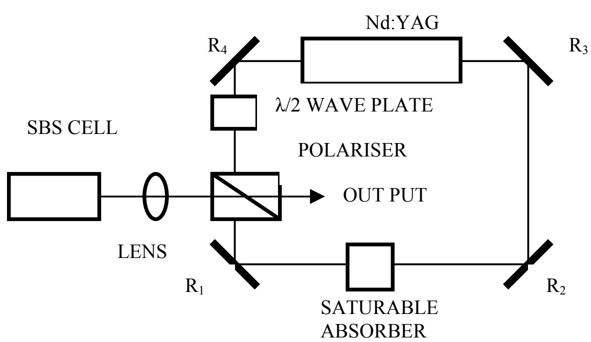

Fig. 2 The experimental SBS ring laser resonator

The four plane mirrors with reflctivity R~100% and the Nd:YAG rod with a small signal pass gain of ~100 defined the ring cavity, whose length was 1 m. The Nd:YAG rod with a 6 mm diameter and a 90 mm length was pumped by a flash lamp in a diffuse, liquid cooled cavity. The radiation at 1.06 μm was outcoupled by a half-wave plate-polariser combination. The Brillouin Cell (L = 10 cm) filled with CS_2 was placed behind a lens, which had a focal length of 10 cm, outside the ring cavity. The Brillouin backscattering radiation returned to the ring resonator has been extracted through the polarizer cube to be analysed.

A fast photodiode and a Le Croy digital oscilloscope (2GHz) have been used to monitor laser pulse durations. Mollectron detectors have been used to measure laser beam energies. The transversal structure of the output radiation was monitored by a CCD camera and a SPIRICON system.

4. Experimental Results

We used a saturable absorber (Kodak liquide saturable absorber for Nd:YAG laser radiation) to initiate the SBS process. It was mounted in the cavity and aligned such the reflection of the windows cell would not cause feedback and the transmission was reduced until a single Q-switched spike was obtained. This has the additional effect of pre-Q switching the laser yielding pulses of duration ~50 ns in the clockwise (I_c) and anti-clockwise (I_a) directions.

The output, I_c, was incident on the cell containing CS_2. Reflection from the SBS cell reinjected, I_c, back into the ring where it contributed to the flux, I_a. The clockwise travelling output from the rod, via polariser, was p-polariser and after one pass through the half wave plate became s polarised component and was focused into the SBS cell. Because the SBS interaction preserves the polarisation corresponded to the first Brillouin Stokes shift $\omega_1 = \omega_0 - \omega_B$, where ω_0 is the linecentre of the Nd:YAG crystal and ω_B is the acoustic frequency. After one complet round trip $s_0(\omega_1)$ was converted to $p_1(\omega_1)$ by the half wave plate and then made a second round trip before reconversion back into $s_2(\omega_1)$ and emission through polariser as the output. The cavity threfore acts as an oscillator-two pass amplifier system.

The laser presented in Fig. 2 started in the free-running regime with a low Q factor determined by the losses of the cell and the saturable absorber. The SBS reflectivity of the cell increased rapidly with the incident wave intensity and the ring resonator with the Brillouin mirror reached a high Q factor.

The output beam with an energy of 40 mJ in a pulse of 15-20 nsec duration was obtained at 2Hz. At higher repetition rates Q-switching action becomes unreliable due to the fact that the saturable absorber was not circulated and excessive thermal loading may appear.

A typical output pulse with a width (FWHM) of 15 nsec is show in fig. 3:

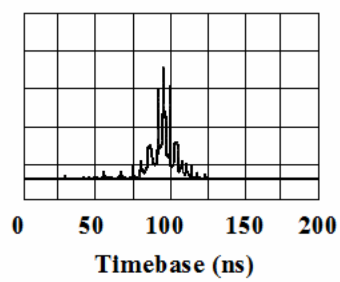

Fig. 3 A typical output pulse of SBS ring laser

The experimental results (fig. 3) are in a good agreement with the theoretical results (curve 3 from fig. 1).

The Q-switched laser was partially mode-locked indicating that there exist many longitudinal modes oscilating during the lasing process.

Under proper alignment of laser mirrors, and with an aperture of d = 1,5 mm the laser could operate in the TEM_{00} mode and the energy of the pulses diminished to 5 mJ.

5. Conclusions

We demonstrated a SBS Q-switching of a ring resonator based on the gain material Nd:YAG. The power generated in the free-running regime proved to be not enough to rich the threshold of the SBS process in the cell. However we succeed to start operation of the laser in the Q-switching regime using a saturable absorber.

A theoretical description of the external SBS Q-switching resonators has been developed, using the stationary approximation for the SBS interaction and good agreement between experimental data and theory was obtained, even our model is very simple in comparision with Lamb's model which uses the general equation model but does not take into account the propagation effects within the resonator and the subsequent frequency shift which is characteristic for SBS.

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