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Characterization of a Nd:YAG phase conjugated laser*

H. MENG**, V. ABOITES+ AND E.J. EICHLER
Optisches Institut, Technische Universität Berlin
Strasse des 17 Juni 135, D-1000 Berlin 12, Germany

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ABSTRACT. The temporal and spatial characterization of a half phase conjugate resonator Q-switched Nd:YAG laser is here reported. The Q-switching was achieved by intracavity phase conjugation in SF_6 gas by stimulated Brillouin scattering. The observation of partially mode locked Q-switched pulses is reported as well as transverse spatial profile pulses with an apparently chaotic structure.

RESUMEN. Se reporta la caracterización temporal y espacial de un láser Q-switcheado de Nd:YAG con medio resonador de conjugación de fase. El Q-switcheo se logró por conjugación de fase intracavidad en gas SF_6 por dispersión de Brillouin estimulada. Se reporta también la observación de pulsos Q-switcheados con amarre de modos parcial, así como pulsos con perfil espacial transversal de estructura aparentemente caótica.

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1. INTRODUCTION

Since the discovery of phase conjugation (PC) by Zel'dovich *et al.* [1], many theoretical and experimental works dealing with the characterization and the applications of this process have been published [2,3,4]. In particular it is known that high power solid state lasers suffer from beam distortion caused by thermal lensing in the active media. By using a PC mirror it is possible to compensate for those internal phase distortions improving the performance of the laser [2]. In addition to this, one of the most interesting applications of PC is the construction of full or half resonant PC laser cavities (cavities where both or one of the mirrors is a PC mirror), where phenomena such as Q-switching or pulse compression can occur [5,6,7,8,9].

In this communication we report the temporal and spatial characterization of a half PC resonator Nd:YAG laser. The PC takes place in an intracavity SF_6 gas filled cell by stimulated Brillouin scattering (SBS). The observation of partially mode locked Q-switched pulses and pulses with an apparently chaotic transversal spatial structure is reported and discussed. In stable operation the laser was able to produce TEM_{00} pulses up to 100 mJ and 15 nsec FWHM at a repetition rate of 5 Hz.

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**Permanent Address: Dept. of Mech. Eng., Houston University, TX 77204, U.S.A.

+Permanent Address: C.I.O., Apdo. Postal 948, 37000 León, México.

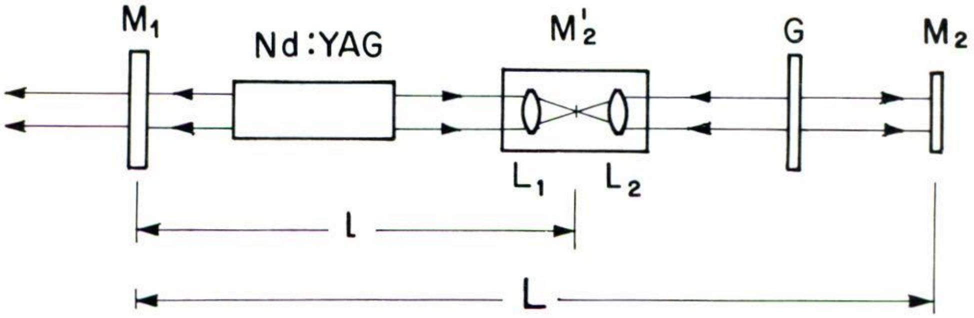

FIGURE 1. Experimental set-up.

2. EXPERIMENT AND RESULTS

The laser set-up [9,10] is shown in Fig. 1. It consisted of a 9.5 mm thick and 65 mm long cylindrically shaped Nd:YAG rod and two mirrors M_1 and M_2 of 16% and 100% reflectivity at 1.06 μm separated by a distance L. The SBS PC cavity consisted of a 150 mm cell filled with SF_6 at 20 atm and two lenses L_1 and L_2 of focal lengths 30 mm and 20 mm separated from each other by 60 mm. These two lenses form a telescope with real focus which defines the position M_2' of the PC SBS mirror. M_1 and M_2' separated by the optical lenght l define the half PC laser resonator. G is a 30% transmition attenuation glass plate.

As it has previously been explained [9,10], once the pumping of the Nd:YAG rod starts, due to the losses caused by the presence of the G plate, we have a low Q laser resonator. In this situation the laser is in free running regime between mirrors M_1 and M_2 with longitudinal mode separation $c/2L$. The interference of counterpropagating fields of frequencies ν_i and ν_{i-m} in the focus of the SBS cell causes the excitation of a sound wave. This sound wave reflects the forward propagating wave of frequency ν_i into its Stokes wave of frequency $\nu_i - \nu_B$. Then the SBS reflectivity of the cell increases exponentially with the incident wave intensity and the reflected wave from the cell is phase conjugated of the incident wave [3]. This rapidly form a new high Q laser resonator between mirrors M_1 and M_2' so that a short Q-switched pulse is produced. As it was experimentally found in our previous work [9,10], the condition for stable operation of the laser (*i.e.*, the condition needed to obtain *repetitive* spatial and temporal laser shapes) is

$$\nu_i - \nu_{i-m} = m(c/2L) = \nu_B, \tag{1}$$

where ν_B is the Brillouin shift of the medium. For SF_6, $\nu_B = 250$ MHz, therefore L can be chosen as 60, 120, 180 cm, etc.

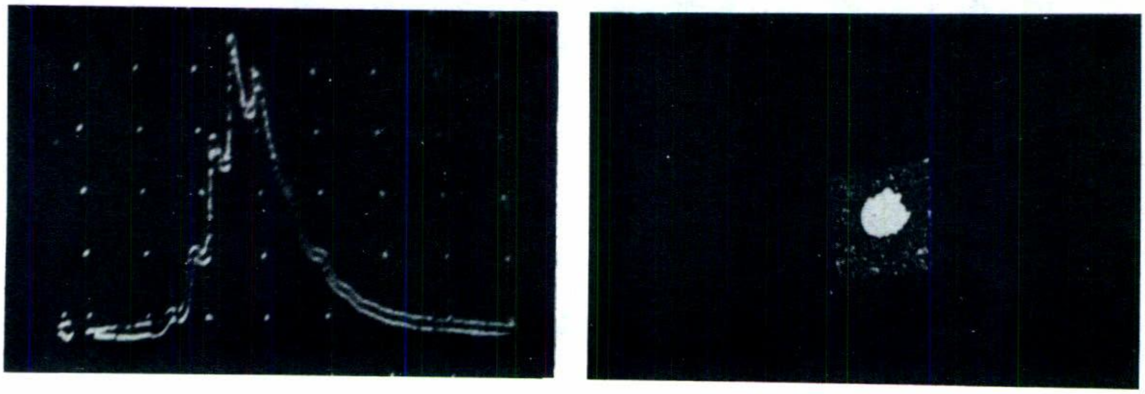

Figure 2. Temporal and spatial profile of a laser pulse obtained for parameters $l = 60$ and $L = 120$ cm, so that Eqs. (1) and (2) are satisfied. a) Temporal profile of the Q-switched laser pulse obtained. FWHM is 15 nsec and we can appreciate the partial mode locking since the small peaks are separated $2l/c = 4$ nsec (horizontal scale 10 nsec/div). b) The laser mode is TEM$_{00}$ mode but by misaligning the output mirror higher order modes can be obtained maintaining the same temporal structure.

An analysis of the temporal structure of the laser pulses produced when Eq. (1) is satisfied shows that the Q-switched pulses are also partially mode locked. Fig. 2-a shows a 15 nsec FWHM Q-switched pulse obtained using parameters $l = 60$ cm and $L = 120$ cm, so that Eq. (1) is satisfied. Once the laser starts oscillation between the output M_1 and the PC mirror M_2', the longitudinal mode separation is $c/2l = 250\ MHz$, which corresponds to the 4 $nsec$ time between peaks observed in the pulse. In this case

$$c/2l = \nu_{\mathrm{B}}. \tag{2}$$

Therefore the Brillouin shifting of any longitudinal mode results in another oscillation mode. Choosing an l value so that expression (2) does not hold will result in longer laser pulses with a more complicated temporal structure. Fig. 3-a shows an example obtained using $L = 120$ cm and $l = 88$ cm. In this case the Brillouin shifting produces new frequencies other than the allowed longitudinal modes. In Fig. 3-a we can see that between the fundamental peaks which are separated by $2l/c = 6$ nsec some new small peaks appear. Moreover, the deviation of the length l from the expression (2) results in an apparently chaotic-like transversal beam structure as shown in Fig. 3-b.

Summarizing our results we obtained that: i) When expressions (1) and (2) were satisfied, the laser was able to operate at a repetition rate of 5 Hz in TEM$_{00}$ as shown in Fig. 2-b, producing pulses of 100 mJ with energy stability whithin 5% and beam divergence estimated to smaller than 3×10^{-4} rad. In this case, as shown in Fig. 2-a, pulse length FWHM was 15 nsec, and the laser pulses showed partial mode locking.

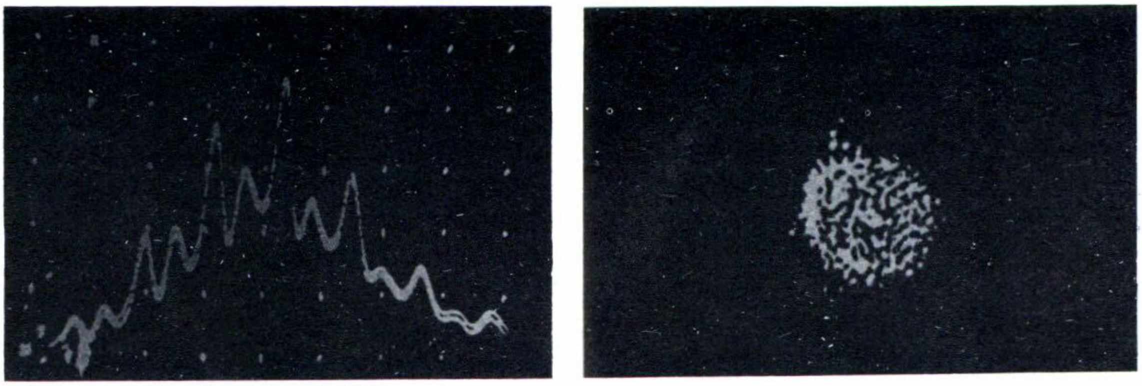

FIGURE 3. Temporal and spatial profile of a laser pulse obtained for parameters $l = 88$ and $L = 120$ *cm*, so that Eq. (1) holds but not Eq. (2). a) Temporal profile of the Q-switched laser obtained. FWHM is 25 nsec and we can appreciate the partial mode locking of the main peaks separated by $2l/c = 6$ nsec (horizontal scale 5 nsec/div). b) Chaotic-like transversal beam structure obtained.

ii) When condition (1) was satisfied but condition (2) was not, the pulse length FWHM was 25–30 nsec as shown in Fig. 3-a. In this case the temporal structure of the pulses was more complex than in case i) showing in addition to the main peaks separated $2l/c$ some smaller peaks due to the presence of Brillouin shifted modes different from the allowed longitudinal ones. Typical pulses energies were 0.5–1 J and the spatial transversal profile showed always to be chaotic-like as shown in Fig. 3-b.

For the sake of completeness the PC SBS cell was taken away from the laser set-up. In this case the pulse width was 200 μsec with a very spiky temporal structure. The transversal oscillation mode was multimode and the output energy was 500 mJ.

3. CONCLUSIONS

A Nd:YAG laser with an intracavity PC SBS mirror was constructed. It was found that the temporal and spatial characteristics of the laser pulses obtained depend on two matching conditions, namely expressions (1) and (2). In order to obtain repetitive spatial and temporal pulse shapes expression (1) must hold. Furthermore, when expressions (1) and (2) are satisfied, short Q-switched partially mode locked pulses are obtained with energy stability within 3% and TEM_{00} transversal mode (by misalignment of the exit mirror higher modes can be obtained). If expression (1) holds but (2) does not, then longer Q-switched laser pulses are obtained with a more complex but repetitive temporal structure and an apparently chaotic transverse spatial structure.

In stable operation the laser was able to produce 100 mJ in TEM_{00} mode at a repetition rate of 5 Hz. A future task is to increase the beam volume and energy of the TEM_{00} mode. In addition to these results a theoretical explanation of the reported results is under way.

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