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RESEARCH NOTE

Experimental Study of a Flash-lamp Pumped Passively Q-Switched Nd:YAG Laser Using Cr^{4+}:YAG Saturable Absorber

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ABSTRACT

This paper deals with the experimental results of a xenon flash-lamp pumped passively Q-switched Nd:YAG laser using Cr4+:YAG saturable absorber. The need of a laser cavity to be integrated into a time-of-flight laser range finder is of great interest as an experimental investigation of several laser resonators. Two types of laser resonator, with different lengths, have been studied: the flat-flat and plano-concave ones. Each laser cavity consisted of a flat output coupler, characterized by its reflectivity, and combined with a high reflectivity mirror, allowed the observation of the laser output characteristics. It has been demonstrated that the radius of curvature, of the high reflectivity mirror, is of great importance in determining the best laser performances. The best results were achieved using a flat-flat cavity of 18.5 cm in length, electrical pump energy of 21 J, and an output coupler reflectivity of 50%. The output laser energy was 28.4 mJ for a pulse width of 38 ns. Multiple laser pulses were also obtained, by increasing the electrical pump energy or through adjusting the laser resonator alignment.

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1. INTRODUCTION

Passively Q-switched Nd:YAG laser using saturable absorber crystal is widely used in several applications, such as time-of-flight laser range finders [1] and gated imaging systems [2, 3]. One of the most used saturable absorbers is the Cr^{+4}:YAG crystal due to its performance compared to other crystals [4, 5]. The need for short laser pulses, with high peak powers, gained a keen interest of the scientific community with the aim to improve the output performances of a passively Q-switched solid-state laser. In this context, several experimental and theoretical works have been done [6-8]. The output coupler reflectivity, the electrical pump energy, the transmission of the saturable absorber, the laser cavity length, the dimensions of the solid-state crystal, and the repetition rate are the main parameters that have been investigated in the major published works [4, 9-13]. However, in all these valuable works, the effect of the radius of curvature of the high reflectivity (HR) mirror has not been investigated yet as a key parameter on the output laser characteristics. This is why our experimental work presented in this paper, comes as a contribution to identify the effect of HR mirrors on the output characteristics of a passively Q-switched solid-state laser.

In order to show the impact of the radius of curvature of the HR mirror, this paper presents an experimental investigation of a xenon flash-lamp pumped passively Q-switched Nd:YAG laser at 1064 nm with a Cr^{+4}:YAG saturable absorber crystal. Two laser resonators have been investigated: the flat-flat and plano-concave ones. The experiments were done for the two resonators with three different cavity lengths, five output couplers, and four HR mirrors with different radii of curvature. In all experiments, the laser output performances were observed in terms of output laser energy and peak power.

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In section 2 of this paper, the experimental setup, the material used to record the laser output energy and the pulse width are presented. In section 3, the results obtained from the different laser cavities are discussed. Finally, concluding remarks are given in section 4.

2. EXPERIMENTAL SETUP

The experimental setup is shown in Figure 1. The Nd:YAG crystal (6 mm bore diameter and 60 mm length) is pumped by a linear xenon flash-lamp (4 mm bore diameter and 60 mm arc length). Figure 2 depicts the simmer mode power supply diagram [14] of the flash-lamp. This diagram includes: an external trigger which allows the first ionization of the gas into the lamp by providing a high voltage pulse (15 to 20 kV), a simmer circuit that keeps a partial steady-state ionization of the gas, a capacitor (C) charging unit, and a solid-state switch (thyristor) that ensures the discharge of the capacitor into the lamp through the inductor. The duration of the flash-lamp pulse was set to 100 µs at a pump energy changed from 9 J to 55 J by increasing the storage capacitor voltage. Three cavity lengths were used (*L* = 18.5 cm, 24 cm, 39.5 cm). A high reflectivity (HR) mirror M1 coated at 1064 nm, with several radii of curvature (*Rc* = 1 m, 2 m, 3 m, and flat). A flat output coupler mirror M2 with various reflectivities (*R* = 50, 60, 70, 80, 85 and 90%). The output laser energy was measured by the energy detector ED200 (Gentec Electro-Optics Inc.) connected to a TDS3052 oscilloscope (Tektronix Inc.). The laser pulse wave form was displayed using a fast Si photo-diode (BPX65) with a rise time of 2 ns.

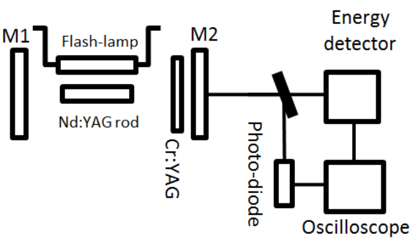


Figure 1. Experimental setup

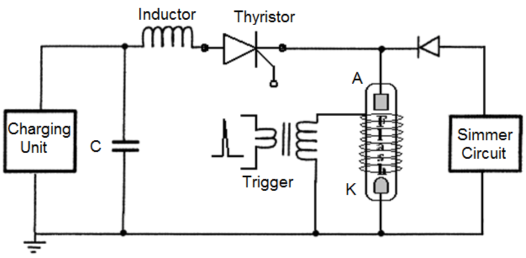


Figure 2. Flash-lamp simmer mode power supply

The initial transmission of the used Cr^{+4}:YAG saturable absorber T_0 is equal to 24.43 %. It was calculated using Equation (1) [14], with: the ground state concentration n_g = 2.7 x 10^{18} cm^{-3}, the absorption cross-section of the ground state σ_g = 8.7 x 10^{-19} cm^2 [10], and the saturable absorber thickness l_s = 0.6 cm.

$$T_0 = exp\left(-n_g \sigma_g l_s\right) \tag{1}$$

3. RESULTS AND DISCUSSION

The first experiment was performed for a free-running laser mode. The laser cavity length (*L*) was set to 18.5 cm; the output coupler has a reflectivity (*R*) of 50 %, and the HR mirror has a radius of curvature of 3m. The pump energy was changed from 9 to 55 J. The flash-lamp waveform and the corresponding output laser pulse are shown in Figure 3. The maximum value of the pump current is equal to 525 A for 100 µs pulse-width, and the laser pulse width is about 80 µs. Figure 4 illustrates the plot of the output laser energy versus the electrical pump energy. For a free-running laser mode operation with a pump energy equals to 9.25 J, the lowest output energy recorded is 2.6 mJ, and the highest one is 604 mJ corresponding to the pump energy of 55J. Under the same conditions, the Q-switched laser mode operation was achieved by inserting the Cr^{+4}:YAG crystal in the laser cavity and the results are depicted by Figure 4. In this mode of operation, for different pump energies (from 21 to 55 J), the output laser energy varies from 22 to 246 mJ.

In the next experiments of this paper, the electrical pump energy is set to the threshold energy of 21 J.

The obtained Q-switched output energy versus the output coupler reflectivity using a laser cavity length of 18.5 cm, different output couplers (*R* = 50, 60, 70, 80, 85 and 90%), and HR mirrors with various radii of curvature (*Rc* = 1 , 2 , 3 m and flat) is represented in Figure 5.

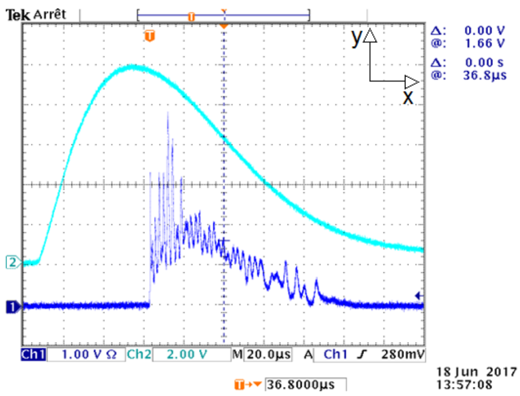


Figure 3. Pump current (Ch2 (Y axis): 2V/div.) and free-running laser pulse (Ch1 (Y axis): 1V/div.), (x axis: time scale 20 µs/div.)

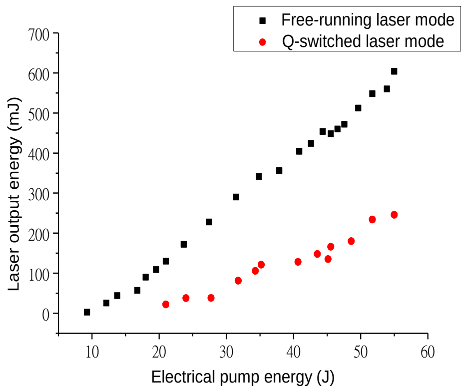


Figure 4. The output laser energy, of free-running and Q-switched laser modes, versus pump energy for R = 50%, Rc = 3m, and L = 18.5 cm

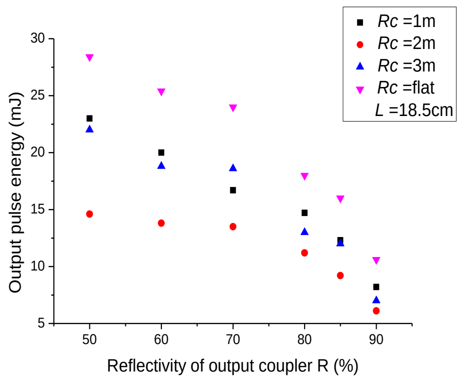


Figure 5. Output laser energy for different output couplers and various HR mirrors for L = 18.5 cm

The flat-flat cavity provides the best output laser energy of 28.4 mJ, with an output coupler reflectivity of 50%. The corresponding plots of the peak power versus the output coupler reflectivity are shown in Figure 6. The highest peak power of 631 kW is obtained also for the flat-flat cavity, and with a pulse width of 38 ns as shown in Figure 7.

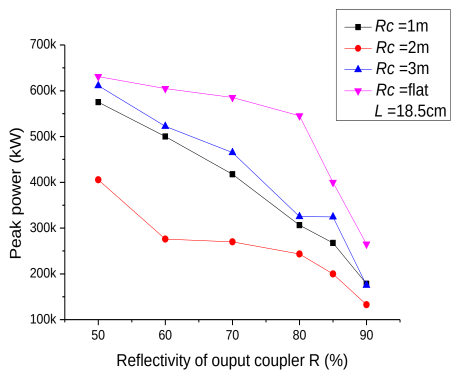


Figure 6. Peak power versus the output coupler reflectivity for L = 18.5 cm

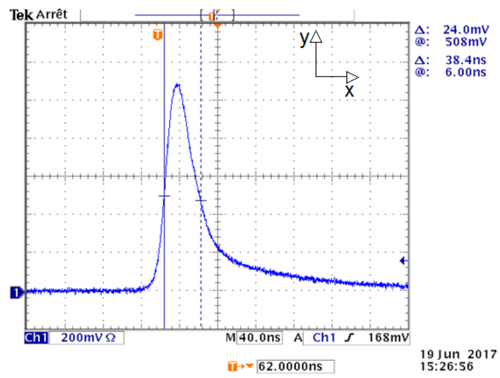


Figure 7. The laser pulse shape (Ch1: 200mV/div.) for L = 18.5 cm, R = 50% and a flat HR mirror (x axis: time scale 40 ns/div.)

The same measurements were repeated using a laser cavity of 24 cm in length. The results of the Q-switched laser output energy are depicted by Figure 8. The plano-concave resonator with an output coupler reflectivity of 50% and an HR mirror with a radius of curvature of 1m, gives the best results with the highest output energy of 24 mJ. As shown in Figure 9, the highest laser peak power of 555 kW is obtained for the output coupler reflectivity of 70%.

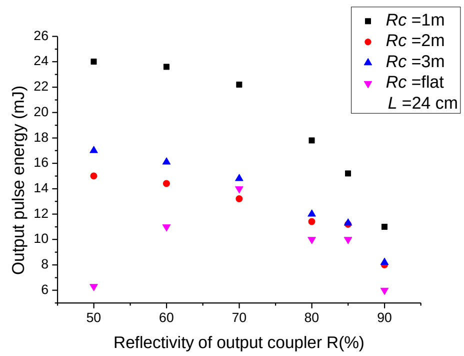


Figure 8. Output laser energy for different output couplers and various HR mirrors for L = 24 cm

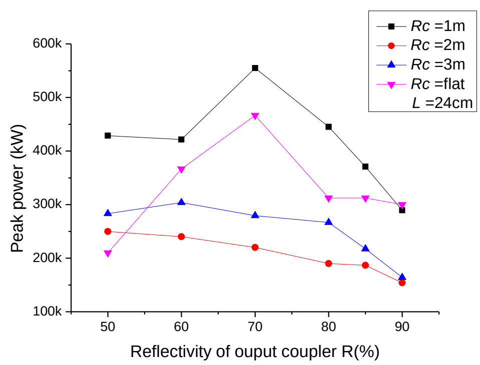


Figure 9. Peak power versus the output coupler reflectivity for L = 24 cm

The cavities with a radius of curvature of 2 and 3 m provide more stable output energies.

Figure 10 shows the Q-switched output laser energy versus the output coupler reflectivity for various curvatures of the HR mirror and using a laser cavity length of 39.5 cm. The flat-flat cavity gives the highest energy of 18 mJ for an output coupler reflectivity of 50%. The corresponding laser peak power is about 450 kW as represented in Figure 11. The plano-concave resonators provide stable results in terms of output laser energy and peak power.

The experiments show that the flat-flat cavity with a length of 18.5 cm gives stable output laser energy. For the cavity length of 24 cm, the flat-flat resonator shows non-stable output energy and the plano-concave resonator with a radius of curvature of 1 m is more stable with the highest output energies. The flat-flat resonator with a length of 39.5 cm, presents also a non-stable output. The non-stable results are due to the fact that the flat-flat laser cavity is difficult to align and to maintain its alignment. When longer is the flat-flat cavity, more difficult is the alignment.

As shown in Figure 12 (a), (b), (c), and (d), the obtained Q-switched output laser energies, with the three cavity lengths, are plotted for different output couplers and various HR mirrors.

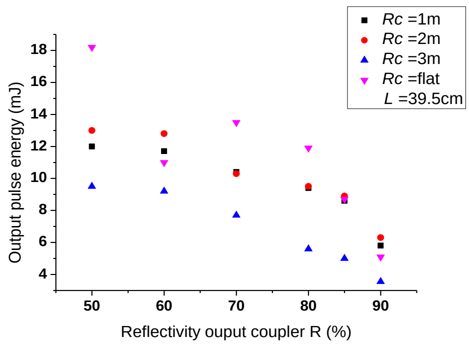


Figure 10. Output laser energy for different output couplers and various HR mirrors for *L* = 39.5 cm

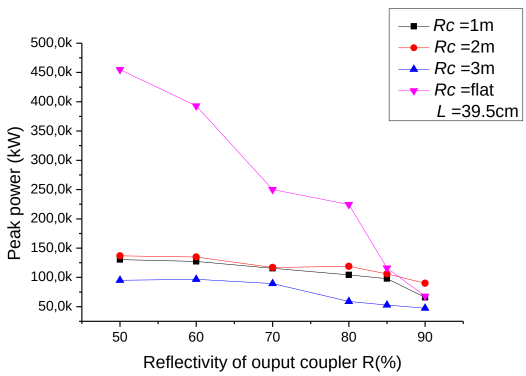
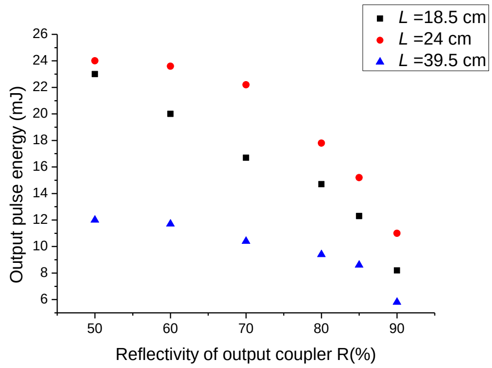
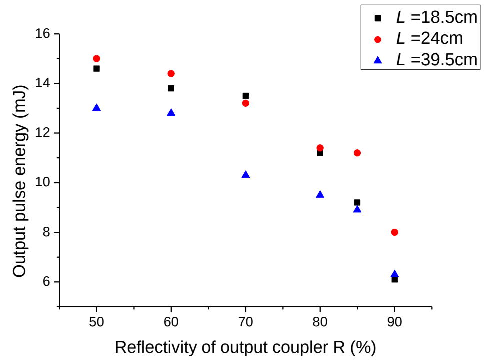


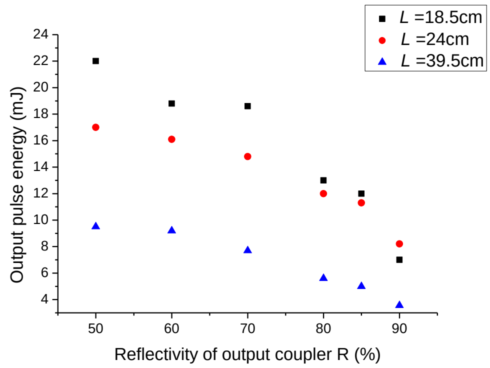
Figure 11. Peak power versus the output coupler reflectivity for *L* = 39.5 cm



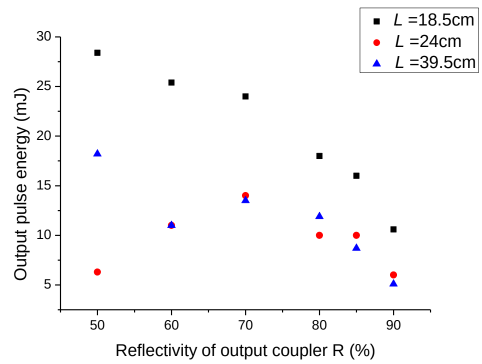
(a) *Rc* = 1m



(b) *Rc* = 2m



(c) *Rc* = 3m



(d) *Rc* = flat

Figure 12. Q-switched output energy versus the output coupler reflectivity for different HR mirrors (*Rc* = 1 m, 2 m, 3 m, flat)

The laser cavity of 24 cm in length provides the highest output energies (Figures 12(a) and 12(b)) with HR mirrors of radii of curvature (*Rc*) of 1 and 2 m. The laser cavity of 18.5 cm provides the best stable output energies (Figures 12(c) and 12(d)), compared to the other cavities, with HR mirrors of radii of curvature of 3 m and a flat one.

Several laser pulses were also generated. Figure 13 shows the train of two pulses that was obtained by increasing the pump energy or by adjusting the alignment mirrors. Figure 14 shows the train of five laser pulses that was obtained only by increasing the pump energy. These multiple laser pulses were generated because of the Cr^{4+} absorption centers bleaching in the Cr^{4+}:YAG crystal, which results in other population inversion in the laser rod [10].

The 2-D and 3-D beam profiles of the passively Q-switched laser cavity, with a length of 18.5 cm and an output coupler reflectivity of 50 %, were observed using a CCD camera and an image processing algorithm. The two profiles are represented in Figure 15.

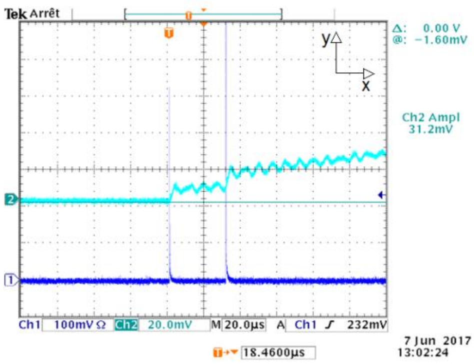


Figure 13. Train of two laser pulses (Ch1: 100 mV/div.) and the response (Ch2: 20 mV/div.) of the Gentec energy detector, (x axis: time scale 20µs/div.)

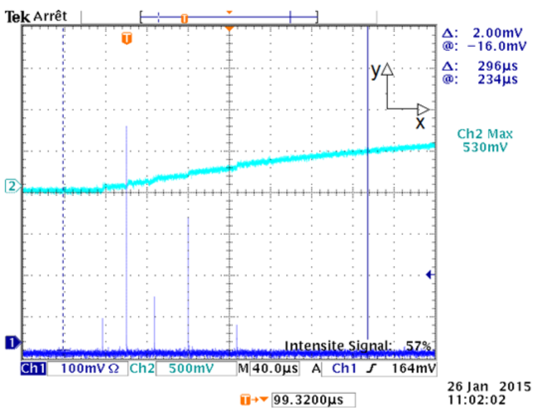
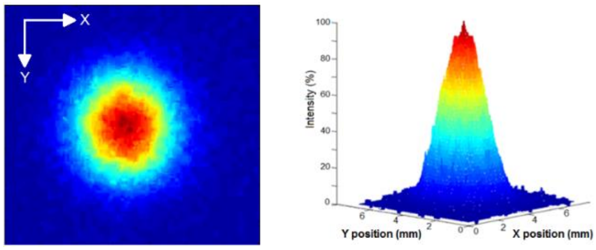


Figure 14. Train of five laser pulses (Ch1: 100 mV/div.) and the response (Ch2: 500 mV/div.) of the Gentec energy detector, (x axis: time scale 40 µs/div)



(a) (b)

Figure 15. 2-D (a) and 3-D (b) beam profiles of the passively Q-switched laser pulse

As observed, the beam has a Gaussian profile, which is more suitable for several interesting applications.

From the different resonators presented in this paper, the experimental studies show that the flat-flat resonator with 18.5 cm cavity length and an output mirror with a reflectivity of 50% exhibits the best performances of the passively Q-switched Nd:YAG laser using Cr^{4+}:YAG saturable absorber with a 28.4 mJ output energy, a 38 ns pulse width, the shortest cavity length, and a Gaussian beam profile. This compact resonator could be easily integrated into a laser system, such as time-of-flight laser range finders [1], medicine applications, and gated imaging systems [2]. In this last application, a second-harmonic generation crystal should be inserted into the laser cavity to get the 532 nm wavelength.

4. CONCLUSION

In this paper, the output performances of a flash-lamp pumped passively Q-switched Nd:YAG laser, with Cr^{+4}:YAG saturable absorber, were experimentally investigated. Flat-flat and plano-concave resonators, with different cavity lengths of 18.5, 24 and 39.5 cm, were studied by the use of different output couplers with a reflectivity of 50, 60, 70, 80, 85 and 90 %. To the best of our knowledge, this is the first experimental study that includes HR mirrors with different radii of curvature. These radii were set to 1, 2, 3 m, and a flat one. It was observed that the radius has an important effect on the output laser performances. The best output laser energy of 28.4 mJ with a pulse width of 38 ns, corresponding to the laser peak power of 631 kW was obtained for the flat-flat resonator with a cavity length of 18.5 cm, pump energy of 21 J and an output coupler reflectivity of 50%.

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Experimental Study of a Flash-lamp Pumped Passively Q-Switched Nd:YAG Laser Using Cr^{4+}:YAG Saturable Absorber

RESEARCH NOTE

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Laser Range Finder

چكيده

این مقاله با نتایج تجربی یک لامپ فلورسنت زنون که با استفاده از لیزر Nd: YAG Passively Q-switched پمپ شده و با جذب اشباع Cr^{4+}: YAG پمپ می شود، مورد بررسی قرار می گیرد. نیاز به یک حفره لیزری در یک فاصله یابنده ی لیزر یکپارچه به عنوان یک آزمایش تجربی از چندین تکنسینر لیزری است. دو نوع رزوناتور لیزر با طول های مختلف مورد مطالعه قرار گرفته است: مسطح و مسطح. هر حفره لیزری شامل یک کوپلر خروجی صاف، مشخص شده با بازتابش، و همراه با یک آینه بازتابنده بالا، اجازه مشاهده ویژگی های خروجی لیزر را می دهد. نتایج نشان داده است که شعاع انحنای آینه بازتابی بالا در تعیین بهترین عملکرد لیزر اهمیت زیادی دارد. بهترین نتایج به دست آمده با استفاده از یک حفره مسطح مسطح با طول ۱۸,۵ سانتی متر، انرژی پمپ الکتریکی ۲۱ J و بازتابنده کوپلینگ خروجی ۵۰٪ است. انرژی لیزر خروجی ۲۸,٤ مگاژول برای پهنای ۳۸ نانومتر بود. پالس های لیزری چندگانه نیز با افزایش انرژی پمپ الکتریکی یا تنظیم تنظیم ترازاتور لیزر به دست می آیند.

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