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BLEACHING AND Q-SWITCHING OF $U^{2+}:CaF_2$ AT 1535nm

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ABSTRACT

Divalent uranium doped CaF_2 Q-switch has been tested as a saturable absorbing Q-switch. Laser output at 1535nm with l0mJ of energy and a 60ns pulse width was demonstrated at 8.5Hz by using $U^{2+}:CaF_2$ as a saturable absorbing Q-switch. The laser media is QE7S and an experimental Er:glass designated QX/ER.

INTRODUCTION

Laser emission at 1535nm, due to the $^4I_{13/2}$ - $^4I_{15/2}$ transition in Er^{3+}:glass, is attractive due to its eyesafe wavelength and ability to transmit with low attenuation through the atmosphere and commercial silica fibers. Additionally, the long fluorescent lifetime (6 – l0ms) makes Er^{3+}:glass an attractive candidate for laser diode pumping. 1535nm lasers are particularly useful for rangefinding, lidar, communications, and atmospheric data measurements.

High repetition rate, high peak power Q-switched pulses are often required for many applications. Mechanical devices, such as rotating mirrors, porro prisms and frustrated total internal reflection (FTIR), are common methods of Q-switching lower repetition rate Er^{3+}:glass lasers. Electro-optical Q-switched Er^{3+}:glass lasers are also available for use at various repetition rates [1]. Passive Q-switching using a saturable absorber may provide a simple, compact, reliable and more economical alternative when compared to these active switching methods.
Using the characteristics of the self-absorption of Er^{3+} in a solid state host, Danker demonstrated passive Q-switching using Er^{3+}:phosphate glass [2] and a low $^4I_{13/2}$ fluorescent lifetime Er^{3+}:borosilicophosphate glass [3] . Q-switched pulses were also experimentally obtained by researchers at the Center for Laser Studies of the University of Southern California using Er^{3+} doped

FAP and CaF_2 [4]. Intracavity focusing was necessary to raise the intracavity power density in order to optimize Q-switching in the low absorption cross section Er^{3+} doped glass and crystal Q-switch materials. The results typically revealed a Q-switched giant pulse followed by a train of free running spikes or multiple Q-switched pulses. Passively Q-switched pulses of 3mJ and 60ns pulse width were successfully obtained using tetravalent uranium doped strontium fluoride (U^{4+}:SrF_2), by R. D. Stultz et al. [5]. In this paper, we report on the bleaching of divalent uranium doped calcium fluoride (U^{2+}:CaF_2), and the results of passively Q-switching an Er^{3+},Yb^{3+}:phosphate glass laser at 1535nm.

SPECTRA AND BLEACHING

Uranium has an outer electronic shell of $5f^3 6d7s^2$ and has been found to exhibit various valence states, (U^{2+}, U^{3+} and U^{4+}) in fluoride crystals. The absorption and fluorescence of uranium in a number of experimental fluoride crystals were measured and reported by W.A. Hargreaves [6,7,8]. Divalent uranium exhibits a broad absorption band centered at 1580nm. This corresponds to a metastable energy level at $^5L7$ with a fluorescence emission at 2600nm. A CaF_2 sample doped with 0.5 atom percent U^{2+} revealed absorption bands at 2530, 1580, 1190, 1100, 650, 540 and 480nm

The absence of any appreciable absorption in the 2100 to 2300nm region or the UV (Caused by U^{3+} and U^{4+}) indicates the presence of a nearly pure U^{2+}valence. The U^{2+} exhibits a relatively

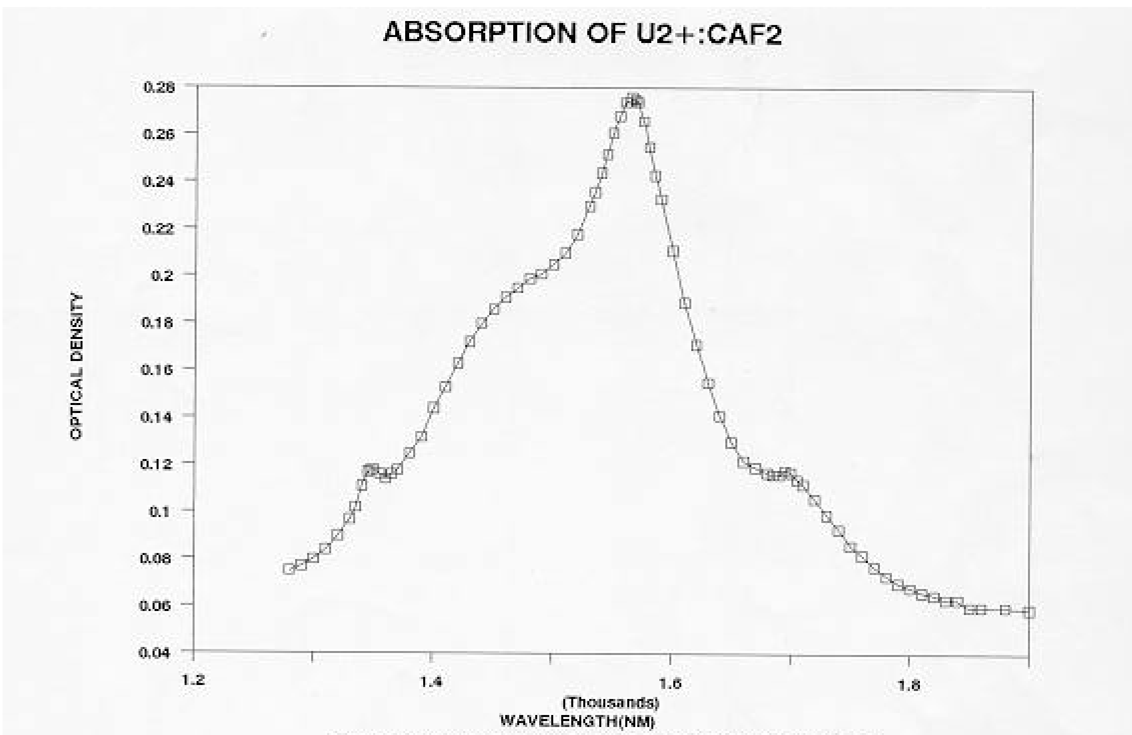

Fig.1 Measured absorption spectra near 1535nm

large absorption cross section at a 1535nm. This in combination with a moderate metastable lifetime are important characteristics for a saturable absorbing Q-switch. The absorption spectra in the vicinity of the 1580nm peak region for $U^{2+}:CaF_2$ is illustrated in Figure 1. The absorption cross section at 1535nm was calculated to be 7.0 x $10^{-20}cm^2$. This value is appreciably larger than the stimulated emission cross section of 0.8 x 10^{-20} cm^2 for Er^{3+} in phosphate glass.

Bleaching experiments were conducted by measuring the transmittance of the samples at various energy densities using a Kigre QE7S Er^{3+} :C^{3+}:Yb^{3+}:phosphate glass pulsed laser. A focusing lens and filters were utilized to increase or attenuate the incidence fluence to the sample. A beam splitter was used to monitor the incidence fluence. Figure 2 illustrates the transmittance as a function of incidence energy. The curve with square symbols represents experimental results while the sohd line is a curve fitted according to the equation by Frantz and Nodvik [9]:

$$T=(F_{sat}/F_{in})\ln(T_0(Exp(F_{in}/F_{sat})-1) + 1).$$

Where F_{sat} is the saturation fluence, F_{in} is the incident fluence and T_0 is the initial transmittance of the sample. The saturation fluence is 57J/cm^2 calculated from experimental data. This is only an approximate value due to the long pumping pulse duration.

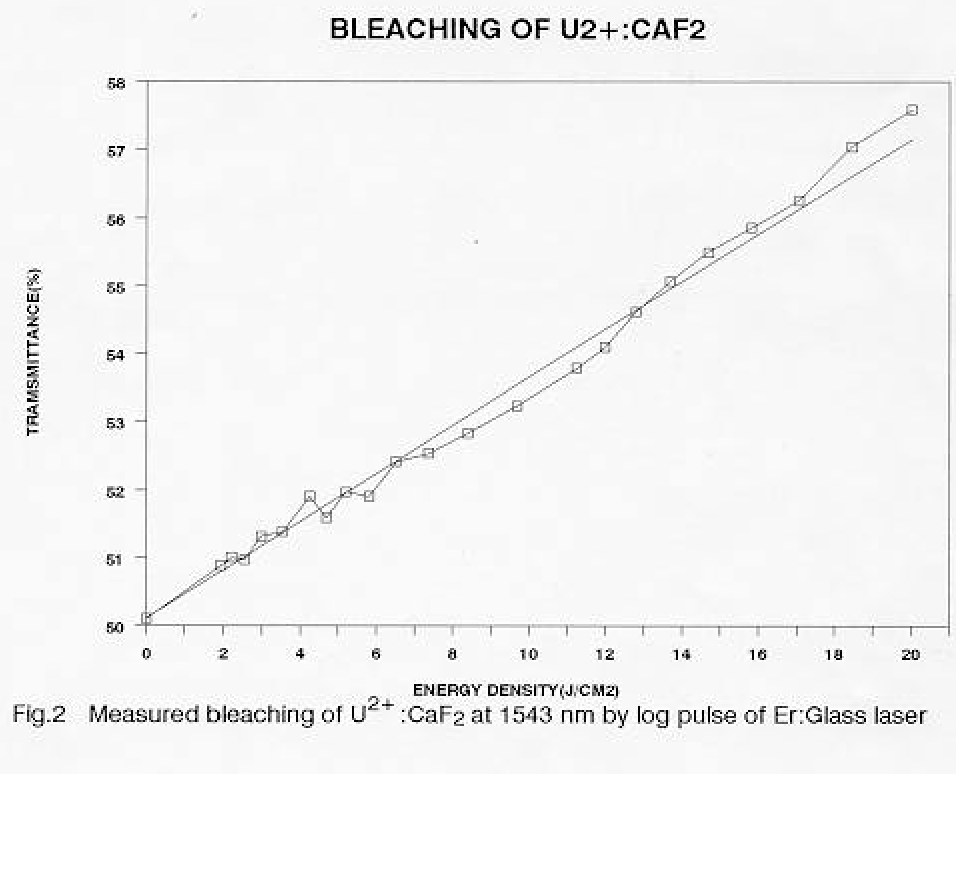

Fig.2 Measured bleaching of U^{2+} :CaF_2 at 1543 nm by log pulse of Er:Glass laser

Q-SWITCHING Due to the large absorption cross section at 1535nm of U2:CaF_2 in comparison to the stimulated emission cross section of Er^{3+} in phosphate glass, intra-resonator focusing was not necessary The first Q-switch experiment was conducted using a normal Er:glass laser resonator, in which the HR mirror is 60cm concave and output coupler is 300cm concave. The 0.5mm diameter of the TEM_{00}mode was nearly constant over the entire cavity length.

Q-switch sample #l had an initial transmission of 82.9%. Output energies of 2mJ and about 60ns pulse widths were obtained in both TEM_{10} and TEM_{30} modes with 33J of pumping. Decreasing the initial transmission to 64% in sample #2 yielded a higher output energy of 6.9mJ with higher transverse modes and a pulsewidth of 27ns with an 87J pump. Adjusting the resonator alignment produced very clear mode patterns such as TEM_{00}, TEM_{10}, TEM_{20}, TEM_{30}, TEM_{40}, TEM_{50}, TEM_{60}, as well as some cylindrical modes. For certain modes, the output energy was found to be quite stable; for example 1.6mJ in TEM_{00} and 2.5mJ in TEM_{10}. The maximum output energy was achieved with a combination of TEM_{00} and cylindrical TEM_{08} modes. This combination of modes has a maximum mode volume and produced output energies up to 6.9mJ. An interesting observation was that the bleaching time for the TEM_{00} and the cylindrical TEM_{08} modes are slightly different and a double pulse output was observed. The delay between the two pulses varied from 50ns to 400ns. We are convinced, this kind of double pulse behavior is completely different from the normal meaning of "double pulse" in saturable absorber Q-switch lasers.

Table 1. Summarized Data of Q-switch Experiments

CAVITY	SAMPLE	BEAM@ SIZE	RATIO*	INPUT ENERGY	REP. RATE	OUTPUT ENERGY	PULSE WIDTH	MODE STRUCTURE
	82.9%	0.5	1:1	33J	1HZ	2.Omj	55ns	TEM30
1	64.0%	0.5	1:1	33	1	1.6	27	TEM00
	64.0%	0.5	1:1	87	1	6.9	27	TEM00+ High
	82.9%	1.04	1.08	53	1	6.4	60	CYL01
	82.9%	0.9	1.21	53	1	8.2	55	CYL01
II	82.9%	0.92	1.21	36	1.5	7.5	65	CYL01
	82.9%	0.53	1.37	33	3.0	6.2	65	MIXED MODE
	82.9%	0.72	1.41	40	1.5	7.6	65	CYL01
	82.9%	0.75	1.47	38	8.5	10	60	MIXED MODE
III	82.9%	0.88	1.25	38	8.5	5	65	CYL01

@ Beam size was calculated according TEM_{00} mode
. Ratio of beam size (TEM_{00} mode) in rod to absorber

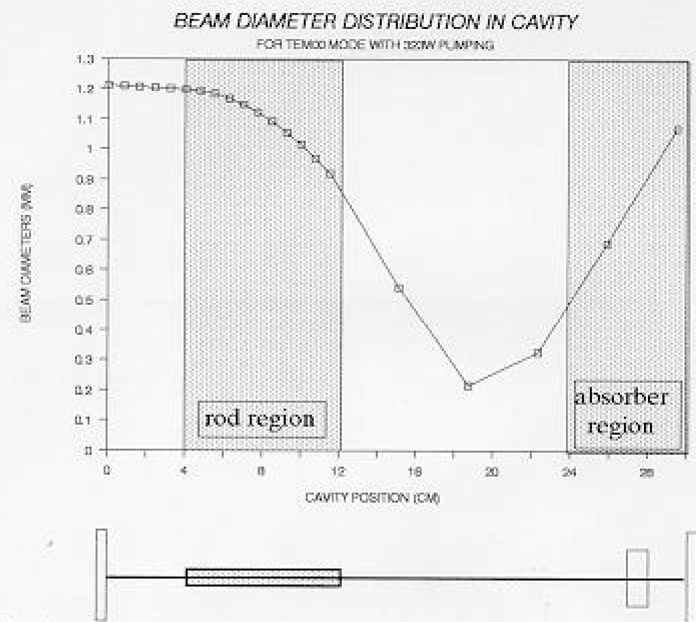

Fig. 3 Designed cavity configuration and beam diameter distrubution along cavity

In order to further increase the Q-switched output a new laser resonator was designed with a variable diameter of mode volume along the axis of the resonator. In this resonator, the influence of the mode size upon the saturable absorber could be easily observed. 8.2mJ of energy with a 55ns pulsewidth was obtained when the saturable absorber sample #1 was moved to the proper beam position with a pump of 53J at l Hz. Table 1 summarizes the results of this experiment illustrating that the control of the beam size in the saturable absorber is very important

Finally, with Kigre's newly developed QX/ER high average power Er:glass exhibiting a maximum thermal loading three times greater than standard QE-7S or about 37OW for a 3X75mm rod, we were able to operate the laser at 10Hz with a 35J pump. The thermal lensing produced by pumping the rod at repetition rates was matched in the resonator design to optimize the spot size in the U^{2+}:CaF_2 passive Q-switch for a single pulse output. Accounting for the thermal lensing in the laser rod, the resonator design produce a high order mode output of l0mJ at 8.5Hz utilizing Q-switch sample #l. This resonator is illustrated in figure 3.

All Q-switch samples were not anti-reflection coated and exhibited poor surface figure and optical quality. We believe that considerable performance improvements are possible; however, this is the first reported operation of a flashlamp pumped, Q-switched, Er:Glass laser operating in excess of 4Hz.

CONCLUSION

Bleaching thresholds for the U^{2+}:CaF_2 crystal have been qualitatively measured and reported. Repetitive passive Q-switching of an E^{3+}:phosphate glass laser using intracavity U^{2+}:CaF2 saturable absorber has been realized for the first time. The results of this work suggest that passive Q-switching of Er:glass lasers is a practical alternative to active Q-switching and may satisfy the demands of numerous eye-safe 1.54m laser applications.

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