IPEN-57

U^{4+}:SrF_2 Efficient Saturable Absorber Q-Switch for the 1.54 μm Er:Glass Laser

R. D. Stultz, M. B. Camargo, S. T. Montgomery, M. Birnbaum,
and K. Spariosu
*Center for Laser Studies, University of Southern California, DRB 17, University Park,
Los Angeles, California 90089-1112*

R. D. Stultz is also with Hughes Aircraft Company at El Segundo, California 90245

*S. T. Montgomery is also with TRW Space and Defense Group at Redondo Beach,
California 90278*

Abstract

Saturable absorber Q-switching of the 1.54 μm Er:glass laser using U^{4+}:SrF_2 has been obtained for the first time. Q-switched pulses of 3 mJ, 60 nanoseconds FWHM were achieved using a 2.69 mm thick Q-switch in a 14 cm long flat-flat cavity, with a 3 x 50 mm Kigre QE-7S Er:glass rod. Pulses of 40 mJ, 64 nanoseconds have been obtained using a 4 x 76 mm Er:glass laser rod. The high absorption cross-section of U^{4+}:SrF_2 at 1.54 μm resulted in efficient Q-switched operation (without intracavity focussing) in agreement with the theoretical predictions.

Introduction

Er:glass has been Q-switched electro-optically,[1] with a rotating mirror,[1] and using frustrated total internal reflection.[2] These methods are usually efficient, but require additional power supplies and moving parts which increase the size, complexity, and cost of the laser system. Er:glass saturable absorber Q-switching using color centers[3] or the Erbium ion in various hosts[4,5,6] has generally performed poorly or has required a certain amount of focussing of the light in the Q-switch material.

We have demonstrated a saturable absorber which efficiently Q-switches the Er:glass laser at 1533 nm in a flat-flat resonator cavity without intracavity focussing. The saturable absorber, tetravalent Uranium ions in Strontium Fluoride (U^{4+}:SrF_2), possesses a broad absorption feature,[7] which peaks close to the Er:glass wavelength (see Figure 1).

Q-Switching Experiments

We had two different U^{4+}:SrF_2 rods available for this work.[8] Their absorption spectra were almost exactly the same at 1.5 μm, however, the second rod possessed significantly reduced U^{3+} absorption peaks (see Figure 2).

The initial Q-switching results were carried out using a Kigre 3 x 50 mm QE-7S Er:glass rod. The rod was flashlamp-pumped with a lamp pulse of about 600 μsec FWHM.

OSA Proceedings on Advanced Solid-State Lasers, 1994, Vol. 20
Tso Yee Fan and Bruce H. T. Chai (eds.)

The resonator cavity consisted of two flat mirrors separated by 14 cm. With the 3 x 50 mm laser rod, two different output mirror reflectivities were used: 82% and 94%. This configuration was used to test Q-switches cut from the first U:SrF_2 rod. The flashlamp energy at threshold for the free-running laser in this case (i.e. without a Q-switch) was 13 J with the 94% output mirror, and about 16 J with the 82% mirror.

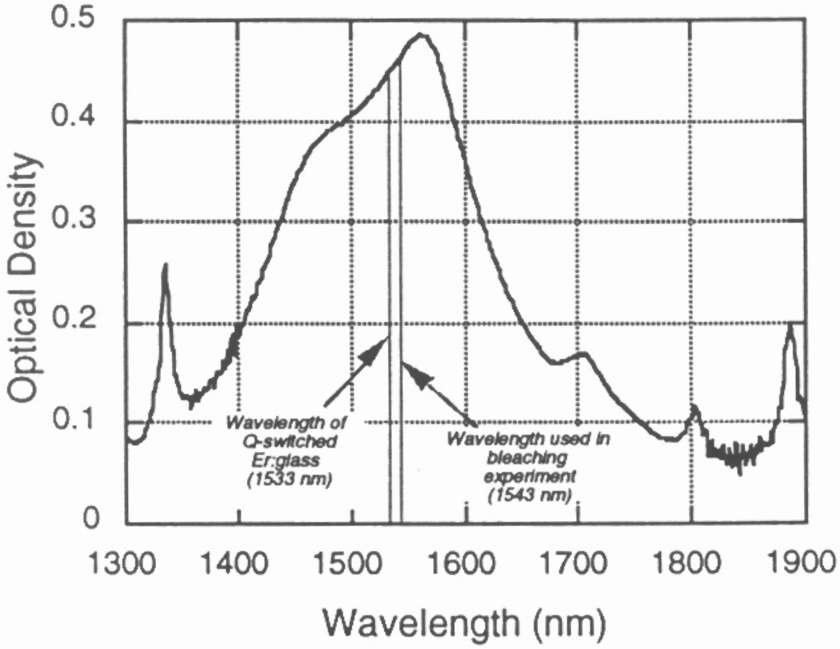

Figure 1. Absorption spectrum of $U^{4+}:SrF_2$ near 1.54 µm.

The Q-switches fabricated from the first U:SrF_2 rod had thicknesses 1.37 mm and 2.69 mm. The Q-switches were polished flat with parallel surfaces and were used uncoated in the laser experiments. The Q-switch surfaces were aligned parallel to the resonator cavity mirrors in all but one case where the 1.37 mm Q-switch was placed at Brewster's angle. These results are summarized in Table I, and a sample pulse (≈60ns FWHM) for the 2.69 mm thick Q-switch with the 94%R output mirror is shown in Figure 3. A 4 x 76 mm (QE-7S) Er:glass rod, with a 63%R outcoupler, was used to test a 2 mm thick Q-switch (at Brewster's angle) cut from the second $U^{4+}:SrF_2$ rod. This result is also summarized in Table I.

The output beam diameter of the Q-switched laser was always much smaller than that of the free-running laser (regardless of Q-switch and Er:glass rod used). Figure 3 shows some sample beam burns, with the 4mm diameter Er:glass rod, which demonstrate this observation. The free-running beam (Figure 4a), was roughly the same size as the laser rod aperture. However, the Q-switched output appeared to be limited to a few low order transverse modes, and as a consequence the output energy was much smaller than that of the free-running laser at the same input. Just above threshold, the Q-switched output was near diffraction-limited (Figure 3b, single-pulse burn), verified by scanning the near and far-field beams with a knife-edge. As the flashlamp input was increased, one or more additional modes appeared, usually as a second pulse (Figure 4b, double-pulse burn). With the 4 mm diameter rod in a 15.5 cm long cavity, we were able to obtain a higher-order mode in a single Q-switched pulse (Figure 4c). As expected, the larger modes, which filled more of the laser rod aperture, resulted in higher output energies.

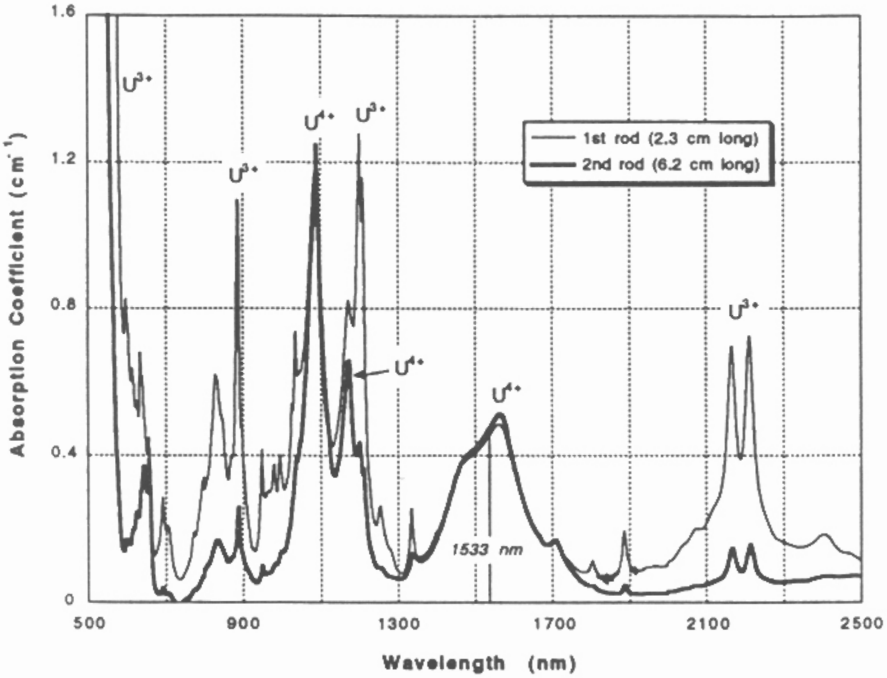

Figure 2. **Room temperature absorption spectra of the two U:SrF_2 rods used in this work.**

Table I. Summary of U^{4+}:SrF_2 Q-Switch Experimental Results.

Output mirror reflectivity	Er:glass rod	Q-Switch Thickness (mm)	Q-Switched Output Energy (mJ)	Q-Switched Pulsewidth (nsec)	Threshold (J)
94%	3 x 50 mm	1.37	2	220	15
94%	"	1.37 (Brewster)	3	91	17
94%	"	2.69	3	60	20
82%	"	1.37	1.2	590	18
82%	"	2.69	5	130	23
63%	4 x 76 mm	2.0 (Brewster)	40	64	55

The wavelengths of both the Q-switched and free-running laser were measured using a 1/4 meter Jarrell-Ash monochromator. The wavelength of the Q-switched laser was about 1533 nm, compared to about 1534 nm with the free-running laser.

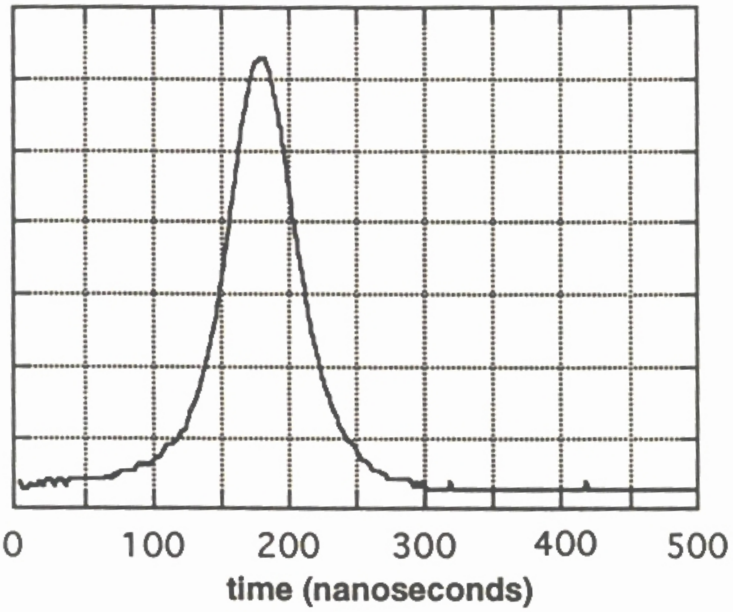

Figure 3. Q-switched pulse (50 nsec per division).

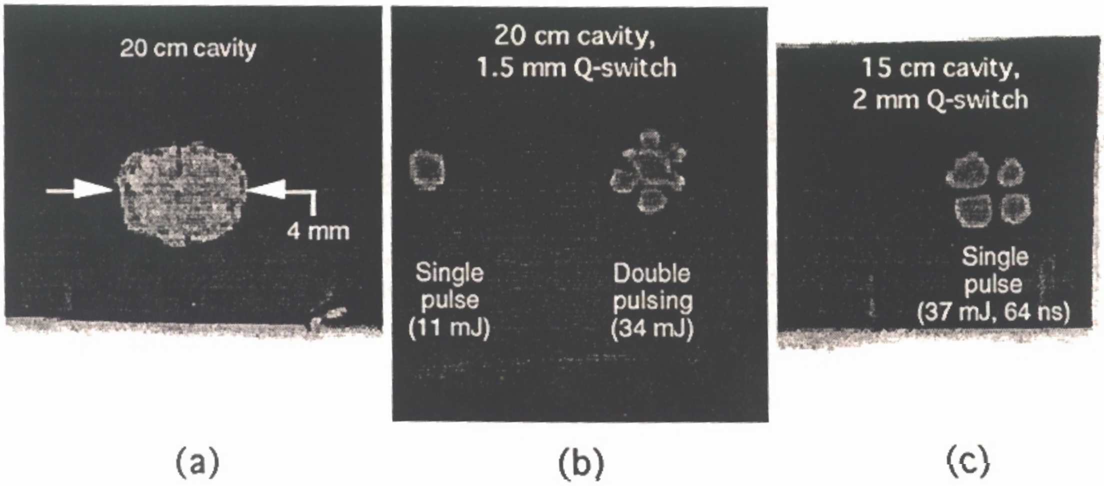

Figure 4. Beam burns of (a) free-running laser, (b) Q-switched laser with 20 cm. cavity and 1.5 mm $U^{4+}:SrF_2$ Q-switch, and (c) Q-switched laser with 15.5 cm. cavity and 2 mm Q-switch.

Measurement of Saturation Fluence

The $U^{4+}:SrF_2$ absorption cross-section was determined by measuring the saturation fluence using a Raman-shifted Nd:YAG laser at 1543 nm. The 1543 nm light was focussed to a 1.3 mm spot diameter and the Full-Width at Half-Maximum (FWHM) pulsewidth was 15 nanoseconds. The FWHM spectral linewidth was less than one nanometer. The results of this experiment are shown in Figure 5.

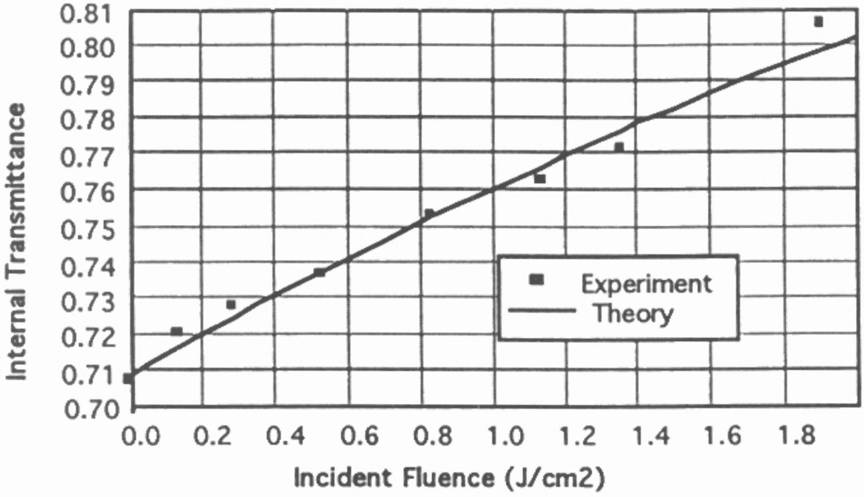

Figure 5. 1543 nm bleaching of 9 mm thick crystal cut from the first $U^{4+}:SrF_2$ rod. Saturation fluence = 1.86 J/cm^2.

Assuming that the lifetime of the upper level of $U^{4+}:SrF_2$ is long compared to the bleaching pulse, the Frantz-Nodvik equation,[9] modified for absorption, can be used to model the experimental results. The transmittance T is given by:

$$T = \frac{F_{sat}}{F_{in}} \ln\{(T_0(\exp[\frac{F_{in}}{F_{sat}}] - 1) + 1\} \quad (1)$$

where F_{in} is the incident fluence (J/cm^2), F_{sat} is the saturation fluence, and T_0 is the small-signal transmittance. A least-squares fit to the experimental data yielded a saturation fluence of 1.86 J/cm^2 (see Figure 5). For a 3-level absorber (i.e., the upper level of the transition empties to a third level infinitely fast compared to the bleaching pulse duration), $F_{sat} = h\nu/\sigma$, where σ is the absorption cross-section. The absorption cross-section so determined using the first $U:SrF_2$ rod was about 0.7 x 10^{-19} cm^2 at 1543 nm. The bleaching results from the second rod indicated an even higher cross section of 0.9 x 10^{-19} cm^2. Theoretical modeling of the Q-switched operation showed good agreement with the results listed in Table I.

In order to measure the upper level lifetime for $U^{4+}:SrF_2$, we used a continuous-wave 1.52 µm Helium-Neon (HeNe) laser to probe a region of the crystal pumped with a single pulse from a Q-switched Er:glass laser. The Q-switched pulse bleached the crystal while the HeNe probe was used to monitor the transmittance as a function of time. Our preliminary results show a e^{-1} lifetime of approximately 65 microseconds. This confirms our assumption of a slowly relaxing saturable absorber.

References

1. I.L.Borob'ev, V.P.Gapontsev, A.K.Gromov, A.A.Izyneev, A.M.Onishchenko, and P.I.Sadovskii, "Erbium minilaser operating under free-running and Q-switching conditions", Sov.J.Quantum Electron. **20**, 1065(1990).
2. B.I.Denker, V.V.Osiko, S.E.Sverchkov, Yu.E.Sverchkov, A.P.Fefelov, and S.I.Khomenko, "Highly efficient erbium glass lasers with Q switching based on frustrated total internal reflection", Sov.J.Quantum Electron. **22**(6), 500(1992).
3. V.V.Bryukvin, A.V.Lukin, E.E.Penzina, and L.M.Sobolev, "Alkali-halide crystals with Z_4 centers as phototropic shutters for lasers", Opt.Spectrosc.(USSR) **67**(3), 413(1989)
4. B.I.Denker, G.V.Maksimova, V.V.Osiko, S.E.Sverchkov, and Yu.E.Sverchkov, "New methods for passive Q-switching of erbium glass lasers", Sov.J.Quantum Electron. **20**(8), 877(1990).
5. B.I.Denker, G.V.Maksimova, V.V.Osiko, S.E.Sverchkov, and Yu.E.Sverchkov, "Erbium glass lasers with passive Q-switching of the resonator by a component containing erbium", Sov.J.Quantum Electron. **21**, 774(1991).
6. K. Spariosu, R. D. Stultz, M. Birnbaum, T. H. Allik, and J. A. Hutchinson, "Er:$Ca_5(PO_4)_3F$ Saturable Absorber Q Switch for the Er:glass Laser at 1.53 μm", Appl. Phys. Lett. **62**, 2763(1993).
7. W. A. Hargreaves, "High-Resolution Measurements of Absorption, Fluorescence, and Crystal-Field Splittings of Solutions of Divalent, Trivalent, and Tetravalent Uranium Ions in Fluoride Crystals", Phys. Rev. **156**, 331(1967).
8. Our thanks to Dr. Robert Sparrow of Optovac, N. Brookfield, MA 01535, for the U^{4+}:SrF_2 crystals used in this work.
9. L. Frantz and J. Nodvik, "Theory of Pulse Propagation in a Laser Amplifier", J. Appl. Phys. **34**, 2346(1963).