

Spectral Bleaching and 1535 nm Q-Switching of Uranium Glass

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INTRODUCTION

Laser emission at 1535nm from Er^{3+} :glass lasers is interesting due to its eye-safe wavelength and high transmission through the atmosphere and commercial fused silica fibers. Er^{3+} :glass lasers have been used for a number of applications including rangefinding, lidar, communication, and atmospheric data measurements. High peak power, Q-switched pulses are required for many of these applications. Mechanical devices, such as rotating mirrors, porro prisms, and frustrated total internal reflection are still the most popular methods of Q-switching Er:Glass Lasers. Spinning prism and Electro-optical Q-switched Er^{3+} :glass lasers have been produced by Kigre, Inc. for various repetition rates[1]. Compared to active Q-switching, passive Q-switching using a saturable absorber is simpler, more compact, and lacks additional auxiliary electronics.

Passive Q-switching of Er^{3+} :glass lasers has recently attracted the attention of many researchers. Q-switching of Er:glass laser has been demonstrated by Danker et. al.[2] using the characteristics of the self-absorption of Er^{3+} at 1.53m and the long lifetime of its $^4\text{I}_{13/2}$ energy level. Denker reported Q-switching with a high concentration

Er^{3+} :phosphate glass as well as a shorter $^4\text{I}_{13/2}$ 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 crystals[4]. In all of the above examples intracavity focusing was found to be necessary to produce the desired Q-switching results. This is primarily due to the low absorption cross section of the Er^{3+} doped glass and crystal samples studied. Results typically revealed a giant Q-switched pulse followed by free-running spikes or multiple Q-switched pulses. Without intracavity focusing Q-switched pulses of 3mJ and 60ns FWHM were reported by Stultz et. al. [5] using tetravalent uranium doped strontium fluoride. 1535nm, 8mj, single mode, 57ns pulses at 1Hz and 6mj, multimode 60ns pulses at 3Hz have also been obtained from Er^{3+} : Yb^{3+} :phosphate glass lasers without intracavity focusing using U^{2+} : CaF_2 at Kigre[6]. This paper presents data on the bleaching and Q-switching of Er^{3+} :phosphate glass lasers using a uranium doped glass saturable absorber.

SPECTRA

Uranium has an electronic shell of $5f^3 6d 7s^2$ and produces various valence of U^{2+} , U^{3+} and U^{4+} in ionic crystals. $(UO_2)^{2+}$ doped silicate glass has been used as filters and as fluorescent materials in the past [7]. The absorption and fluorescence of uranium in fluoride crystals were carefully measured by W.A. Hargreaves [8,9]. A large absorption cross section at the laser wavelength and an appropriate lifetime of the metastable level are important for a saturable absorber to be appreciably bleached at a reasonable fluence level. Divalent uranium in a fluoride crystal host exhibits a broad absorption band with a peak at 1560nm and a fluorescence emission at 2600nm corresponding to a metastable $5L_7$ energy level.

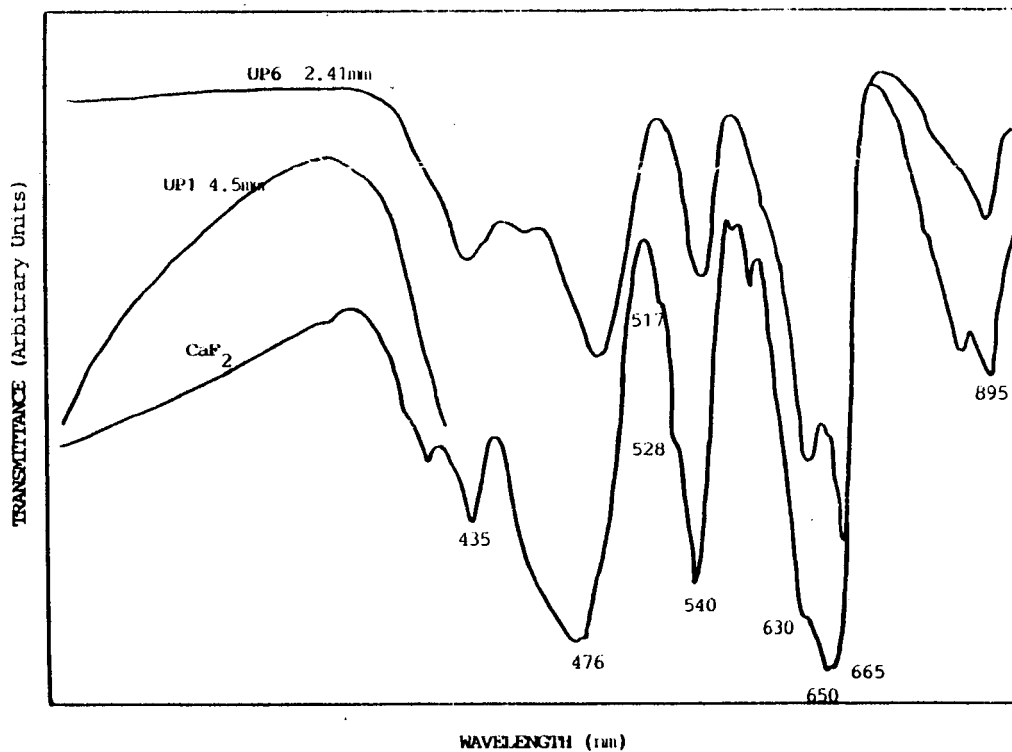
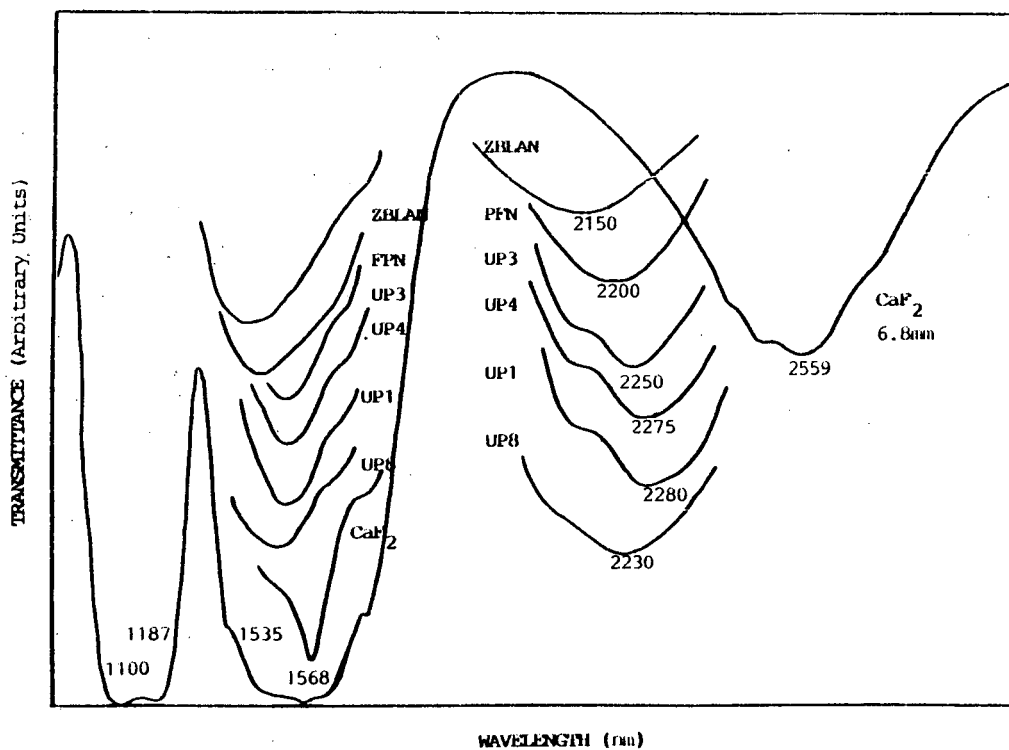
The absorption bands of uranium ions in the visible and near infrared regions correspond to the excitation of unfilled 5f electrons. The 5f electron shell is well shielded by the filled $6s^2$, $6p^6$ and $7s^2$. The influence of a given ligand field will be small compared to the spin-orbit and electrostatic interactions among the 5f electrons. The energy levels and spectra of uranium in a glass host are similar to that of a crystal host. These similarities indicate that divalent uranium doped glasses also lend themselves to bleaching and Q-switching at 1535nm.

Various uranium doped fluoride, fluorophosphate and phosphate glasses were melted under oxidizing and reducing environments. The optical absorption spectra of these glasses is shown in Fig.1 for the near IR region and Fig.2 for the visible region. The spectra of $U^{2+} : CaF_2$ is shown for comparison. When compared to the spectra of $U^{2+} : CaF_2$, the measured absorption bands of glasses at 2250, 1500, 1100, 900, 660, 540 and 470nm indicate that most of the uranium

is in the divalent state. The peak wavelengths of typical absorption bands of U^{2+} at 1500 and 2200nm changed with each different glass base. For example, 1500 and 2270nm peaks are exhibited for the phosphate glass 1400 and 2150nm peaks for the zirconium fluoride based glasses. A similar variation of peak absorption occurs for the 4f transition in rare-earth doped oxide and fluoride glasses. Compared to the change of absorption peak from 2560nm in $U^{2+} : CaF_2$, 2350nm in $U^{2+} : SrF_2$ to 2270nm in $U^{2+} : BaF_2$, it is reasonable for U^{2+} doped barium metaphosphate based glass to show a peak absorption at the vicinity of 2250nm.

U^{3+} has a very strong characteristic absorption band at 2200nm and U^{4+} has a very strong broad absorption in the ultraviolet with a maximum at approximately 369nm caused by the d-band absorption in fluoride crystals. Phosphate glasses designated UP3, UP4 and UP1 were melted under moderately reducing or air atmosphere. These glasses exhibit an absorption shoulder at 2150nm which is caused by small amounts of U^{3+} and absorption in the UV at less than 390nm which is evidence of an U^{4+} . The absence of absorptions in the 2150nm and UV wavelength region for ZBLAN, fluorophosphate PFN and phosphate glass UP6, which melted under a very strong reducing environment, verifies the nearly pure valence of U^{2+} .

The optical density of a strongly reduced phosphate glass doped with 0.5wt% UO_2 is shown in Fig.3. The 1500nm absorption band width is 306nm FWHM. This is broader than that of $U^{2+} : CaF_2$ which exhibits a 235nm FWHM absorption band width. The U:Phosphate Glass absorption cross section at 1535nm was calculated to be $5.56 \times 10^{-20} \text{ cm}^2$. This is much larger than the stimulated emission cross section of $0.8 \times 10^{-20} \text{ cm}^2$ for Er^{3+} in phosphate glass, but slightly less than the



The Visible Spectra of U^{II+} Doped Glasses and CaF_2

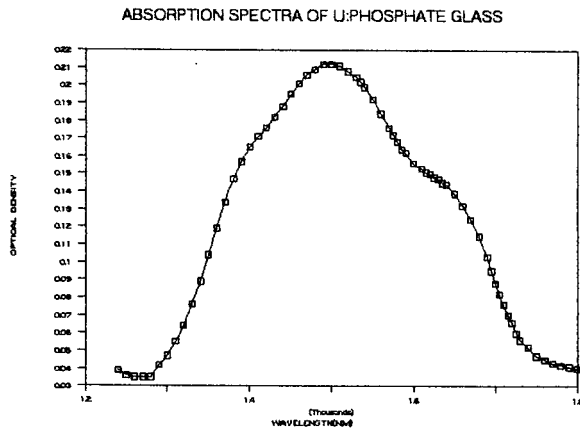


Fig.3 absorption Spectra of U:Glass

absorption cross section of $U^{2+}:\text{CaF}_2$ ($7 \times 10^{-20} \text{ cm}^2$).

BLEACHING

Bleaching experiments were carried out by measuring the transmittance of samples at various energy densities using a Kigre QE7S $\text{Er}^{3+}:\text{Yb}^{3+}$:phosphate glass laser. A focusing lens and filters were utilized to increase or attenuate and a beam splitter was used to separate and monitor the incident fluence. The incident and transmitted laser pulses were measured by energy meters displaying average values of 100 shots. Shown in Fig.4 is the transmittance variation as a function of incident energy of the glass sample designated UP3. The curve with square symbols denotes the experimental results. The transmittance increases quickly in the low energy density region of less than 4 J/cm^2 and appears to slowly change at higher energy densities. This is quite different from the bleaching data obtained for U^{2+} doped CaF_2 by the authors[6]. The crystal data exhibits a linear rate in increase of transmittance with energy density. We believe that this behavior is due to the influence of an excited state absorption in U^{2+} :glass from the metastable energy level to a higher energy state with a energy gap equal to the energy of excitation. A similar result was observed in the bleaching

experiments of Er^{3+} doped phosphate glass samples by the authors.

The two segment solid line shown in Fig.4

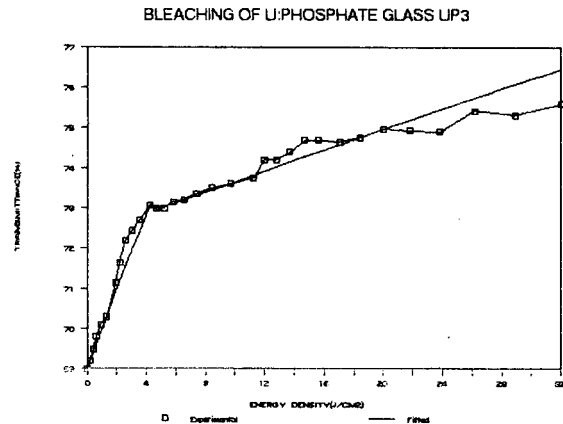


Fig.4 Bleaching of U:Phosphate Glass

is a curve fitted according to the equation by Frantz and Nodvik[11] for a slowly relaxing absorber with only saturable loss:

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

Where F_{sat} is the saturation fluence, F_{in} is the incident fluence and T_0 is the initial transmittance of the sample. Using this equation the calculated saturation fluences for UP3 are 10.5 J/cm^2 for the first segment at the energy density of less than 4 J/cm^2 and 72 J/cm^2 for the second segment at the energy densities from 4 to 36 J/cm^2 . These data points are only approximate values, due to the long pumping pulse duration.

Q-SWITCHING

A Kigre Er^{3+} glass pulsed laser with a 5mm dia. \times 75mm long QE7S rod was employed for U^{2+} :glass Q-switching experiments. The rod was flashlamp-pumped with a lamp pulse of about 1ms. The resonator cavity used was plane-parallel with a 95% reflective output mirror. The U^{2+} :glass samples were polished parallel and left un-

coated. They were placed intracavity, perpendicular to the optical axis and parallel to the resonator cavity mirrors. High transmission samples were utilized due to the relatively low gain provided by Er^{3+} doped solid state laser mediums. Fig.5 shows a typical Q-switch result consisting of one switched gain pulse followed by several free-running spikes of much lower peak power. We believe that this result is attributed to the low saturation fluence of uranium glass in combination with the long lifetime of the $^4\text{I}_{13/2}$ upper laser energy level of Er^{3+} in glass.

CONCLUSION

We believe that this is the first time that a divalent uranium doped glass has been demonstrated as a saturable absorber, passive Q-switch material for a 1535nm laser.

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REFERENCES

- (1) S.J. Hamlin, J.D. Myers and M.J. Myers, SPIE Processing 1419, 100 (1991)
- (2) B.I. Denker, G.V. Maksimova, V.V. Osiko et. al., Sov. J. Quantum Electron. 20,877 (1990)
- (3) B.I. Denker, G.V. Maksimova, V.V. Osiko et. al., Sov. J. Quantum Electron. 21,774 (1991)
- (4) M.B. Camargo, R.D. Stultz, M. Birnbum and K. Spariosu, CLEO '94 Technical Digest, 115 (1994)
- (5) R.D. Stultz, M.B. Camargo, S.T. Montgomery, M. Birnbum and K. Spariosu Advanced Solid-State Lasers, 1994 Technical Digest, 348 (1994)
- (6) Yasi Jiang, Rukun Wu, Daniel Rhonehouse, Michael J. Myers and John D. Myers, to be published at SPIE's International Symposia, Photonics West '95.
- (7) T.E. Stark, L.A. Cross, J.L. Hobart, Semi-annual Technical Report to Naval Research Physical Sciences Division, Contract No.NONT-4125(00), NR015-702, Feb. 1964
- (8) W.A. Hargreaves, Physical Rev. 156, 331 (1967). Physical Rev. B2, 2273 (1970)
- (9) W.A. Hargreaves, Private communication, 1992
- (10) L. Frantz and J. Nodvik, J. Appl. Phys. 34,2346(1963)