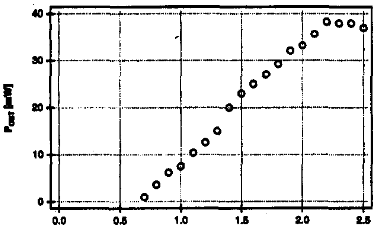

CFE2 Fig. 2 Cr^{4+}:forsterite laser output as a function of 744-nm pump power. The use of a 3% output coupler resulted in a 0.7 W threshold power.

portant in applications that require laser designs using shorter crystals such as for diode pumping and femtosecond pulse generation. For diode laser pumping, short crystals enable a wider range of cavity designs, which can effectively mode-match the diode pump and laser cavity modes necessary for efficient laser operation. Previous studies in mode-locked Ti:sapphire demonstrate that short laser crystals are essential for reducing the effects of higher order dispersion, which limit pulse duration.[6] This paper suggests the possibility of using Cr:forsterite for achieving diode-pumped operation as well as improved femtosecond pulse generation in the 1.3 micron regime.

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1. V. Petricevic, S. K. Gayen, R. R. Alfano, Appl. Phys. Lett. **53**, 2590 (1988).
2. T. J. Carrig, C. R. Pollock, Opt. Lett. **16**, 1662 (1991).
3. V. Yanovsky, Y. Pang, F. Wise, B. I. Minkov, Opt. Lett. **18**, 1541 (1993).
4. M. I. Demchuk, N. I. Zhavoronkov, V. P. Mikhailov, B. I. Minkov, J. Quantum Electron. **21**, 19 (1994).
5. T. J. Carrig, C. R. Pollock, IEEE J. Quantum Electron. **QE-29**, 2835 (1993).
6. M. T. Asaki, C. P. Huang, D. Garvey, J. Zhou, H. C. Kapteyn, M. M. Murnane, Opt. Lett. **18**, 977 (1993).

CFE3 **8:45 am**

Saturable Bragg reflector mode-locking of Cr^{4+}:YAG laser pumped by a diode-pumped Nd:YVO_4 laser

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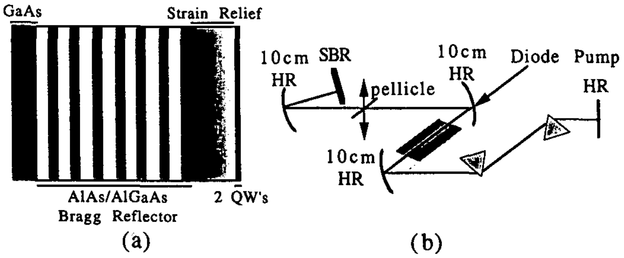
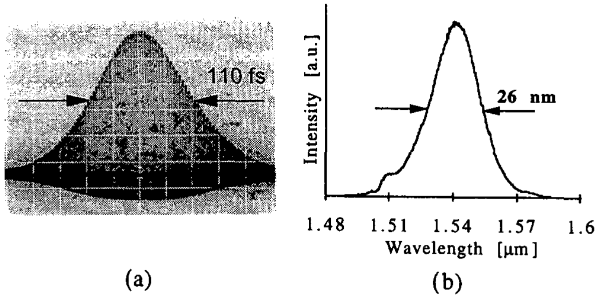
Mode-locked solid-state lasers with broadband gain have led to rapid advancements in the production of the ultrashort pulses. In 1991, Shestakov *et al.* reported the first room-temperature cw lasing of Cr^{4+}:YAG[1] in the 1550-nm telecommunications window of optical fiber. Kerr-lens mode-locking (KLM) of Cr^{4+}:YAG has produced pulses as short as 46 fs.[2,3] In this paper, we demonstrate self-starting passive femtosecond mode-locking of Cr^{4+}:YAG using a nonlinear mirror called a saturable Bragg reflector (SBR). We pump the Cr^{4+}:YAG, whose absorption band is centered around 1000 nm, with a diode-pumped Nd:YVO_4 laser.[4] We discuss the SBR mode-locking of this laser and compare with KLM techniques.

Recently, Tsuda *et al.* demonstrated self-starting passive SBR mode-locking of a Cr:LiSAF laser by a Bragg reflector fabricated in AlAs/AlGaAs with a single quantum well [Fig. 1(a)] providing the mode-locking saturation dynamics.[5] We have extended that SBR technology to the 1550-nm region. Our laser configuration consists of an astigmatically compensated folded Z cavity with a 20-mm Brewster cut Cr^{4+}:YAG crystal (IRE-POLUS), 10-cm radii focusing mirrors and two SF-10 prisms 17 cm apart providing GVD compensation [Fig. 1(b)]. All mirrors have reflectivities centered about 1550 nm. The pump beam from a diode-pumped Nd:YVO_4 (Spectra-Physics OEM) is focused through one of the focusing mirrors delivering about 10 W of power at 1060 nm. The maximum cw power obtained is 1.35 W at 1500 nm. A 10-cm mirror focuses one end of the cavity on the surface of the SBR. A pellicle is used as a variable output coupler for SBR mode-locking.

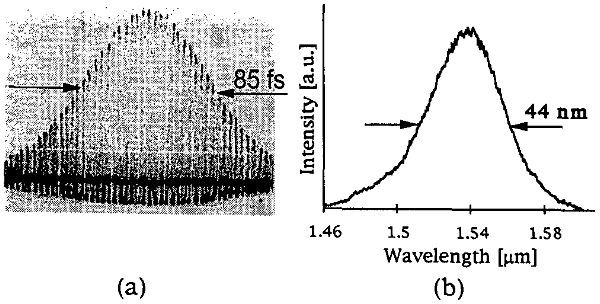
Self-starting SBR mode-locking is obtained between 1530 and 1545 nm with pulses as short as 110 fs and a total output of 70 mw for approximately 9 W of pump power. Figures 2(a) and 2(b) show the spectrum and autocorrelation trace of the output. The repetition rate of the laser is 150 MHz with TEM_{00} mode output. When saturated, the SBR is estimated to have 0.5% loss. The total output coupling



CFE3 Fig. 1 (a) Diagram of the structure of the SBR. (b) Diagram of the cavity with the intracavity SBR.



CFE3 Fig. 2 (a) Typical spectrum of SBR mode-locked output. (b) Typical autocorrelation trace for SBR mode-locked output.



CFE3 Fig. 3 (a) Typical spectrum of KLM mode-locked output. (b) Typical autocorrelation trace for KLM mode-locked output.

is 1.4%. The SBR focusing mirror is then replaced with a 1.5% flat output coupler and KLM is started by an SBR in a coupled external cavity. Pulses as short as 85 fs between 1510 and 1545 nm with an average output power of 150 mw are obtained. Figures 3(a) and 3(b) show the spectrum and autocorrelation trace of the output.

In the case of mode-locking with the SBR, it is believed that the transient saturation dynamics of the SBR is the dominant mode-locking mechanism.[5] By changing the SBR focusing, the pulsewidth can be varied well into the picosecond regime were as much as 160 mw total output is obtained. Increasing or decreasing the SBR-focusing mirror separation away from this point causes the pulsewidth and average power to decrease.

We discuss further comparisons between SBR and KLM mode-locking in this material system, optimum design of the SBR, and the advantages of the use of a diode-pumped solid-state source for this application.

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1. A. V. Shestakov, N. I. Borodin, V. A. Zhitnyuk, A. G. Ohrimtchyuk, V. P. Gapontsev, in *Conference on Lasers and Electro-Optics*, Vol. 10, 1991 OSA Technical Digest Series (Optical Society of America, Washington, DC, 1991), paper CPDP11.
2. P. M. W. French, N. H. Rizvi, J. R. Taylor, Opt. Lett. **18**, 39–41 (1993).
3. Y. Ishida, K. Naganuma, Opt. Lett. **19**, 2003–2005 (1994).
4. A. Sennaroglu, C. R. Pollock, H. Nathel, J. Opt. Soc. Am. B **12**, 930–937 (1995).
5. S. Tsuda, W. H. Knox, E. A. de Souza, W. Y. Jan, J. E. Cunningham, Opt. Lett. **20**, 1406–1408 (1995).

CFE4 **9:00 am**

Amplification of broadband chirped pulses up to the 100 mJ level using alexandrite-pumped neodymium-doped glasses

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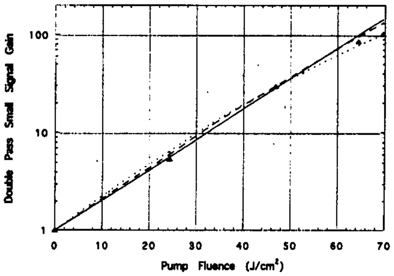
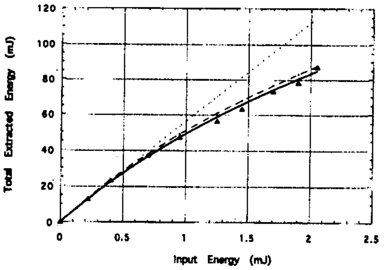
We report the amplification of broadband pulses in laser-pumped Nd:glasses with obvious applications to ultrashort pulse technology and to a front-end for the envisioned Megajoules laser facility devoted to inertial confinement fusion (ICF) studies and ignition demonstration.[1] The broadband capability is then required to implement optical smoothing techniques with nanosecond pulses[2] or possibly the fast ignition scheme based on the use of picosecond pulses.[3]

Nd:glass systems have been already demonstrated as able to deliver very-high-peak-power pulses when associated with the chirped pulse amplification (CPA) technique.[4,5] Furthermore, there has been interesting previous demonstrations of CPA Nd:glass regenerative amplifier[6] and amplifier stage[7] pumped by an alexandrite laser. Alexandrite lasers have several advantages in terms of high repetition rate, large tunability, large energy delivery in a duration fully compatible with the Nd^{3+} excited-state lifetime and a mode quality allowing longitudinal pumping.

Although the advantage of using Nd:glass includes that rods can be cast into a great variety of forms and sizes with excellent homogeneity at relatively low cost, major limitations of Nd:glass in terms of amplification consist of limited bandwidth and poor thermo-mechanical properties. Another concern lies in the spectroscopic properties of Nd:glass. This is important in determining whether or not pumping in the wings of absorption bands may result in any narrowing of the emission and decrease the energy extraction capability. This is important also to determine the energy storage in glasses, which is depending on transitions rates as a function of temperature, doping and excitation wavelength.[8]



CFE4 Fig. 1 Experimental small-signal double-pass gain measurements versus pump fluence, with 0.56 μJ input energy and 10.2-nm input bandwidth. ▲ Total extracted energy/input energy. Theoretical small signal gain when adjusting η_Q to be equal to 0.49 in continuous line. The theoretical small signal gain when taking into account Upconversion Auger (equivalently η_Q is equal to 0.51) is in dashed line, the theoretical small signal gain when taking into account upconversion effect and excited state absorption (equivalently η_Q is equal to 0.59) in dotted line.



CFE4 Fig. 2 Output energy versus input energy with 10.2-nm initial bandwidth. ▲ Total energy extracted. The theoretical curve with η_Q equal to 0.49 is in dark line, the small signal gain in dotted line and when η_Q is equal to 0.59 in dashed line.

We have therefore developed an amplifying stage made of Nd^{3+}-doped phosphate and silicate glass rods, which are respectively placed in a symmetric configuration and pumped from one side by a free-running Alexandrite laser. The amplifier is fed by the output of an all-Titane Sapphire chirped-pulse amplifier system, which includes a Kerr-lens mode-locked Ti:sapphire oscillator and a regenerative amplifier able to deliver up to 5 mJ of chirped pulses at 1.06 μm. We have studied the gain versus pump fluence and pump wavelength. We find that pumping in the wings of the absorption spectrum allows us to better distribute the deposition of thermal energy while keeping a broadband amplification capability. A double-pass small-signal gain of up to 100 has been measured (Fig. 1) when pumping at 782.5 nm with only 2.4 joules at a 1-Hz repetition rate. We have also studied the total extracted energy versus input energy with 10-nm input bandwidth. We demonstrate that pulses in the 100 mJ range can be produced (Fig. 2). A model of amplification that takes into account the exact configuration is shown to agree with these experimental performances only when assuming that the stored energy is half of what should be obtained with a pump quantum efficiency of one. We discuss the physical origins of this loss mechanism in terms of spectroscopics properties of high density and excited states of Neodymium ions such as Auger upconversion and excited state absorption,[8,9] and present related experimental results.

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1. Proceedings of the IAEA Technical Committee Meeting on Drivers for Inertial Confinement Fusion, Nov. 14–18, 1994, Paris, France, J. Coutant, ed. IAEA-CEL-V.
2. R. H. Lehmberg, S. P. Oberschain, Opt. Commun. **46**, 27–31 (1983).
3. M. Tabak, J. Hammer, M. E. Glinsky, W. L. Kruer, S. C. Wilks, J. Woodworth, E. M. Campbell, M. D. Perry, R. J. Mason, Phys. Fluids **4**, 11 (1992).
4. D. Strickland, G. Mourou, Opt. Commun. **56**, 219 (1985).
5. N. Blanchot, C. Rouyer, C. Sauteret, A. Migus, Opt. Lett. **20**, 4 (1995).
6. J. Squier, S. Coe, K. Clay, G. Mourou, Opt. Commun. **92**, 1, 2, 3 (1992).
7. C. Gamache, D. Descamps, D. Husson, S. Seznec, A. Migus, in *Technical Digest Solid-State Lasers for Application to Inertial Confinement Fusion (ICF)*, First Annual International