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Savitski, Vasili G. and Metzger, Nikolaus K. and Calvez, Stephane and Burns, David and Sibbett, W. and Brown, C. T. A. (2012) *Optical trapping with "on-demand" two-photon luminescence using Cr:LiSAF laser with optically addressed saturable Bragg reflector.* Optics Express, 20 (7). pp. 7066-7070. ISSN 1094-4087

Optical trapping with “on-demand” two-photon luminescence using Cr:LiSAF laser with optically addressed saturable Bragg reflector

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Abstract: We demonstrate a diode-pumped Cr:LiSAF laser with controllable and reliable fast switching between its continuous-wave and mode-locked states of operation using an optically-addressed semiconductor Bragg reflector, permitting dyed microspheres to be continuously trapped and monitored using a standard microscope imaging and on-demand two-photon-excited luminescence techniques.

OCIS codes: (140.4050) Mode-locked lasers; (140.3580) Lasers, solid-state; (350.4855) Optical tweezers or optical manipulation.

References and links

1. J. M. Hopkins, G. J. Valentine, W. Sibbett, J. A. der Au, F. Morier-Genoud, U. Keller, and A. Valster, “Efficient, low-noise, SESAM-based femtosecond Cr^{3+}: $LiSrAlF_6$ laser,” Opt. Commun. **154**(1-3), 54–58 (1998).
2. V. G. Savitski, A. J. Kemp, S. Calvez, and D. Burns, “Optically Pumped Saturable Bragg Reflectors: Nonlinear Spectroscopy and Application in Ultrafast Lasers,” IEEE J. Quantum Electron. **46**(11), 1650–1655 (2010).
3. V. G. Savitski, D. Burns, and S. Calvez, “Optically-pumped saturable absorber for fast switching between continuous-wave and passively mode-locked regimes of a $Nd:YVO_4$ laser,” Opt. Express **17**(7), 5373–5378 (2009).
4. S. Tsuda, W. H. Knox, E. A. de Souza, W. Y. Jan, and J. E. Cunningham, “Low-loss intracavity AlAs/AlGaAs saturable Bragg reflector for femtosecond mode locking in solid-state lasers,” Opt. Lett. **20**(12), 1406–1408 (1995).
5. B. Agate, C. T. A. Brown, W. Sibbett, and K. Dholakia, “Femtosecond optical tweezers for in-situ control of two-photon fluorescence,” Opt. Express **12**(13), 3011–3017 (2004).
6. http://optics.org/article/36573.
7. J. Ando, G. Bautista, N. Smith, K. Fujita, and V. R. Daria, “Optical trapping and surgery of living yeast cells using a single laser,” Rev. Sci. Instrum. **79**(10), 103705 (2008).
8. P. W. Roth, A. J. Maclean, D. Burns, and A. J. Kemp, “Direct diode-laser pumping of a mode-locked Ti:sapphire laser,” Opt. Lett. **36**(2), 304–306 (2011).

1. Introduction

Ultrafast pulsed solid-state lasers are becoming ubiquitous tools for an ever-increasing range of applications including scientific research, material processing and bio-photonics [1–5]. This use has widespread as they have gained in reliability, ease of operation and reduced maintenance. A key element to this success has been the delivery of robust self-starting pulsed systems which exploit an intra-cavity semiconductor saturable absorber (SA) in the form of a Semiconductor Bragg Reflector (SBR) [2,4] as the element to initiate and maintain the ultrashort pulse generation. More recently, the emphasis has turned to the development of lasers with higher performance and/or which present more advanced functionalities. Among the identified functionalities is the ability to simply switch the laser between continuous-wave (CW) mode-locked (ML) and CW regimes of operation - this *state-switching* has been shown to offer novel opportunities and benefits to the bio-photonics application sector [5–7].

Here, we demonstrate that a diode-pumped Cr:LiSAF laser can controllably and reliably be switched between its CW and ML states of operation using an optically-addressed SBR,

#160288 - $15.00 USD
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Received 19 Dec 2011; accepted 23 Jan 2012; published 13 Mar 2012

permitting dyed microspheres to be continuously trapped and monitored using standard microscope imaging and on-demand two-photon-excited luminescence techniques.

2. Experimental set-up

The demonstrator platform for on-demand two-photon luminescence and/or optical tweezing of polymer microspheres consists of a diode-pumped Cr:LiSAF laser with optically addressed SBR for a fast switching between CW and ML modes of operation and a homemade optical microscope.

The Cr:LiSAF laser used in the system is schematically represented in Fig. 1 and was pumped on either side by two polarisation-coupled laser diodes emitting up to 130mW at 660nm [1]. A *Z*-shape cavity was established using two folding mirrors with radii of curvature of 100 mm separated by 146mm. The SBR was positioned at the end of the short (100mm-long) arm of the cavity whist its long arm (which is 508mm long) included two FS10 prisms setup to promote positive intra-cavity group dispersion. This arrangement provided TEM_{00} mode radii within the Cr:LiSAF crystal and on the SBR of 36μm and 30μm respectively. The output coupler at the end of the longest cavity arm had a reflectivity of 99%, and the oscillation wavelength was tuned by a slit positioned between the output coupler and the FS10 prism. The SBR employed in the laser included a single GaAs/AlGaAs quantum well positioned in the last high index layer of a 30-pair AlGaAs/AlAs distributed Bragg Reflector. Its saturation characteristics presented at the peak of the exciton 0.5% modulation depth with a saturation fluence of ~12μJ/cm^2 as shown in [2]. The laser mode of operation (CW or ML) was controlled by optical pumping of the SBR with external diode laser (EDL) emitting at 670nm with pump power of ~1W [2].

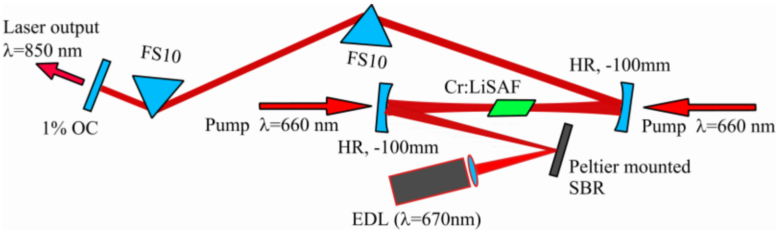

Fig. 1. Schematic of the diode-pumped Cr:LiSAF laser arrangement. OC – 1% output coupler. All curved mirrors are highly reflective (HR) within 800-900 nm spectral range. EDL – External Diode Laser.

For the remainder of the work, the Cr:LiSAF laser emission wavelength was tuned to 835nm and SBR substrate temperature maintained at room temperature. In this case, when the SBR is unpumped (EDL off) the laser operated in CW mode. When the EDL was turned on with 1W of output power and its ~100μm-radius beam coincided with the Cr:LiSAF laser cavity mode on the SBR, the laser switched to CW ML operation. The physical processes behind this change of mode of operation were discussed in details in [2,3] where it was shown that the major factor responsible for switching is a fast heat-induced shift of the absorption edge of the SBR towards longer wavelengths resulting from the pumping of the SBR. Indeed, this localized heating induces laser mode switching with transient times orders of magnitude shorter than when the SBR is directly heated by a Peltier element [2–4].

Here, the typical switching times from CW into ML mode of operation were measured to be ~1.5ms (Fig. 2, inset). As shown in Fig. 2, it was a fully controllable and reproducible process where the EDL was operated in a quasi-CW regime and led to a periodical switching of the Cr:LiSAF laser from CW into ML mode of operation and back. This method of control of the laser mode of operation is advantageous over previously reported alternatives where either a mechanical modification of the laser cavity (as in the case of the Kerr-lens ML Ti:sapphire laser in [5]) or a change of the pump laser output power [6,7] were required.

Received 19 Dec 2011; accepted 23 Jan 2012; published 13 Mar 2012

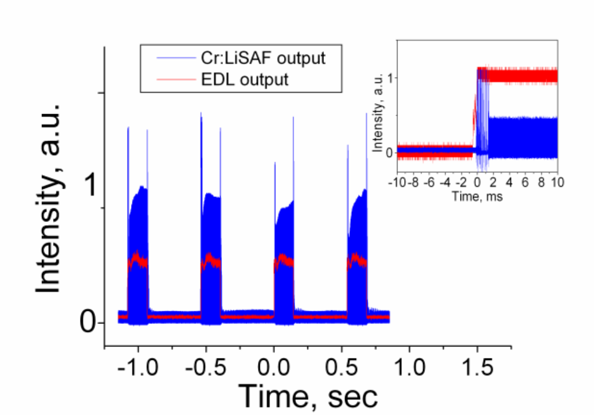

Fig. 2. Output from the Cr:LiSAF laser (blue) with SBR periodically pumped by EDL (red). Inset: Typical response of the Cr:LiSAF laser output on external optical pumping of the SBR.

The maximum output power of the Cr:LiSAF laser in CW mode at 430mW of absorbed pump power was measured to be 30mW whilst in ML mode it was slightly lower – 28mW. The produced pulses at maximum output power were measured to be 212fs (Fig. 3) with a corresponding spectral width of 3.9nm (Fig. 3, inset), giving a near-transform-limited time-bandwidth product of 0.33.

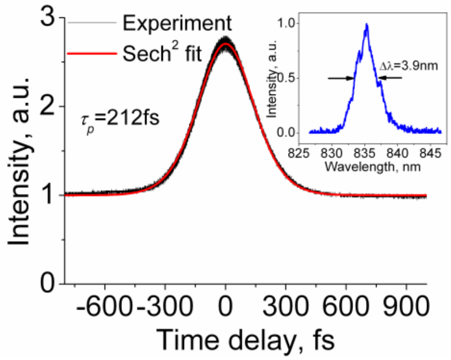

Fig. 3. Intensity autocorrelation trace of the ML pulse from the Cr;LiSAF laser. Inset, corresponding optical spectrum (duration– bandwidth product = 0.33).

Subsequently, a home-made optical microscope for optical tweezing and two-photon luminescence experiments was built. It included a two lens telescope to expand the beam emitted by the Cr:LiSAF laser to fill the back aperture of a 100x objective (Fig. 4). The laser emission after the 100x objective was focused onto a microscope slide on top of which the sample in water solution was introduced and covered with a coverslip. To monitor the sample, white-light illumination was set up on the backside of the microscope slide and images were recorded by a CCD camera using a dichroic-mirror pick-off from the light collected by the 100x objective (see Fig. 4). The average pump power at the sample was measured to be ~10mW and is sufficient to induce two-photon excitation from dyed microspheres as shown hereafter. This power level would also be adequate for optical dissection of biological cells [7], a topic which will form the basis of further investigations.

Received 19 Dec 2011; accepted 23 Jan 2012; published 13 Mar 2012

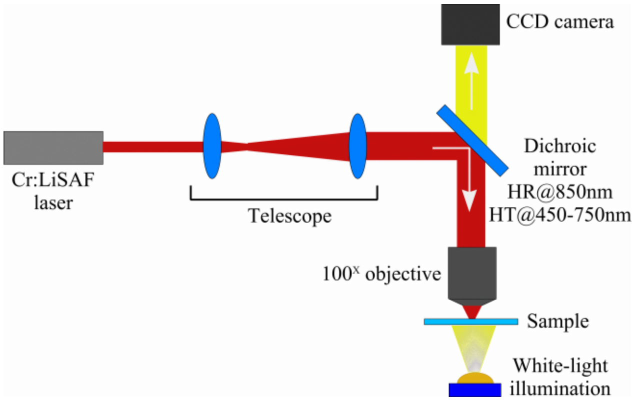

Fig. 4. A schematic set-up for experiments on optical trapping and two-photon luminescence.

3. “On demand” two-photon luminescence of a trapped microsphere

The sample in the experiment was a water solution containing blue-dyed polymer microspheres with a mean diameter of 3μm (Thermo-Scientific). The microspheres being pumped at 412nm exhibit luminescence with peaks at 445 and 473nm. Emission from the Cr:LiSAF laser at the wavelength of 835nm can lead to two-photon absorption in this dye and subsequent luminescence from a microsphere, providing that the pulse peak intensity is high enough [5], which is the case when the above-described laser operated in ML regime with pulse peak powers of ~670W.

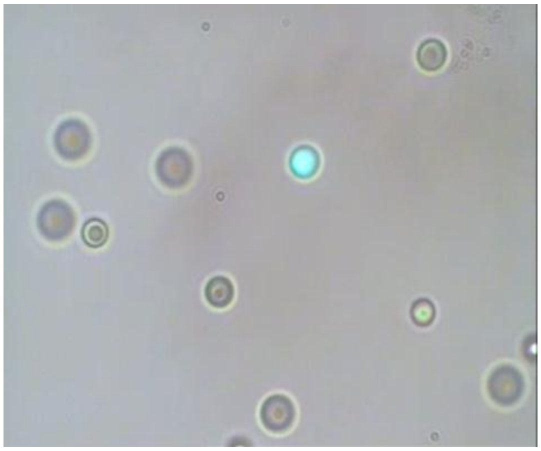

Fig. 5. Movie of on-demand two-photon luminescence of a trapped microsphere doped with the dye. Two-photon luminescence is excited by emission from the Cr:LiSAF laser operating in ML regime. (Media 1)

The movie presented in Fig. 5 demonstrates the control of a trapped microsphere with on-demand two-photon luminescence. At the beginning of the movie, a microsphere is trapped by the ML output of the Cr:LiSAF laser and displays two-photon-induced luminescence. It was shown before that efficiencies (Q-value) of optical trapping using CW and ML mode of operation of the same laser are equal [5]. Indeed, when the laser is switched into its CW mode of operation (approximately 3 seconds after beginning of the movie) the microsphere remained trapped. In this regime of operation, the CW laser emission is too low to induce any two-photon absorption in the dye; therefore the luminescence from a microsphere disappears.

The subsequent movie sequence demonstrates on-demand two-photon excitation of the constantly trapped microspheres as well as the reliability of the laser operation and switching.

Received 19 Dec 2011; accepted 23 Jan 2012; published 13 Mar 2012

4. Conclusion

We demonstrated that diode-pumped Cr:LiSAF laser which incorporates an optically-addressed SBR is an efficient, compact, simple and reliable tool for biological applications where optical tweezing of the object should be accompanied with two-photon luminescence from a trapped particle. We believe, this method of optically addressing the SBR could be implemented in a Ti:sapphire laser with higher output powers [2] and pumped with blue laser diodes [8] to create a compact real-time multitasking platform for bio-photonics applications.

Acknowledgments

The authors would like to acknowledge EPSRC programme "Ultrafast Modular Lasers" for funding.

Received 19 Dec 2011; accepted 23 Jan 2012; published 12 Mar 2012