

Femtosecond laser operation based on sesquioxide crystals

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Ytterbium doped materials are attractive for compact high-power femtosecond laser sources in the 1 μm spectral range due to their small quantum defect, lack of excited state absorption and upconversion processes and the possibility for efficient pumping with InGaAs diodes. The isotropic sesquioxides Sc_2O_3 , Y_2O_3 and Lu_2O_3 , doped with Yb represent a potential alternative to Yb:YAG for high power applications because of their excellent thermal properties. The splitting of the ground state is larger and the thermal conductivity of the sesquioxides is better than of YAG. The advantages of the sesquioxides have already been evidenced in terms of the slope efficiency in continuous wave (cw) laser experiments [1]. Very recently, also for a sesquioxide ceramic (Yb:Y₂O₃) mode-locking has been reported [2].

Here we present mode-locked operation of the crystalline Yb³⁺:Sc₂O₃ and Yb³⁺:Lu₂O₃ and report results obtained both in the picosecond and the femtosecond regime. We studied a Z-shaped astigmatically compensated resonator with two folding mirrors in the middle to form a cavity waist at the position of the sesquioxide crystals which were used under Brewster angle. No active cooling was applied at the crystals. One arm contained an additional focusing mirror to increase the intensity on the saturable absorber mirror (SAM, BATOP GmbH) which terminated the resonator. The other arm contained a plane output coupler and in this arm two dispersion compensating prisms could be included. More than 70% of the incident pump power at 976 nm, corresponding to the maximum absorption band, were absorbed by the 0.7% Yb-doped Sc₂O₃ (thickness: 2.7 mm) or the 2.7% Yb-doped sample of Lu₂O₃ (thickness: 1.3 mm).

Applying a Ti:sapphire laser pump source and without intracavity prisms the passively mode-locked lasers operated in the picosecond regime with pulse durations of about 1.2 ps. The highest mode-locked slope efficiency amounted to 54% using Yb:Sc₂O₃ at a pulse repetition rate of 109 MHz, compared to 44% with Yb:Lu₂O₃. The femtosecond regime was achieved by adding two 60° SF6-prisms into the arm containing the output coupler. The temporal and spectral characteristics at the maximum output power of 540 mW at 1045 nm for Yb:Sc₂O₃ and 266 mW at 1033 nm for Yb:Lu₂O₃ are shown in Fig. 1a and Fig. 1b, respectively. Both the experimental data (squares) and the fit assuming sech²-pulse shapes (line) are plotted. Pulses as short as 220 fs could be generated which differs not significantly between the two hosts. The time-bandwidth-product amounted to 0.33 in both cases which is very close to the Fourier limit.

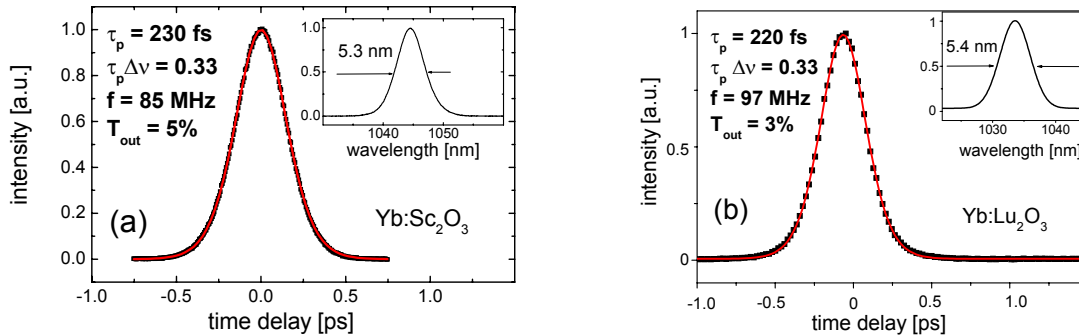


Fig. 1: Autocorrelation trace and spectrum (inset) of (a) the Yb:Sc₂O₃ laser and (b) the Yb:Lu₂O₃ laser.

In conclusion, we have demonstrated highly efficient mode-locked laser operation based on two sesquioxide crystal hosts. Yb:Sc₂O₃ and Yb:Lu₂O₃ are very promising materials for compact short-pulse lasers in the 1 μm spectral range which possesses larger gain bandwidth and better thermal conductivity than Yb:YAG.

1. K. Petermann, L. Fornasiero, E. Mix, and V. Peters, "High melting sesquioxides: crystal growth, spectroscopy, and laser experiments" *Opt. Mat.* **19**, 67-71 (2002).
2. A. Shirakawa, K. Takaichi, H. Yagi, J-F. Bisson, J. Lu, M. Musha, K. Ueda, T. Yanagitani, T. S. Petrov, and A. A. Kaminski, "Diode-pumped mode-locked Yb³⁺:Y₂O₃ ceramic laser", *Opt. Express* **11**, 2911-2916 (2003).