Towards a monolithic, multi-gigahertz mode-locked Ti:Sa laser

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Multi-gigahertz, low-noise ultrafast lasers have been subject to considerable research interest. They are used in frequency metrology, optical spectroscopy [1] and calibration of astronomical spectrographs [2]. Titanium-doped sapphire (Ti:Sa) is a suitable gain medium due to its broad gain bandwidth. To this day, the highest repetition rate of a Ti:Sa laser is 10 GHz [3]. We present a monolithic design of a fundamentally mode-locked Ti:Sa laser for repetition rates between 30 GHz and 300 GHz.

The laser crystal is a Ti:Sa disk with a thickness in the range of 0.3 mm to 3 mm and 10 mm diameter. Both optical surfaces are planar and coated with dispersion-compensating dielectric coatings. Stable laser operation is achieved by thermal lensing due to absorption of the pump beam. For homogeneous pumping, the medium becomes a gradient index lens whose fundamental eigenmode is a TEM_{00}-mode with a constant diameter along the propagation axis. We want to use soft-aperture Kerr-lens mode-locking. Since the gain bandwidth of Ti:Sa exceeds several tens of nanometers, up to a hundred longitudinal modes can be sustained even at a repetition rate of 300 GHz. Such a monolithic mode-locking scheme allows for low pulse timing jitter and constant pulse repetition rates since there will be no vibrations of resonator mirrors or air turbulence inside the resonator.

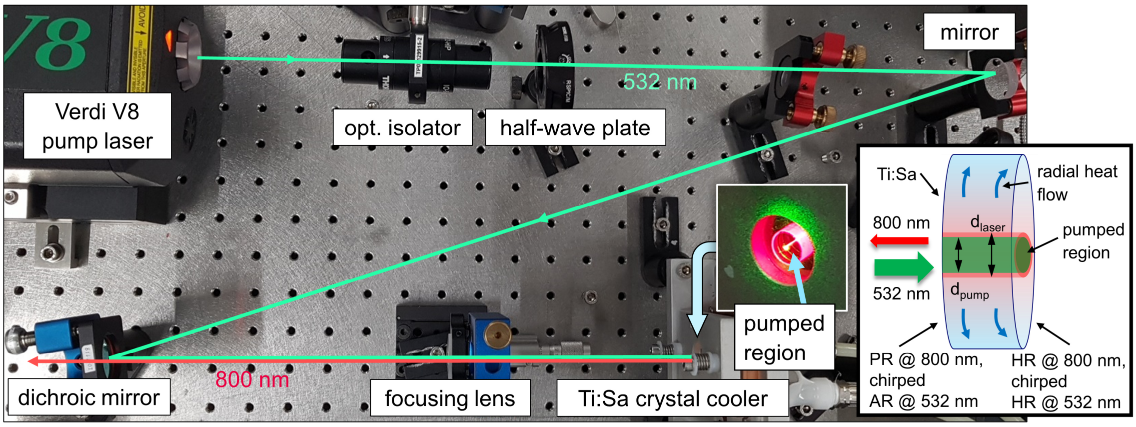

Fig. 1 Experimental pumping setup of the Ti:Sa crystal. The schematic illustration of the monolithic mode-locked Ti:Sa laser shows the coatings on both end faces and the predominantly radial heat flow.

A first batch of 3 mm Ti:Sa crystals was coated and tested. The pump source is a frequency-doubled stabilized single-frequency $Nd:YVO_4$ laser at 532 nm. With an incident pump power of up to 8.5 W and 60% absorption, output powers up to 1.8 W with power stability of $\leq 0.04\%$ rms over one hour and 10 nm bandwidth are produced. The interferometric autocorrelation shows a contrast of just 3:1 instead of 8:1 which indicates that we are not seeing mode-locked pulses [4]. The laser beam was then sent into a pulse stretcher introducing 10^4 fs² and later 10^6 fs² of group delay dispersion and then measured again by the autocorrelator. The measured autocorrelation trace did not change. This suggests that we have not achieved mode-locking but are simply seeing white light interference of the laser light.

Our laser has 10 nm bandwidth in continuous wave operation because for a smaller bandwidth spatial hole burning in the gain regions close to the mirror would produce undepleted gain. Solition mode-locking is only possible if sufficient dispersion compensation by the coatings is achieved over an even larger bandwidth. Mode-locking might also be prevented by frequency pulling due to gain modulation which is caused by the standing wave of the pump beam. An improved coating design is currently being applied to a batch of 1 mm thick Ti:Sa crystals. During the conference, results of experiments with these 1 mm thick crystals will also be presented.

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References

[1] S. M. Link, D. J. H. C. Maas, D. Waldburger, and U. Keller, "Dual-comb spectroscopy of water vapor with a free-running semiconductor disk laser", Science 356, 1164 (2017).
[2] T. Udem, R. Holzwarth, and T. W. Hänsch, "Optical frequency metrology," Nature 416, 233–237 (2002).
[3] A. Bartels, D. Heinecke, and S. A. Diddams, "Passively mode-locked 10 GHz femtosecond Ti:sapphire laser," Opt. Lett. 33, 1905-1907 (2008).
[4] S. Toenger, R. Mäkitalo, J. Ahvenjärvi, P. Ryczkowski, M. Närhi, J. M. Dudley and G. Genty, "Interferometric autocorrelation measurements of supercontinuum based on two-photon absorption," J. Opt. Soc. Am. B 36, 1320-1326 (2019).