Broadly tunable diode-pumped femtosecond Tm:LuScO$_3$ laser

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Tm^{3+}-doped sesquioxides RE_2O_3 (RE = Lu, Sc, Y, or any $Lu_aSc_bY_c$ composition, where $a + b + c = 1$) possess advantageous thermo-mechanical properties and unique spectroscopic features compared with other Tm^{3+}-doped gain media. These characteristics make them ideal candidates for high power laser development in the 2 – 2.1 μm region [1]. Despite having a relatively low thermal conductivity (3.9 W/(m·K)) the sesquioxide host $LuScO_3$ brings the invaluable benefit of a broad and smooth gain spectrum extending well beyond 2.1 μm when doped with Tm^{3+}. Recently we exploited this characteristic to demonstrate the first diode-pumped femtosecond Tm:LuScO$_3$ laser [2]. Utilising an ion-implanted InGaAsSb quantum-well-based semiconductor saturable absorber mirror (SESAM), pulses as short as 170 fs at 2093 nm with an average output power of 113 mW and repetition frequency of 115.2 MHz were generated. Here we report on further development of a diode-pumped femtosecond Tm:LuScO$_3$ laser capable of generating <373 fs pulses continuously tunable over an 87 nm range around 2.06 μm.

To achieve this result the system described in [2] was modified to include a specially designed dive cut birefringent filter (BRF). The quartz filter was designed to have a thickness of 2.7 mm and was cut at an angle of 24° with respect to the surface normal. This thickness was found through modelling to provide the best balance between optical bandwidth and suppression losses, whilst the dive angle was chosen as it complies with that reported by Naganuma *et al* [3] as being optimal for the quartz material.

Initially, characterisation in the continuous wave regime was performed over the first four orders of the filter and showed tuning ranges of >140 nm around 2.06 μm for all four orders. Mode-locked operation was realised using the SESAM device, demonstrating tunable femtosecond operation for the 1st and 2nd orders. With a 1% output coupler in use and operating in the 1st order, output powers ranging from 48 – 88 mW for 2.5 W of incident pump power (1.8 W of absorbed power) were recorded over a tuning range of 2020 – 2107 nm (Fig. 1(a)). Pulse durations were recorded to vary between 225 fs and 372 fs (assuming a $sech^2$ intensity autocorrelation profile) roughly following the variation in output power (intracavity pulse energy) as soliton mode-locking theory predicts. The optical spectrum and autocorrelation trace for a 228 fs pulse at 2090 nm can be seen in Figs. 1(b) and 1(c), respectively. Adjusting the filter to operate in the 2nd order realised similar output powers ranging from 44 – 82 mW and longer pulse durations of 329 – 508 fs. A tuning range of 2025 – 2115 nm was recorded. No mode-locked performance was observed for the 3rd or 4th orders.

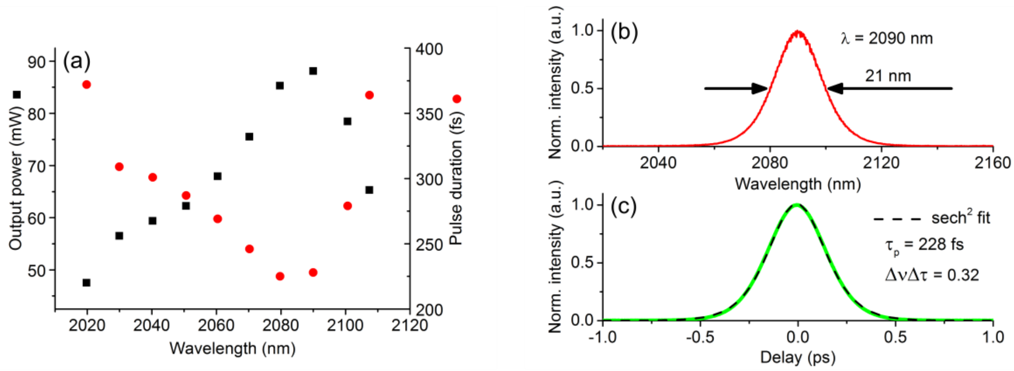

Fig.1 (a) Tuning characteristics of the Tm:LuScO$_3$ mode-locked laser with the BRF operating in the 1st order. Optical spectrum (b) and autocorrelation trace (c) of mode-locked pulses at 2090 nm.

The utilisation of the dive cut BRF to achieve broad femtosecond pulse tuning allows for less complex and more robust cavity designs compared with the traditionally used slit and prism pair combination. Further development of this system should yield a compact and tunable ultrashort pulsed seed source capable of matching the peak emission bands of high power Ho-based amplifiers.

References

[1] C. Kränkel, "Rare-Earth-Doped Sesquioxides for Diode-Pumped High-Power Lasers in the 1-, 2-, and 3-μm Spectral Range," IEEE J. Sel. Top. Quantum Electron. **21**, 250 (2015).

[2] N. K. Stevenson, C. T. A. Brown, J.-M. Hopkins, M. D. Dawson, C. Kränkel, and A. A. Lagatsky, "Diode-pumped femtosecond Tm 3+-doped LuScO3 laser near 2.1 μm," Opt. Lett. **43**, 1287 (2018).

[3] K. Naganuma, G. Lenz, and E. P. Ippen, "Variable bandwidth birefringent filter for stable femtosecond lasers," IEEE J. Quantum Electron. **28**, 2142 (1992).