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Quentin Berthomé, Arnaud Grisard, Basile Faure, Grégoire Souhaité, Eric Lallier, et al.. Single-Longitudinal-Mode Tunable Actively Q-switched 2 μm Tm:YAP Laser Using a Transversally Chirped Volume Bragg Grating. Conference on Lasers and Electro-Optics 2020, May 2020, Washington (virtual), United States. pp.SM3E.5, 10.1364/CLEO_SI.2020.SM3E.5 . hal-03152635

HAL Id: hal-03152635

<https://hal.science/hal-03152635>

Submitted on 25 Feb 2021

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Single-Longitudinal-Mode Tunable Actively Q-switched 2 μm Tm:YAP Laser Using a Transversally Chirped Volume Bragg Grating

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Abstract: A pulsed, single-longitudinal-mode, wavelength-tunable Tm:YAP laser was realized, delivering 270- μJ , 50-ns pulses with 1-kHz repetition rate. Spectral narrowing and tuning from 1940 to 1960 nm is carried out with a transversally chirped volume Bragg grating. © 2020 The Author(s)

1. Context

Tunable longwave infrared coherent sources emitting between 8 and 12 μm can be used for versatile remote sensing of hazardous gases. In ref [1], we implemented a parametric oscillator, pumped by a 2 μm microlaser, in which wavelength tunability was achieved by temperature tuning of the crystal indices of refraction. An attractive alternative to address a similar wavelength range with a significantly faster tuning speed is to change the pump wavelength rather than the crystal temperature [2]. In this context, to control the spectral output of the optical parametric oscillator (OPO), which is based on Vernier spectral filtering in doubly resonant cavities [1], we also need a single longitudinal mode (SLM) pump laser. Pulsed, tunable 2 μm laser sources have been reported [3,4] but they require complex alignment or do not deliver narrow linewidth emission, and they exhibit relatively long pulses. For this purpose, we have developed, and recently presented, a 2 μm Tm:YAP laser with a transversally chirped volume Bragg grating (TC-VBG) to narrow the spectrum and perform wavelength-tunable actively-Q-switched operation with an acousto-optic modulator (AOM) [5]. Pulses with $\sim 200 \mu\text{J}$ energy and $\sim 50 \text{ ns}$ duration were obtained, which is suitable to pump the OPO and a parametric amplifier. In this work, we also investigate spectral narrowing down to SLM pulsed operation owing to the combination of a TC-VBG and an etalon.

2. Experimental set-up

We designed a Tm:YAP laser with a TC-VBG as the output coupler and an AOM to perform active Q-switching with repetition rates of a few kilohertz. The cavity, shown in Fig. 1, is composed of a highly reflective dielectric concave mirror around 2 μm with a radius of curvature of 50 mm, a 4 mm thick YAG etalon, an AOM working at 2 μm , a 4 mm long 3 %at. thulium-doped a-cut YAP rod, and a TC-VBG provided by OptiGrate with 1940 nm to 1960 nm tuning range, 85 % reflectivity and 0.8 nm bandwidth (FWHM). The AOM is used to switch the cavity losses and achieve pulsed operation. The etalon was designed to obtain SLM operation in combination with the VBG. The cavity is about 50 mm long and is pumped with a continuous-wave (CW) 9 W laser diode emitting near 790 nm, which results in 7 W incident on the laser crystal due to Fresnel losses of VBG facets at 790 nm. The pumping laser is focused in the laser medium through the TC-VBG with a lens doublet to get a beam radius of 100 μm ($1/e^2$). A dichroic mirror is used to separate the 2 μm laser output from the input pump beam.

Fig. 1. Schematic diagram of the laser set-up

3. Results and comments

Without the etalon, we obtained a 28 % slope efficiency with a 4 W pump threshold in CW operation, see Fig 2. In

pulsed operation the threshold was around 3.5 W and the slope efficiency was 31.6 % at a pulse repetition rate of 1 kHz. Repetition rates of 0.5, 1 and 2 kHz have been tested. Configurations with up to 300 μ J and less than 50 ns duration have been found. Similar performances were obtained with the etalon. We selected a working point with 270 μ J and $\sim$ 50 ns duration at 1 kHz repetition rate leading to 5.4 kW peak power. Although higher peak and average powers could be reached through the increase of the system efficiency, this working point is enough to efficiently pump both the OPO at a few times the oscillation threshold and a parametric amplifier with a gain of 10.

Fig. 2. Average output power at different repetition rates without the etalon

The laser has a 20 nm tuning range between 1.94 μ m and 1.96 μ m when translating the volume Bragg grating, see Fig. 3(a). As Fig. 3(b) shows, the combination of the TC-VBG and the etalon reduced the output spectrum to a single longitudinal mode. The linewidth was measured to be less than 4 pm which is the measurement resolution. It is expected to be close to the Fourier transform limit for 50 ns pulses which is $\sim$ 0.1 pm. The spectrum is narrow enough to control the spectral output of the OPO with doubly resonant Vernier filtering.

Fig. 3. (a) Output power and wavelength measured as a function of the transverse position of the TC-VBG. (b) Output spectrum measured with a scanning Fabry-Perot.

4. Conclusion

We demonstrated, for the first time to our knowledge, efficient single-longitudinal-mode actively Q-switched diode pumped Tm:YAP laser tunable from 1.94 μ m to 1.96 μ m, using a transversally chirped volume Bragg grating as output coupler and an acousto-optic modulator. Spectral linewidth was narrowed between 4 pm and the Fourier transform limit $\sim$ 0.1 pm. The tunability over a 20 nm range obtained on the 2 μ m laser translates to a 500 nm range tunability near 10 μ m after down conversion which is enough to record some significant spectral absorption features for gas sensing [1]. Work is currently under progress to increase the system efficiency and to implement down conversion to long wave infrared with the OPO. Advances toward these goals will also be discussed.

Acknowledgement

The authors acknowledge V. Smirnov and R. Vasilyeu from OptiGrate Corp. for fruitful discussion about the TC-VBG design and fabrication.

This work was supported by DGA RAPID program (SPICE project).

- [1] Q. Clément, J.-M. Melkonian, J.-B. Dherbecourt, M. Raybaut, A. Grisard, E. Lallier, B. Gérard, B. Faure, G. Souhaité, and A. Godard, "Longwave infrared, single-frequency, tunable, pulsed optical parametric oscillator based on orientation-patterned GaAs for gas sensing", *Opt. Lett.* **40**, 2676 (2015)
- [2] F. Guty, A. Grisard, C. Larat, D. Papillon, M. Schwartz, B. Gérard, R. Ostendorf, M. Rattunde, J. Wagner, and E. Lallier, "140W Peak Power Laser System Tunable in the LWIR", *Opt. Expr.* **25**, 18897 (2017)
- [3] C. Jin, D. Li1, Y. Bai1, Z Ren and J. Bai, "Wideband tunable graphene-based passively Q-switched Tm:YAP laser", *Laser Physics* **25**, 045802 (2015)
- [4] B. Cole and L. Goldberg, "Highly efficient passively Q-switched Tm:YAP laser using a Cr:ZnS saturable absorber", *Optics Letter* **42** 12, 2259:2262 (2017)
- [5] Q. Berthomé, A. Grisard, B. Faure, G. Souhaité, E. Lallier, A. Godard, V. Smirnov, R. Vasilyeu, "Actively Q-switched Tunable Narrowband Tm:YAP Laser Using a Transversally Chirped Volume Bragg Grating", paper JTU3A.9 in ASSL, OSA (2019)