Narrow Bandwidth Tunable Watt Level Tm:YAP Laser using Two Etalons

Uzziel Sheintop[1,2], Eytan Perez[1] and Salman Noach[1]
[1]*Department of Applied Physics, Electro-optics Engineering Faculty, Jerusalem College of Technology, Jerusalem, Israel*
[2]*Department of Applied Physics, The Hebrew University of Jerusalem, Jerusalem, Israel*

Keywords: Lasers, Solid-state, Mid Infrared Lasers, Tunable Laser, Narrow Bandwidth Laser.

Abstract: Narrow band, tunable, end pump Tm:YAP laser is demonstrated in this paper. The 35 nm wavelength tunability, ranges continuously from 1917 to 1951 nm, having a spectral linewidth of 0.15 nm FWHM. The tuning and spectral band narrowing was obtained using a pair of YAG Fabry-Perot Etalons with thicknesses of 25 and 500 μm. Watt level output power were measured along the laser tunable range. Maximum output power of 3.84 W was achieved at 1934 nm. Slope efficiency of 43.2% was calculated for an absorbed pump power of 12.1 W. The combination of the narrow bandwidth with tunability at those levels of output power, makes this laser a promising tool for bio-medical, sensing and material processing applications.

1 INTRODUCTION

Diode-pumped Tm^{3+}-doped solid state lasers emitting in the 2 μm region, have many applications in a variety of fields, such as medical surgery, material processing, gas spectroscopy (Eremeikin, 2010), Doppler LIDAR and as a pumping source for the mid infra-red region lasers e.g. Cr:ZnSe and Cr:ZnS lasers. Some of the applications require the source to deliver both tunable and narrow bandwidth emissions. (Godard, 2007, Scholle et al., 2010, Sorokina, 2003)

Tunable lasers in the 2 μm area are a key technology for environmental applications, such as sensitive detection of atmospheric gases and molecules, as well as for remote chemical sensing, in terms of safety, quality control and regulatory enforcement.

As a pump source for other lasers in the IR region, the ability of tuning the pump source to the maximum absorption peaks of the laser gain medium, can improve significantly the system performance. Narrowing the pump source bandwidth contributes to the efficiency of the pump source in the case of narrow band absorption peaks.

For medical application, the high absorption coefficient of water in the 2 μm region allows limited penetration depth in biological tissues. Since the absorption of liquid water changes significantly as a function of wavelength, spectral tunable source allows to achieve varying and precise penetration depth, while the laser radiation interacts with the tissue. This property is considered to be very applicable in micro surgery.

Tm-doped lasers have a broad spectral tunability range, due to the relative large Stark splitting of the laser low energy level $^3H_6$. The exact Stark splitting changes from one host to another, depending on the host symmetry and host crystal field intensity at the Tm site. This causes changes in the amplification curve from host to host.

Numerous techniques are used for wavelength laser tuning such as Prisms, Lyot filter, Volume bragg grating and Etalon plates.

Despite its limited spectral range, comparing to other methods, tuning by Etalon has its advantages: avoiding the necessity of polarized beam, simplicity of operation as well as being relatively low cost.

It can be mentioned, that tunable Tm-doped lasers were widely implemented. Works on this topic that were performed up to 2007, were reviewed in (Godard, 2007). Since then, tunability was also achieved with the following Tm-doped crystals: Tm:LuAG (2018-2029 nm) (Wang et al., 2013), Tm:LuYAG (1935-1995 nm) (Sun et al., 2012), Tm:LiLuF (1817-2056 nm) (Coluccelli et al., 2007), and Tm:LSO (1959-2070 nm) (Feng et al.,2013, Feng et al., 2014).

Sheintop, U., Perez, E. and Noach, S.
Narrow Bandwidth Tunable Watt Level Tm:YAP Laser using Two Etalons.
DOI: 10.5220/0006721403030307
In *Proceedings of the 6th International Conference on Photonics, Optics and Laser Technology (PHOTOPTICS 2018)*, pages 303-307
ISBN: 978-989-758-286-8
Copyright © 2018 by SCITEPRESS – Science and Technology Publications, Lda. All rights reserved

In addition to the spectral tunability the Etalon allows, it can also be exploited as a bandwidth narrowing device, due to its Fabry Perot design.

The use of one Etalon, gives a tradeoff between the free spectral range (FSR) determined by the thickness and the spectral bandwidth. In comparison, the use of two different thicknesses Etalons can maximize the tuning range and the bandwidth narrowing level. Bandwidth narrowing using this method was also implemented in Tm:YAP (Yu-Feng et al., 2007, Li et al., 2010).

None of the aforementioned works achieved a combination of a narrow bandwidth, tunable and Watt level source laser in Tm-doped crystals ions, specifically for the Tm:YAP crystal being one of the most promising lasers in the 2 µm area.

We report a CW Tm:YAP tunable laser with narrow bandwidth using 2 Etalons, having a maximum output power of 3.84 W at 1934 nm. The laser was tuned between 1917 to 1951 nm with an output power ranging from 2.46 to 3.84 W. The laser bandwidth was narrowed to 0.15 nm full width at half maximum (FWHM).

To the best of our knowledge, this is the first Tm:YAP laser having such spectral narrow band-width with a 35 nm tunable range in the watt level.

2 TM: YAP CRYSTAL

Tm-doped lasers have numerous and important optical characteristics. The noticeable of those are, long fluorescence lifetime, cross relaxation mechanism allowing for high quantum yield, as well as high power eye-safe lasing. Moreover, the absorption spectrum of Tm ions near 790 nm matches with the commercially available AlGaAs laser diodes.

Yttrium aluminum perovskite (YAP), has been a well known laser host, and also being one of the most attractive Tm-doped crystals. The Tm:YAP is important especially in the medical field because of his emission near 1940 nm, which is an absorption peak of water (twice as strong than the 2 µm from Tm:YAG and four time stronger than the 2.1 µm from Ho:YAG) (see Figure 1).

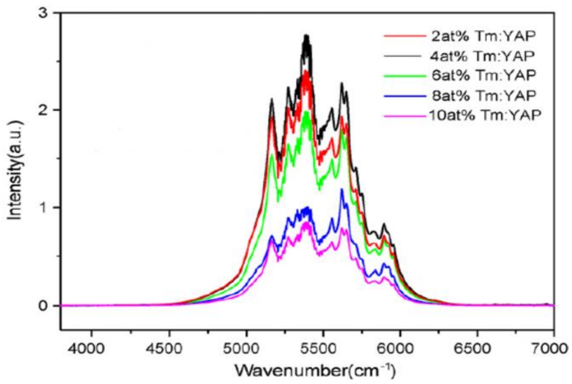

Figure 1: Fluorescence spectrum of Tm:YAP crystals for different doping concentrations (Godard, 2007).

Due to the quasi-three-level nature of the Tm 2µm transition, most of Tm laser are blue shifted as the output coupler (OC) transmission or the cavity losses increases. As an example, the Tm:YLF changes its emitted wavelength from 1910 to 1880 nm, in contrast to the Tm:YAP gain spectrum peak, which barely changes for increased OC transmission, making the Tm:YAP spectral emissions insensitive to cavity losses shown in Figure 2.

The Tm:YAP has higher absorption and emission cross section than the Tm:YLF. Additionally, the YAP thermal conductivity is comparable with the well-known YAG host (Koechner, 2006).

The Tm dopant has a wide absorption peak around 795 nm, which allow for efficient pumping with high brightness diodes. Moreover, the wide fluorescence spectra allow for a broad range of tunability.

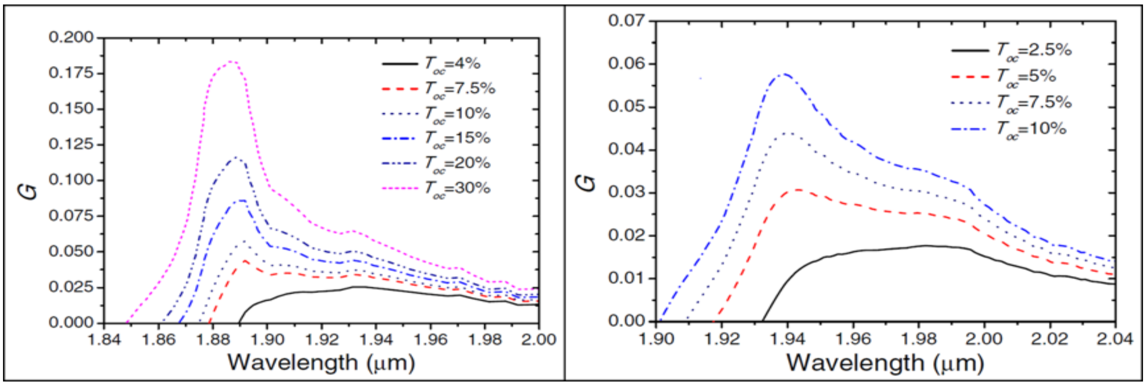

Figure 2: Calculated gain spectrum for different output couplers. Left-Tm:YLF, Right-Tm:YAP. (Li, 2014).

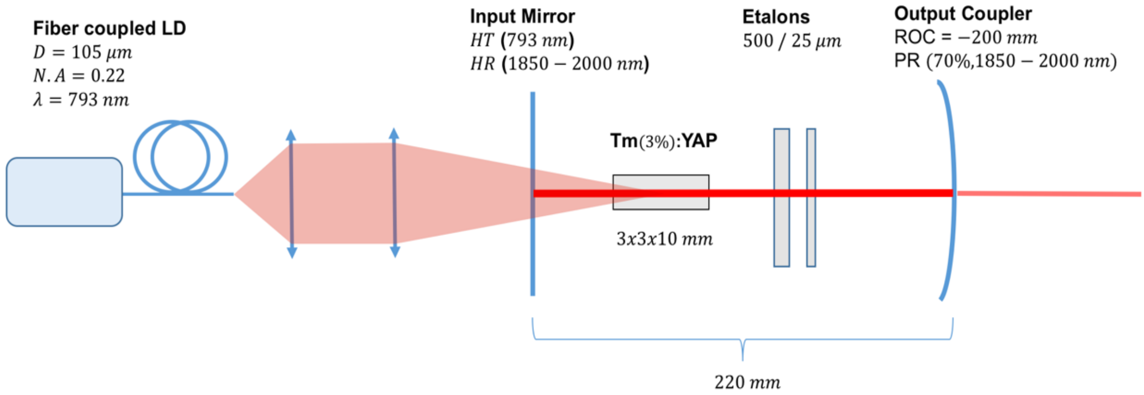

Figure 3: Schematic of the experimental setup.

3 SETUP

The Tm:YAP laser setup is shown in Figure 3. The pumping source is a fiber-coupled laser diode emitting up to 15.8 W at 793 nm with a 105 µm core diameter and a N.A of 0.22. The pump beam was focused using a pair of antireflection (AR) coated at 650-1050 nm bi-convex lenses on the Tm:YAP crystal, allowing a minimal spot size inside the Tm:YAP crystal of about 260 µm. The pump was delivered through a plano-plano rear cavity mirror, having AR coating for the pump wavelength and high reflectance (HR) coating for the 1850-2000 nm. We used a plano-concave mirror with ROC of 200 mm as OC. The OC was partially reflecting (PR) coated with 70% reflectance for the 1850-2000 nm. The total cavity length was 220 mm.

The Tm:YAP gain crystal having a Tm concentration of 3%, was 10 mm long while having a cross-section of 3x3 mm. The laser crystal was AR coated for both the pump and laser wavelengths, and was wrapped within indium foil and fasten into an aluminum holder cooled by a water chiller at a stable 18˚C.

Two uncoated YAG Etalon plates, with 500 µm and 25 µm thickness were fixed on a rotating stage inside the laser cavity in order to narrow the emission spectral width. Additionally, by rotating the 25 µm Etalon angle we were able to tune the laser wavelength.

By implementing two intra-cavity Etalon plates, it is possible to achieve a narrow spectral bandwidth, having the thinner Etalon responsible for the tuning range according to his free spectral range (FSR), while the thicker Etalon defines the spectral bandwidth.

The output power was measured using power meter (Ophir, L50(150)A-35), after filtering the residual pump power. The laser spectrum was acquired by an OSA (Thorlabs, OSA205C) having a resolution of 0.13 nm.

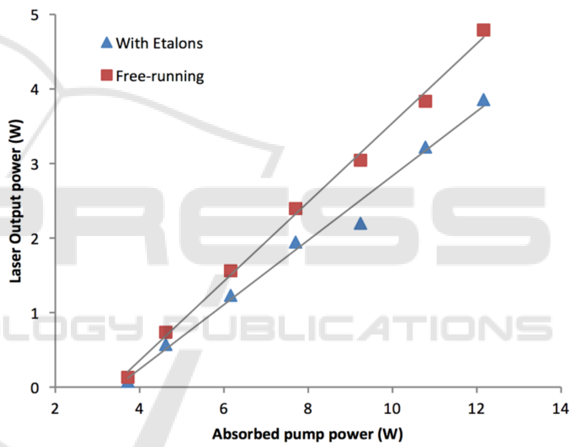

Figure 4: Laser performance.

4 EXPERIMENTAL RESULTS

The Tm:YAP laser performance for the Free-running operation, without the intra-cavity Etalons, is shown in Figure 4 as a function of the absorbed pump power. The Tm:YAP crystal absorbed 77% of the pump power. The laser threshold was 3.73 W of the absorbed pump power. A maximum output power of 4.79 W was achieved at 12.1 W absorbed pump power, corresponding to an optical-to optical conversion of 39.3%, and a slope efficiency of 53.1%. The measured emission wavelength was of 1935 nm, for a spectral width of ~2 nm at the FWHM shown in Figure 5 having a beam profile quality $M^2 = 1.4$.

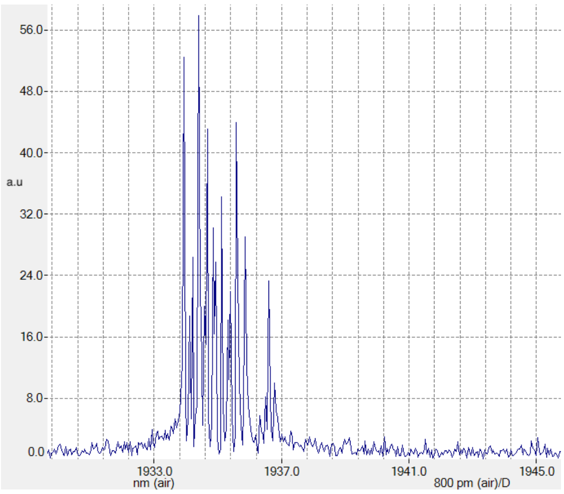

Figure 5: Free running spectrum of the Tm:YAP laser.

By inserting the two Etalons plates intra-cavity, we achieved a spectral bandwidth reduction down to ~0.15 nm (near the resolution limit of the OSA used) at the FWHM shown in Figure 6. The laser wavelength was tuned from 1917 to 1951 nm, giving a tuning range of 35 nm. The tuning range achieved, agrees closely to the 40 nm calculated FSR, corresponding to the 25 µm thick Etalon. Along this range, the output power measured did not fall from 2.46 W for a constant maximal pump power as shown in Figure 7. For the narrowed bandwidth operation of the laser, a maximum output power of 3.84 W was achieved at a wavelength of 1934 nm, corresponding to an optical-to optical conversion of 31.7 % and a slope efficiency of 43.2 %. The data is shown as function of the absorbed pump in Figure 4.

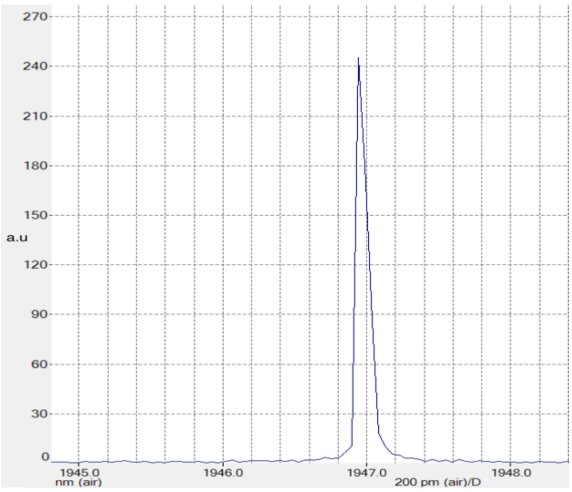

Figure 6: Narrowed band spectrum of Tm:YAP laser using two etalons.

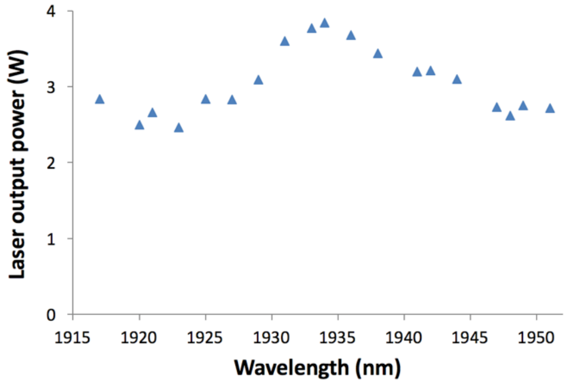

Figure 7: Laser tunability Performance.

5 DISCUSSION

In this work, a Tm:YAP laser was designed. Up to 3.84 W output power in the tunable configuration using two Etalon plates for bandwidth narrowing was observed for a maximum pump power of 15.8 W (corresponding to an absorbed pump power of 12.1 W). This relatively low pump power, in combination with the small dimension of the overall resonator (about 22 cm), opens a path toward the realization of 2 µm solid state lasers in multiple field of interest.

Concerning further developments of the present laser system, several paths should be investigated.

Within the application point of view, the Tm:YAP laser should be used to perform preliminary experiments of laser ablation of biological tissue to check parameter such as, heat affected zone, ablation depth and collateral damage in order to assess its potential as a surgical tool. At the peak absorption of water near 1940 nm. Using the tunability demonstrated in this paper, we could expect precise control for ablation depths smaller than 100 µm. Such a small penetration depth enables precise ablation of tissue in microsurgical schemes.

Moreover, scaling up the pump power and modifying the configuration to active or passive Q switch, together with improved thermal management efforts could enable higher average powers and could be useful especially in the plastic material processing field.

6 CONCLUSIONS

In summary, we demonstrate a tunable CW Tm:YAP laser with a compact diode end pumped architecture, reaching Watt level output power with a tunability of 35 nm between 1917-1951 nm, with a maximum power of 3.84 W at 1934 nm wavelength. The use of Etalon plates allowed us to reach a narrow bandwidth of ~0.15 nm.

Comparing to previous work done with Tm:YAP lasers, we report a first Watt level tunable narrow bandwidth laser. Tm:YAP with the b-cut orientation, which emits around the water absorption peak at 1940 nm, could be applicable for tissues ablation with a controlled penetration depth, besides the other applications of tunable source in the 2 μm region.

ACKNOWLEDGEMENTS

The authors would like to thank Y. Sebbag and Prof. U. Levy from the Hebrew University of Jerusalem, for there willingness and support, and to D. Sebbag and R. Nahir for his fruitful discussion and collaboration.

REFERENCES

Coluccelli, N., Galzerano, G., Laporta, P., Cornacchia, F., Parisi, D. and Tonelli, M. (2007). Tm-doped LiLuF_4 crystal for efficient laser action in the wavelength range from 182 to 206 μm. *Optics Letters*, 32(14), p.2040.

Eremeikin, O., Savikin, A., Pavlenko, K. and Sharkov, V. (2010). Diode-pumped tunable Tm:YLF laser for mid-infrared gas spectroscopy. *Quantum Electronics*, 40(6), pp.471-474.

Feng, T., Yang, K., Zhao, S., Zhao, J., Qiao, W., Li, T., Zheng, L. and Xu, J. (2014). Broadly wavelength tunable acousto-optically Q-switched Tm:Lu2SiO5 laser. *Applied Optics*, 53(27), pp.6119-6122.

Feng, T., Zhao, S., Yang, K., Li, G., Li, D., Zhao, J., Qiao, W., Hou, J., Yang, Y., He, J., Zheng, L., Wang, Q., Xu, X., Su, L. and Xu, J. (2013). Diode-pumped continuous wave tunable and graphene Q-switched Tm:LSO lasers. *Optics Express*, 21(21), pp.24665-24673.

Godard, A. (2007). Infrared (2–12 μm) solid-state laser sources: a review. *Comptes Rendus Physique*, 8(10), pp.1100-1128.

Koechner, W. (2006). *Solid-State Laser Engineering*. New York (NY): Springer.

Li, J., Yang, S., Zhang, H., Hu, D. and Zhao, C. (2010). Diode-pumped room temperature single frequency Tm:YAP laser. *Laser Physics Letters*, 7(3), pp.203-205.

Li, J., Yang, S., Zhao, C., Zhang, H. and Xie, W. (2010). High efficient single-frequency output at 1991 nm from a diode-pumped Tm:YAP coupled cavity. *Optics Express*, 18(12), pp.12161-12167.

Li, G., Liu, H., Lu, F., Wen, X., Gu, Y. and Wang, Y. (2014). Analysis on preferential free running laser wavelength and performance modeling of Tm3+-doped YAP and YLF. *Applied Optics*, 53(22), p.4987.

Scholle, K., Fuhrberg, P., Koopmann, P. and Lamrini, S. (2010). *2 μm Laser Sources and Their Possible Applications*. INTECH Open Access Publisher.

Sorokina, I. (2003). Crystalline Mid-Infrared Lasers. *Topics in Applied Physics*, 89, pp.262-358.

Sun, M., Long, J., Li, X., Liu, Y., Ma, H., An, Y., Hu, X., Wang, Y., Li, C. and Shen, D. (2012). Widely tunable Tm:LuYAG laser with a volume Bragg grating. *Laser Physics Letters*, 9(8), pp.553-556.

Wang, L., Gao, C., Gao, M., Liu, L. and Yue, F. (2013). Diode-pumped 2 μm tunable single-frequency Tm:LuAG laser with intracavity Etalons. *Applied Optics*, 52(6), pp.1272-1275.

Yu-Feng, L., You-Lun, J., Bao-Quan, Y., Yue-Zhu, W. and Ubizskii, S. (2007). A Laser-Diode-Pumped Widely Tunable Single-Longitude-Mode Tm:YAP Laser at Room Temperature. *Chinese Physics Letters*, 24(9), pp.2594-2596.

SCIENCE AND TECHNOLOGY PUBLICATIONS