PRAMANA — journal of physics

Vol. 82, No. 2
February 2014
pp. 185–190

LOPUT Laser: A novel concept to realize single longitudinal mode laser

J GEORGE*, K S BINDRA and S M OAK
Solid State Laser Division, Raja Ramanna Centre for Advanced Technology, Indore 452 013, India
*Corresponding author. E-mail: jogy@rrcat.gov.in

DOI: 10.1007/s12043-013-0660-y; ***e*Publication:** 5 February 2014

Abstract. We propose a novel type of cavity design to generate single longitudinal mode laser known as LOPUT cavity. LOPUT cavity stands for linear orthogonally polarized modes resulting in unidirectional travelling wave cavity. The technique can be applied to both isotropic as well as anisotropic gain mediums. In the present paper, we applied the technique to anisotropic gain medium such as a-cut Nd:YVO_4. Using the LOPUT cavity, we demonstrated nearly 2 W of single longitudinal mode laser with nearly diffraction-limited spatial profile. Linewidth measurement using a custom-made Fabry Perot interferometer revealed instrument-limited linewidth of ∼5 MHz at 1064 nm.

Keywords. Solid state laser; diode pumping; single longitudinal mode.

PACS Nos 42.60.jf; 42.60.da; 42.60.by

Single longitudinal mode (SLM) lasers based on homogeneous gain mediums such as Nd:YAG, Nd:YVO_4, Nd:$GdVO_4$ found many applications in the field of spectroscopy, LIDAR, communications etc. A homogeneous medium should in fact lead to SLM operation naturally. However, in practice it is limited by the spatial hole burning (SHB) effect observed in standing wave cavities [1,2]. Elimination of the standing wave can be either achieved using a unidirectional ring cavity [3] or by using a twisted mode cavity (TMC) [4–6]. A typical TMC contains two quarter wave plates (QWP) and a polarizer kept on either side of the gain medium, so as to result in orthogonally circularly polarized counterpropagating waves inside the gain medium to suppress the effect of SHB in the laser cavity [4–6]. Even though the TMC presents a unique and compact design compared to the ring cavity in terms of the cavity length involved, the TMC cavity can only be applied to isotropic gain mediums such as Nd:YAG [7] or anisotropic gain medium cut along very special direction such that gain is uniform and it performs just like an isotropic gain medium, such as c-cut Nd:$GdVO_4$ crystal [7]. In other terms, TMC technique cannot be directly applied to anisotropic gain medium such as a-cut Nd:YVO_4 or even a-cut Nd:$GdVO_4$. Here, we present a novel design, i.e. LOPUT laser, to realize SLM laser in anisotropic as well as in isotropic gain mediums. LOPUT stands for linear orthogonally polarized modes resulting in unidirectional travelling wave cavity. The strategy adopted here is to have counterpropagating linearly polarized modes in a cavity to eliminate the standing waves and thus to suppress the effect of SHB altogether. In fact, the counter-propagating linearly polarized modes add up to result in a travelling wave along the gain medium, thus totally eliminating the effect of SHB at all locations inside the gain medium. Thus, LOPUT cavity offers a new way to suppress SHB and is applicable for anisotropic as well as isotropic gain mediums compared to a TMC. We have applied the technique to realize SLM laser in an anisotropic gain medium such as a-cut Nd:YVO_4.

Figure 1 shows the schematic of the experimental set-up. It consists of a diode-pumped Nd:YVO_4 crystal placed in a plane–plane cavity stabilized by pump-induced thermal lens effect in the gain medium. The output coupler transmission was 15% at 1064 nm. A fibre-coupled laser diode with 30 W maximum CW output at 809 nm (FWHM of spectral width ∼2.1 nm) and having 400 μm core diameter was used as the pump source. The pump beam was transferred to the gain medium using 2× imaging optics. The gain medium was a 1-at%-doped a-cut Nd:YVO_4 with 5 × 5 mm^2 cross-sectional area and 3 mm thickness. The crystal was wrapped with indium foil and was placed in a water-cooled copper mount. The *c*-axis of the crystal was aligned in the vertical direction or p-polarized light emission. The input coupler M1 has HR coating at 1064 nm and HT (T > 95%) at the pump wavelength.

The LOPUT action was enforced by keeping a quarter wave plate (QWP), Faraday rotator (FR) and Brewster plate (BrP) in proper location and orientation. The QWP was inserted between the HR mirror and Nd:YVO_4 crystal with its fast axis at 45° to the *c*-axis of Nd:YVO_4. This helps to rotate the plane of polarization by 90° in a double pass through the QWP, ensuring orthogonal polarization for the onward and return beams through Nd:YVO_4 crystal. The Faraday rotator was kept between the output coupler and Nd:YVO_4 and was rated for 45° rotation of the beam (in the clockwise direction from the output coupler side and for a beam coming out of the Faraday rotator). It is to be noted that the rotation direction of Faraday rotator is independent of the direction of traversal of the beam through it. A Brewster plate was kept between the Faraday rotator and the output coupler with its transmission axis at 45° to the horizontal direction. This unique set-up of LOPUT cavity always ensures that the beam is unidirectional inside the gain medium as far as a given polarization direction is concerned. The beam travelling towards the mirror M1 will always be polarized in the horizontal direction (i.e. parallel to the *b*-axis of Nd:YVO_4) and the beam moving in the direction of the output coupler M2 will be polarized along the vertical (orthogonal to the previous case, and parallel to the *c*-axis

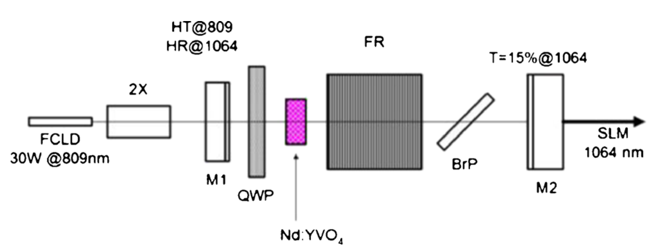

Figure 1. Schematic of the LOPUT-based Nd:YVO_4 laser.

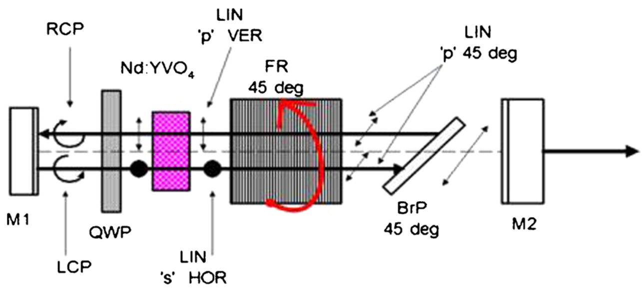

Figure 2. Polarization picture of LOPUT cavity.

of Nd:YVO_4) direction. A beam travelling in the opposite direction is rejected by the intracavity polarizer and hence prevented by the LOPUT cavity, ensuring unidirectional travelling wave as the resultant beam inside the gain medium. Figure 2 shows the directions and ellipticity of polarizations of the component beams inside the LOPUT cavity in detail.

The SLM performance was checked with a commercially available scanning plane–plane Fabry Perot interferometer (PP-FPI). Figure 3 shows the recorded SLM performance at 2 W output. The resolution of the instrument can be varied from 15 GHz to the instrument limit of 250 MHz. The FWHM measurement at 2 W output reveals that the SLM performance was instrument-limited with 250 MHz linewidth, and hence the actual linewidth could be smaller. Since, no direct instrument is available with us at this wavelength with a better resolution, we measured the linewidth by converting the laser to its second harmonic wavelength. A commercially available scanning confocal FPI (Make: Coherent) with the free spectral range (FSR) of 1.5 GHz and finesse of 200 for the SLM detection at 532 nm was used. The resolution of the instrument was 7.5 MHz at 532 nm and would correspond to $\sim$ 7.5 MHz/$\sqrt{2}$ = 5.3 MHz at 1064 nm, due to SHG process

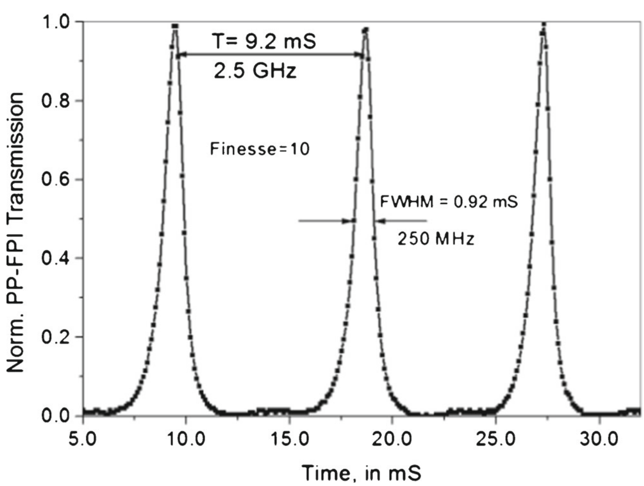

Figure 3. SLM Performance recorded with PP-FPI at 1064 nm at 2 W output.

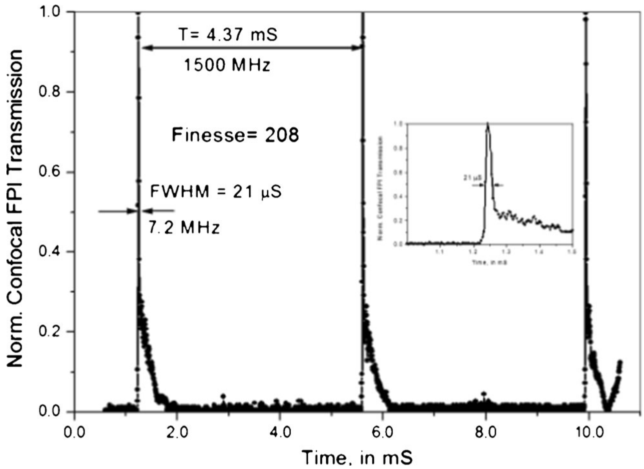

Figure 4. SLM performance recorded with a custom-made scanning FPI set-up at 532 nm.

involved. Extra cavity SHG of the CW beam resulted in a signal input level, which is 100 times lower than the allowed minimum input level (~10 mW) for the photodiode-based detection set-up of the standard instrument. Hence, we developed a custom-made detection set-up based on PMT to detect the SHG signal. We used an ORIEL make PMT (Serial Number: 77343) as the detector, and fabricated a transimpedance amplifier to transfer the signal from the high impedance output of the PMT to 50 Ω input of the digital storage oscilloscope. The transimpedance amplifier had RC constant of 30 μs and a load resistor of 3 MΩ.

Figure 4 shows the typical SLM performance recorded with the custom-made FPI at 532 nm. The measured FWHM was instrument-limited with 7.2 MHz at 532 nm, which corresponds to ~5 MHz at 1064 nm. It is to be noted that 5 MHz linewidth at 1064 nm corresponds to a linewidth of ~18 fm in the metre scale. In addition, the analysis of the SLM spectra reveals that the measured finesse of the instrument was ~208, and was slightly better than the typical finesse of the instrument (~200). Thus, the measured linewidth of the laser at 1064 nm with a custom-made FPI is again limited by the resolution of the instrument itself.

In fact, we believe that the linewidth of the instrument could be much smaller, and we may have to develop a custom-made delayed self-heterodyne measurement (DSHM) based device [8,9] to measure the linewidth. We are planning to develop a high resolution instrument with an instrument-limited resolution of ~20 kHz to measure the linewidth of the laser in the near future.

We also characterized our laser for polarization purity and the M^2 parameter. Polarization quality measurement using a Glan Thompson prism with 10,000:1 extinction ratio, reveals that the output was linearly polarized with extinction ratio limited by the Glan Thompson Prism analyser. To study the M^2 parameter, a fraction (3.7%) of the laser output was focussed using a P/V lens with 100 mm focal length, and the spot sizes were measured using a knife edge, and the propagation method was used to measure the M^2

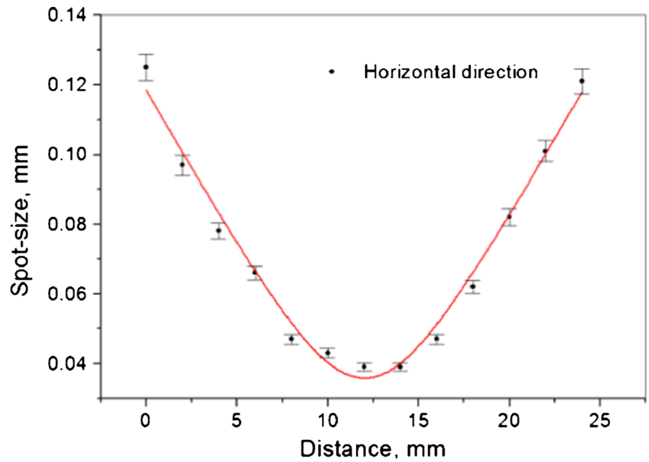

Figure 5. M^2 measured at 1 W output using propagation method.

parameter from the measured spot size variation along the axial direction. Figure 5 shows the typical measurement results at 1000 mW along the horizontal direction. The measured M^2 parameter was 0.95 ± 0.05 and hence diffraction-limited within the experimental error limit. Figure 6 shows the measured M^2 parameter as a function of the output power. It can be noticed that the LOPUT laser output is diffraction-limited up to 1 W power and beyond that the output is nearly diffraction-limited with $M^2 < 1.5$ value. Instead of a hard aperture, the soft aperture due to the finite pump spot was employed to generate diffraction-limited laser output. However, as the pumping power increases, the focal length of the thermal lens reduces, leading to a reduction in spot size of the cavity mode at the gain medium. The observed increase in M^2 parameter beyond 1 W laser output could

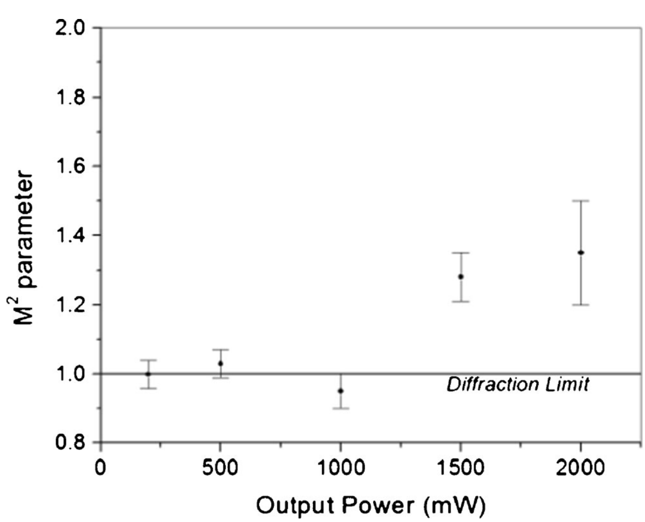

Figure 6. M^2 variation of the LOPUT laser.

be due to lower cavity mode size. For example, M^2 of 1.35 at 2 W output could be due to 16% lower mode spot size compared to the pump spot size. A thermal lens-stabilized cavity would stop working and will be driven to unstable regime, when the focal length of the thermal lens becomes smaller than the effective length of the laser cavity itself. The output power can be further scaled up by using a properly designed cavity with larger pump spot that would give rise to a weaker thermal lens and by using a hard aperture to limit the mode size.

In conclusion, by using a novel type of cavity proposed by us, known as the LOPUT cavity, we have demonstrated ∼2 W of single longitudinal mode laser with instrument-limited linewidth of ∼5 MHz in a linearly polarized output with diffraction-limited beam quality up to 1 W, and nearly diffraction-limited with $M^2 < 1.5$ up to 2 W. The output power was limited by the pump-induced thermal lens in the gain medium. The LOPUT cavity is proposed to be applicable for isotropic as well as anisotropic gain mediums for SLM generation, and we have demonstrated the working of the cavity for anisotropic gain medium (a-cut $Nd:YVO_4$) in this paper.

Acknowledgements

The authors would like to express their sincere gratitude to Shri K Ranganathan and Shri D N Rawat from SSLD for providing the necessary experimental support.

References

[1] W Koechner, *Solid state laser engineering,* 6th edn (Springer, 2006) pp. 152–155, 265
[2] J George, S M Oak and B P Singh, *Opt. Laser Technol.* **42**, 192 (2010)
[3] K M Murdoch, D A Clubley and M J Snadden, *Proc. SPIE* **7193**, 71930P-1-71930P-10 (2009)
[4] V Evtuhov and A E Siegman, *Appl. Opt.* **4**, 142 (1965)
[5] D D Jong and D Andreou, *Opt. Commun.* **22**, 138 (1977)
[6] A E Siegman, *Opt. Commun.* **24**, 365 (1978)
[7] E Wu, H Pan, S Zhang and H Zeng, *Appl. Phys. B.* **B80**, 459 (2005)
[8] T Okoshi, K Kikuchi and A Nakayama, *Elect. Lett.* **16**, 630 (1980)
[9] H Tsuchida, *Opt. Lett.* **15**, 640 (1990)