PRAMANA
— journal of
physics

© Indian Academy of Sciences

Vol. 82, No. 1
January 2014
pp. 143–146

Erbium–ytterbium fibre laser emitting more than 13 W of power in 1.55 μm region

SRIKANTH GURRAM*, ANTONY KURUVILLA, RAJPAL SINGH, BLACIUS EKKA, B N UPADHYAY, K S BINDRA and S M OAK
Raja Ramanna Centre for Advanced Technology, Indore 452 013, India
*Corresponding author. E-mail: srikanth@rrcat.gov.in; srikanthgurram18@gmail.com

DOI: 10.1007/s12043-013-0653-x; ***e*Publication:** 5 January 2014

Abstract. We report the work on erbium:ytterbium-doped double clad fibre laser (EYDFL), that is pumped at 976 nm. The maximum output power generated is 13.6 W in 1550 nm region with a slope efficiency of about 21%. To the best of our knowledge, this is the highest power reported from an EYDFL, that uses commercially available off-the-shelf large mode area Er:Yb-doped double-clad fibre.

Keywords. Fibre lasers; Er:Yb-doped fibre; 1550 nm; erbium:ytterbium-doped double clad fibre laser.

PACS Nos 42.55.Wd; 42.60.Pk

1. Introduction

Erbium-doped fibre lasers emitting 1550 nm radiation have applications in dermatology [1], lidar and optical communications [2]. Fibre lasers typically use cladding pumping for efficient coupling of pump light from fibre pig-tailed laser diodes to the core of the doped fibre. The erbium-doped fibre's absorption in 976 nm is not sufficient to achieve large amount of output power for cladding pumping configuration. Ytterbium has an absorption cross-section of ~1.8 pm^2, which is an order of magnitude more than that of Er at 976 nm. This, coupled with the resonant energy transfer between Yb's $^2F_{5/2}$ level to Er's $^4I_{11/2}$ level, makes Yb a co-dopant of choice in Er-doped fibres to increase the output power in 1550 nm region. There have been recent reports of observing about 88 W with in-band pumping in erbium-doped fibres without any co-doping of sensitizers such as ytterbium [3]. However, till date, Er–Yb-doped fibre (EYDF) seems to be the only efficient way for achieving multi-hundred Watts (up to ~300 W) of power in the 1550 nm region [4]. The presence of Yb in such a fibre laser causes emission of considerable power in 1 μm region, which may compromise the otherwise 'eye-safe' nature of this radiation source. However, the radiation in 1 μm region can be removed from the output of the laser by employing suitable means such as dichroic separators combined with beam dumps, as is done in the current work. We have earlier reported work on EYDFL that used a small core diameter EYDF which limited the output power to about 5 W [5]. Due to the limitation of small core diameter fibre in the scaling-up of the output power, we employed EYDF with large mode area (LMA) in our current work. Most of the literature on EYDFLs reports work on proprietary EYDFs, which are produced in lab scale and are not available commercially off-the-shelf. To the best of our knowledge, the reported maximum power in EYDFL systems by using commercially available off-the-shelf EYDFs is 10 W [6], which makes our current work reporting 13.6 W the highest power reported till date.

2. Experimental set-up

Figure 1 shows the schematic of the EYDFL. We have used a large core diameter EYDF in double side pumping configuration. The pump section on one end of the fibre contains an aspheric lens pair and two dichroic mirrors at non-normal incidence. One of the dichroic mirrors (M_1) with high reflectivity in 1550 nm region and high transmission in 975 nm region is kept between the coupling lens pair, and is used as an output coupler. Another dichroic mirror (M_3/M_4) with high transmission for pump wavelength and high reflectivity in 1 μm region is used not only to prevent 1 μm radiation from entering pump diode, which could cause irreversible damage to the laser diode, but also to direct the unwanted 1 μm radiation onto beam dumps. The pump section at the other end of the active fibre is similar except that the output coupler is replaced with a feedback mirror that has high reflectivity for 1550 nm region and high transmission for pump radiation (M_2). Pump light from fibre pig-tailed laser diodes is coupled into the inner cladding of the EYDF with ∼85% coupling efficiency. The coupling efficiency is measured by coupling pump beam into a matched passive fibre. We have kept initial lengths of the active fibre at both ends in long water-cooled V-grooves to remove heat generated by the absorption of large amounts of pump power in these regions. The remaining part of the fibre is provided with forced air cooling.

The fibre-pig tailed laser diodes (LD1 and LD2) have a maximum rated power of ∼30 W, which can be increased up to ∼40 W for short durations at the expense of slight reduction in life-time. The active fibre, made by M/s Nufern, has a double clad structure with core/cladding/coating diameters of 25/300/450 μm respectively. The 300 μm cladding (called inner cladding) has a refractive index which is slightly lower than that of the core whereas the fluoroacrylic coating has still lower refractive index (∼1.37). Hence,

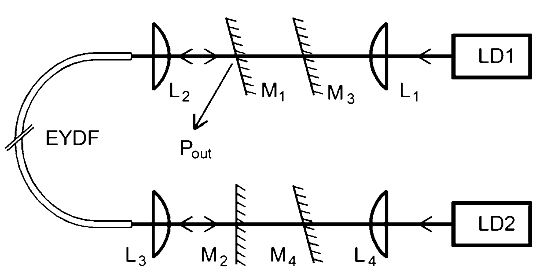

Figure 1. Schematic of the EYDF laser system.

the pump beam coupled into the inner cladding is gradually coupled to the absorptive inner core along the length. The effective absorption of inner cladding at 976 nm is about 2.5 dB/m. The numerical aperture of the inner cladding and fibre core are 0.46 and 0.1, respectively. The combination of the core diameter and the core numerical aperture makes this fibre slightly multimode that supports ~12 higher order modes near 1550 nm.

3. Results and discussion

One end of the fibre (M_2 side) is angle cleaved to suppress feedback from that fibre end and hence to reduce the output at 1 μm region. By angle cleaving one end of the fibre, the output power at 1 μm region has been reduced by 50%, compared to the case where both ends of the fibre are normal cleaved. This enhanced power at 1550 nm region, though is not exactly in proportion to the observed reduction in power at 1 μm region. The emission wavelength of the laser diodes is also tuned by tuning the laser diode temperature using TEC controllers to optimize absorption in the EYDF. By operating the laser diodes at their maximum power (combined output power of both diodes is about 80 W, which is beyond the rated power of diodes), we are able to generate about 13.6 W of power in 1550 nm region. Figure 2 shows plot of output power vs. absorbed pump power (after accounting for the coupling loss and leakage power). The maximum slope efficiency in terms of the absorbed power is about 21%. The output power of EYDFL is limited by the available pump power, as there is no roll-off in the output power, as shown in figure 2. Thermal management of the pump diodes limited the operation of the laser at this power level to few minutes, beyond which the temperature of the pump laser diodes cross the upper limit of safe operating temperature. The laser power was checked for its temporal stability over a period of 30 min while operating at output power levels of ~10 W. The temporal

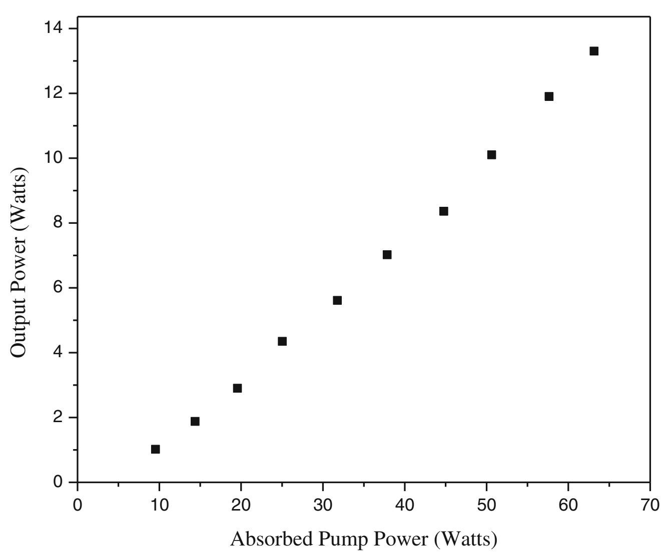

Figure 2. Variation of output power vs. input power of EYDFL.

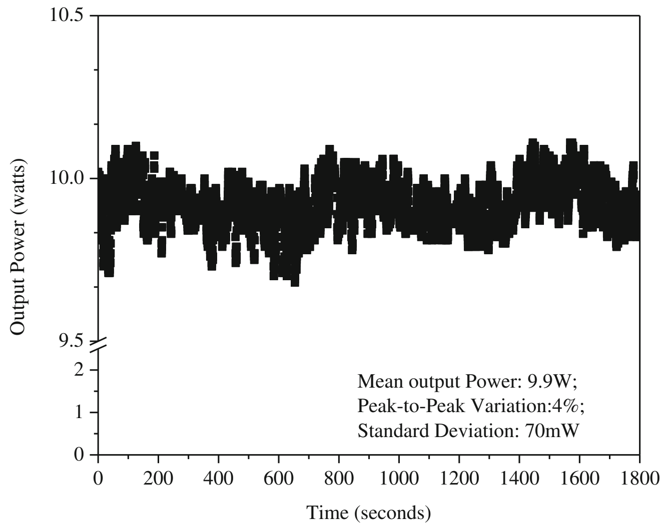

Figure 3. Temporal stability of EYDFL at 10 W of output power.

stability graph is shown in figure 3. The laser output power showed good stability with a mean output power of 9.9 W and a peak-to-peak variation of ∼4%.

4. Conclusion

We have demonstrated 13.6 W of output power in 1550 nm region from an EYDFL, which to the best of our knowledge, is the highest power reported so far by using commercially available off-the-shelf Er:Yb-doped large mode area fibres. The unwanted 1 μm radiation is separated from 1.5 μm radiation by appropriate dichroic mirrors. The laser has shown good temporal stability with ∼4% peak-to-peak variation of output power while operating at 10 W of output power levels.

References

[1] K Kincade, Dermatology lasers: 'Battle of the fractionals' heats up in dermatology, http://www.biopticsworld.com/articles/print/volume-1/issue-2/departments/news-views/dermatology-lasers-lsquobattle-of-the-fractionalsrsquo-heats-up-in-dermatology.html, *BioOptics World* **1(2)**, (2008)
[2] M J F Digonnet (ed.), *Rare earth doped fibre lasers and amplifiers* (Marcel Dekker, Inc., 1993)
[3] Jun Zhang, Viktor Fromzel and Mark Dubinski, *Opt. Exp.* **19(6)**, 5574 (2012)
[4] Yoonchan Jeong, Seongwoo Yoo, C A Coderaard, J Nilsson, J K Sahu, D N Payne, R Horley, P W Turner, L Hickey, A Harker, M Lovelady and A Piper, *IEEE J.* **13**, 573 (2007)
[5] G Srikanth, B N Upadhyaya, B K Saini and S M Oak, Development of a 5 W CW single transverse mode Er:Yb co-doped fibre laser at 1565 nm, *Proc. of DAE–BRNS National Laser Symposium, NLS-19* (RRCAT, Indore, Dec. 01–04, 2010)
[6] Morasse Bertrand, Agger Søren, Hovington Carl, Chatigny Stéphane, Gagnon Éric, de Sandro Jean-Philippe and Poulsen Christian, *Proc. SPIE* **6453**, 645324 (2007)