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Ytterbium-doped large-core fibre laser with 272 W of output power

Y. Jeong, J. K. Sahu, R. B. Williams, D. J. Richardson. K. Furusawa, and J. Nilsson

We report a highly efficient cladding-pumped Yb-doped large-core fibre laser, generating up to 272 W of continuous-wave output power at 1.08 μm with a beam quality (M^2) of 3.2. The slope efficiency was 83 % with respect to the launched pump power. No saturation (roll-off) was observed in output power with increasing pump power.

Subject categories and indexing terms: *Lasers (Fiber lasers), Optics (Optical pumping)*

Introduction: The continuous-wave (cw) output powers of fibre lasers operating with ytterbium (Yb) doped fibres continue to grow and such lasers are now beginning to compete with conventional solid state lasers (for example, Nd:YAG lasers) in many application areas. Fibre lasers benefit from a geometry that allows simple thermal management and a high beam quality. By applying the technique of cladding-pumping, fibre lasers with high-brightness, even diffraction-limited output can be realized, even when low-brightness diode lasers are used as pump sources. Yb-doped fibre lasers offer a broad emission spectrum extending from ~1 μm to ~1.1 μm and provide an excellent conversion efficiency of over 80 % due to the low quantum defect when pumped with radiation around 915 nm or 975 nm. The low quantum defect and beneficial geometry make cladding-pumped Yb-doped fibre lasers (YDFLs) an ideal candidate for high-power sources operating around 1 μm.

Recently, for example, 2 kW of output power was reported from highly multi-moded devices that combined the output power from several fibre lasers [1]. The output powers achieved from close to diffraction-limited laser configurations are still somewhat lower. A 110-W cladding-pumped YDFL with an M^2 value of 1.1~1.7 and a conversion efficiency of 58 % with respect to the incident pump power was reported in 1999 [2]. More recently, a 135-W YDFL with an M^2 value of 1.05 and a slope efficiency of 51 % with respect to the total optical diode pump power was reported [3]. In both of these publications, fibres with relatively small cores of ~9-μm diameter were used. As a consequence of the long length of fibre used in these experiments (~60 m) and the small core, stimulated Raman scattering (SRS) limited the maximum achievable output power in ref. 3. Use of a larger core is preferable to realize further power scaling, (assuming that good spatial mode quality can be maintained), because the effects of Raman scattering can be reduced via the corresponding reduction in the power density. Use of as short a fibre length as possible also helps to increase the SRS threshold. Maximising the pump absorption by fibre design, doping concentration (whilst maintaining good efficiency), and the choice of pump wavelength is thus an important issue when developing high power, high-brightness, fibre lasers.

Besides the recent results of YDFLs, high-power dual doped fibre lasers have started to be explored, in which the core was doped with Nd (neodymium) and Yb [4], [5]. A 485-W cw output power from a 35-m long dual doped fibre with an M^2 value of 1.5 has been reported [5], in which the core had a 24.5-μm diameter and was doped with both Nd and Yb. The pump power was wavelength-multiplexed as 350 W at 976 nm, 175 W at 940 nm, and 175 W at 808 nm. The overall slope efficiency was 72 % with respect to the launched pump power. This result supports the large-core fibre is promising for further power scaling of YDFLs operating in a single transverse mode.

Results: In this letter we report a highly efficient, 975 nm diode stack-pumped, cladding-pumped YDFL with 272 W of output power at 1.08 μm based on just 4.7 m of large-core diameter, high Yb concentration double-clad fibre.

The double-clad Yb-doped large-core fibre used in these experiments was designed and pulled from a preform that was fabricated in-house by the standard modified chemical-vapour deposition (MCVD) and solution doping technique. Before being drawn to fibre, the preform was milled to have a D-shape so as to improve the cladding-mode overlap with the Yb-doped core. The fibre had a 30-μm diameter Yb-doped core with a numerical aperture (NA) of 0.07. The D-shaped inner cladding had a 375-μm diameter, and was coated with a low-refractive-index polymer outer cladding which provided an inner-cladding NA of 0.48. The small-signal absorption at the pump wavelength was ~3.5 dB in a 1-m long piece of fibre.

The experimental setup is shown in Fig. 1. A diode-laser stack operating at 975 nm was used as the pump source, and its output was coupled into the 4.7-m length of double-clad Yb-doped fibre through a combination of lenses with an estimated launch efficiency of >85 % relative to power incident on the fibre. Both ends of the fibre were cleaved perpendicular to the fibre axis. A laser cavity was formed between the facet at the pump launch end of the fibre and a lens-coupled, dichroic mirror with high reflectivity at 1~1.1 μm at the other end of the fibre. The full laser output was taken through the pump launch end. A dichroic mirror in front of the launch end separated the output beam from the input pump beam. Both ends of the fibre were held by temperature-controlled metallic V-grooves that were devised to prevent the fibre coatings from being heated and then damaged by the non-guided pump power.

The laser output power characteristics are shown in Fig. 2, together with a typical output spectrum. The maximum laser output power was 272 W at the maximum diode drive current. The slope efficiency with respect to the absorbed pump power was 85 % (83 % with respect to the launched pump power), which is close to the quantum limit. The laser spectrum extended from 1060 nm to 1100 nm. The YDFL operated as efficient as most of the launched pump power converted into the signal power. The output power increased linearly with the launched pump power. It is worth noting that no evidence of any power limitation due to nonlinear scattering, or indeed any other undesired effect, was observed. Compared to the configuration of the fibre from ref. 5 (35 m, Nd/Yb-doped 24.5-μm core size), the fibre length was much shorter with a comparable core size (4.7 m, Yb-doped 30-μm core size) that this YDFL was relatively free from undesirable nonlinear scattering. The measured beam quality factor (M^2) was 3.2 and no active steps were taken to restrict the laser to operate on a single transverse mode.

Conclusion: We have demonstrated a highly efficient, high Yb concentration, double-clad Yb-doped large-core fibre laser with a cw output power of 272 W at 1.08 μm. The slope efficiency was 83 % with respect to the launched pump power, and our results show that the thermal load per unit length could be kept sufficiently small as to avoid thermal damage when operating at power levels approaching 300 W and using fibre lengths as short as 4.7 m. No evidence of roll-off in laser output power at the highest launched pump powers that we could achieve with our current pump source (~340 W) was observed, showing that our laser could be power-scaled to even higher powers using a more powerful pump source. We believe that in due course it will be possible to obtain similar output powers in a diffraction-limited output using slightly more advanced core designs and/or other higher order mode suppression techniques.

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REFERENCES

1. V. Gapontsev and W. Krupke, "Fiber lasers grow in power," Laser Focus World, Aug., 2002, pp. 83-87.
2. V. Dominic, S. MacCormack, R. Waarts, S. Sanders, S. Bicknese, R. Dohle, E. Wolak, P. S. Yeh, and E. Zucker, "110 W fibre laser," Electron. Lett., vol. 35, pp. 1158-1160, 1999.
3. N. S. Platonov D. V. Gapontsev, V. P. Gapontsev, and V. Shumilin., "135W CW fiber laser with perfect single mode output," in Proc. Conference on Lasers and Electro-Optics 2002, Long Beach, USA, May 19-24, 2002, postdeadline paper CPDC3.
4. J. Limpert, A. Liem, S. Höfer, H. Zellmer, and A. Tünnermann, "150 W Nd/Yb Codopedfiber laser at 1.1 mm," in Proc. Conference on Lasers and Electro-Optics 2002, Long Beach, USA, May 19-24, 2002, paper CThX1.
5. J. Limpert, A. Liem, H. Zellmer, and A. Tünnermann, "Continuous-wave ultra high brightness fiber laser systems," in Proc. Advanced Solid-State Photonics 2003, San Antonio, USA, Feb. 2-5, 2003, postdeadline paper PD1.

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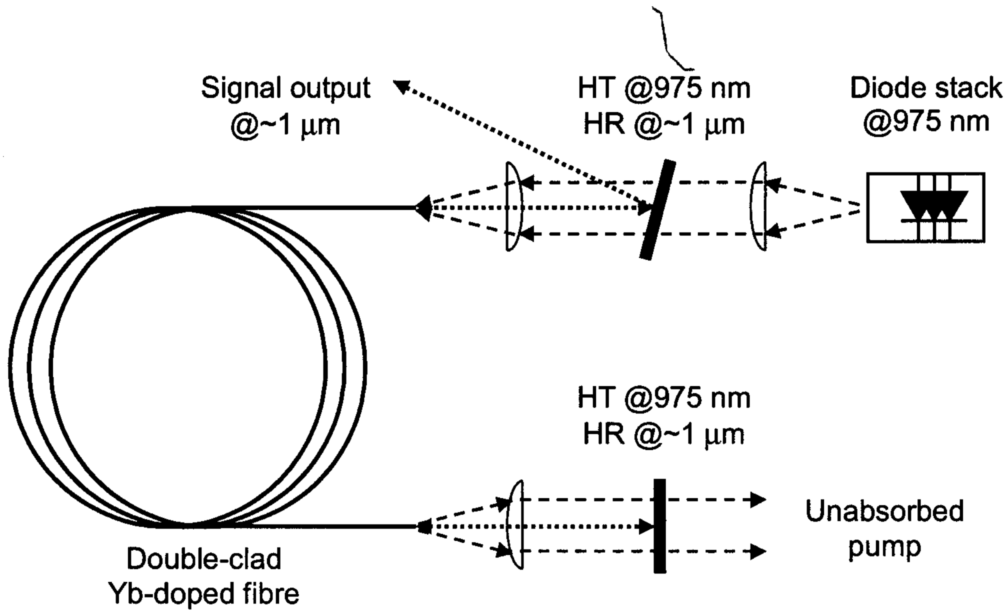
FIGURE CAPTIONS

Fig. 1. Yb-doped fibre laser arrangement used with a diode-stack pump source. HR: high reflectivity, HT: high transmission.

Fig. 2. (a) Fibre laser output power with respect to the absorbed pump power and (b) the laser output spectra.

Fig. 1



Signal output
@~1 μm
HT @975 nm
HR @~1 μm
Diode stack
@975 nm
HT @975 nm
HR @~1 μm
Unabsorbed
pump
Double-clad
Yb-doped fibre

Fig. 2(a)

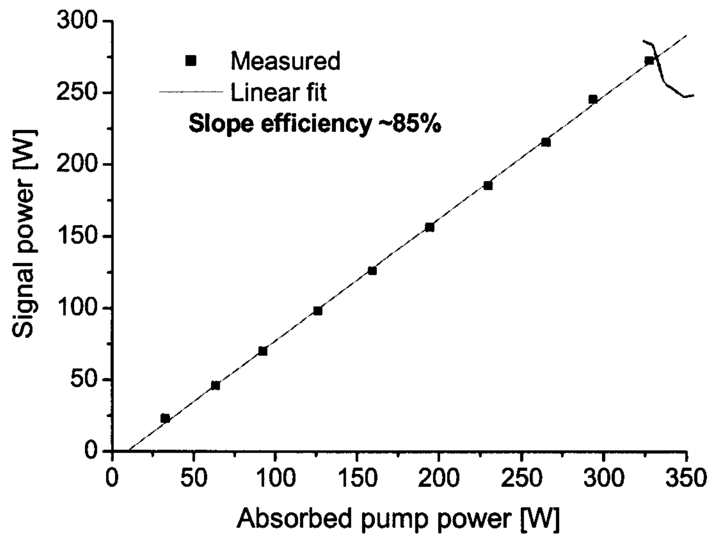
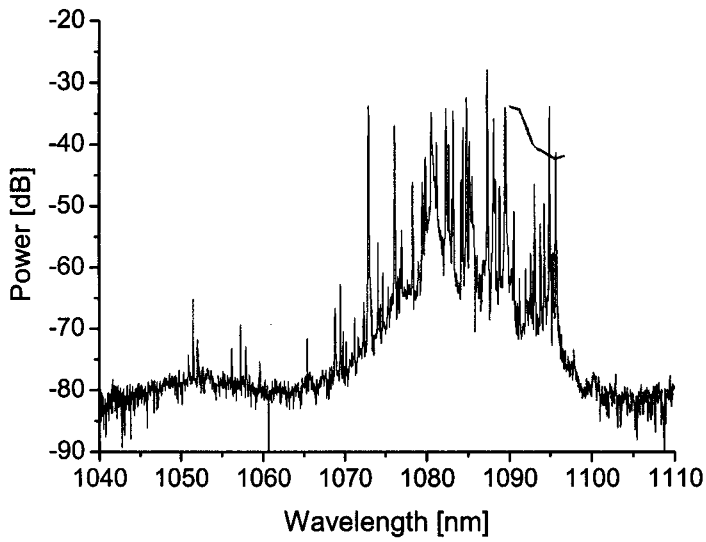

Measured
Linear fit
Slope efficiency ~85%
Signal power [W]
0
50
100
150
200
250
300
0
50
100
150
200
250
300
350
Absorbed pump power [W]

Fig. 2(b)



-20
-30
-40
-50
-60
-70
-80
-90
Power [dB]
1040
1050
1060
1070
1080
1090
1100
1110
Wavelength [nm]