High power tandem pumping fibre amplifier

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We demonstrate a high efficiency 1083 nm fibre amplifier tandem pumped by a 1030 nm fibre laser. The 1030 nm fibre laser is coupled into a 25 m long single clad ytterbium doped fibre via a high power wave division multiplexer to core pump the 1083 nm signal laser. An output power of 4.5 W and a power conversion efficiency of 76.6% are achieved without power-roll. The performance of the amplifier can be improved by optimizing the gain fibre length.

Keywords: tandem pump, fibre amplifier, single clad fibre

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1. Introduction

With the development of high-power laser diode (LD) sources and advances in the double-clad fibre (DCF) design and fabrication, the power scaling of ytterbium doped fibre (YDF) lasers and fibre amplifiers is stepping up rapidly.[1−4] Kilowatt level fibre lasers pumped by 975 nm LDs have already been successfully achieved.[4−6] Nevertheless, there are still several limits needed to be addressed for further power scaling, one of which is the low brightness of the high power diode lasers. Due to the low brightness, the pump light is difficult to be coupled efficiently into a fibre with a small diameter size. The thermal loads, the nonlinearities and the damage are also equally important limiting factors for the higher power scaling.[7]

The tandem pumping, in which one or several fibre lasers pump another one, has been considered to be an ideal scheme for achieving a high power fibre laser.[8,9] The output of a fibre laser can be 3–4 orders brighter than that of the 975 nm LD,[10,11] and thus can be much easier to be launched into a small size fibre. The tandem pumping also makes it possible to pump close to the emission wavelength, so the quantum defect heating can be low, which results in a reduced thermal load.[7] Take the IPG's 10 kW fibre laser for example,[8] which is pumped by 1018 nm fibre lasers and emits the 1070 nm laser light, the quantum defect is only 5%, nearly half of that pumped directly by 975 nm LDs. Thus, the thermal load in the gain fibre can be effectively relieved. Another reason to use the tandem pumping is that the unsaturated gain can be much lower in the gain fibre tandem pumped at longer wavelengths than that pumped with the conventional LD at 910–980 nm.[11]

Though the tandem pumping is promising for higher power scaling, the much lower absorption of the Yb ions at 1 μm than that at 975 nm[7] make it difficult to achieve power scaling with the conventional gain fibres. Up to now, there is still a lack of published details on the tandem pumping.

In this paper, we present experimental results on the tandem pumping at the watt level. Firstly, we setup a 1030 nm seed laser based on an fibre Bragg grating (FBG). Then it is boosted to 5.85 W through a two-stage amplification. After that, the 1030 nm laser used for the tandem pumping and the 1083 nm seed laser are launched into a length of single clad YDF through a wave division multiplexer (WDM). A maximum output power of 4.5 W is achieved with an optical to optical efficiency of 76.6%. The performance of the amplifier can be further improved by optimizing the gain fibre length or increasing the pump power. Our experimental results have indicated the possibility for high power scaling with the tandem pumping.

2. Experiment

The experimental setup is shown in Fig. 1. The pump source used in our tandem pumping fibre amplifier is a 1030 nm fibre laser. The output power of the 1030 nm seed laser is preamplified to about 150 mW and then seeded to the power scaling amplifier.

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The pump sources of this stage are two 975 nm pigtailed LDs, the outputs of which are launched into the inner cladding of the 4 m double-clad YDF purchased from Nufern. The gain fibre has a 5 μm/130 μm core/inner cladding size with a numerical aperture (NA) of 0.12/0.46 and the average absorption coefficient is 1.7 dB/m at 975 nm. The signal light in this tandem pumping experiment comes from a 1083 nm fibre laser and is preamplified to about 120 mW. The two lasers are launched into a 25 m-long single clad YDF (Nufern SM-YSF-HI) through a high power 1030 nm/1083 nm WDM. The core and the cladding diameters of the single cladding fibre (SCF) are 6 μm and 125 μm, respectively. The absorption coefficient is 250 dB/m at 975 nm. The gain fibre's output end is 8° cleaved to suppress the parasitic oscillation. Isolators (ISO) are used between the amplification stages to prevent the backward light.

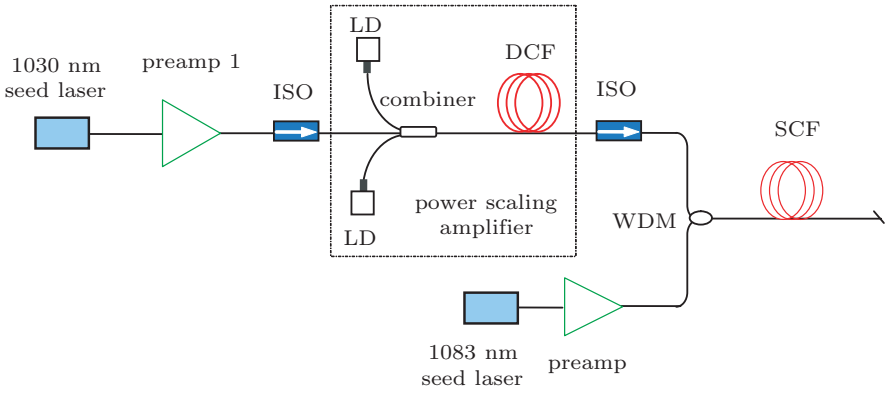


Fig. 1. (colour online) Experimental setup of tandem pumping fibre amplifier.

The two seed lasers used in our experiment have the same resonant cavity structure based on the FBG, which is shown in Fig. 2. The reflectivity of the FBG at the centre wavelength is only 50%, far insufficient to be used as a high reflectivity (HR) mirror. So a 50:50 wide-band fibre coupler is used in the resonant cavity. By splicing the two output ports together, we can attain a reflectivity as high as 99%. The FBG is used as the output coupler. The gain fibre is also of the Nufern SM-YSF-HI type and has a length of 0.5 m. The 975 nm pump light is launched into the gain fibre through a single mode WDM. The maximum output power of the seed laser is about 20 mW and can be amplified to 200 mW by preamp 1. The 1083 nm seed laser has the same structure as the 1030 nm seed one except that the optical components are 1083 nm based, so we will not describe in detail here.

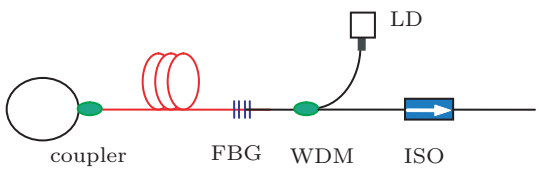


Fig. 2. (colour online) Schematic diagram of the seed laser.

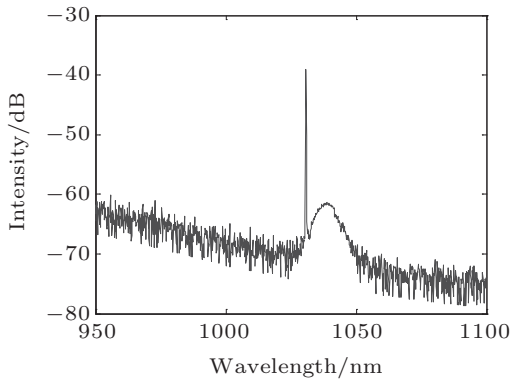


Fig. 3. Spectrum of the 1030 nm fibre amplifier.

Shown in Fig. 3 is the spectrum distribution of the 1030 nm power scaling amplifier measured with an optical spectrum analyzer (Agilent 86142B) at the maximum output power of 5.85 W. The unabsorbed pump light may also propagate into the next amplifier and contribute to the amplification of the 1083 nm signal laser. In order to diminish the effect of the residual 975 nm laser on the tandem pumping, a pump stripper is used to get rid of the residual pump light at the end of the gain fibre. There is no residual pump power in the spectrum, which indicates the good performance of our pump striper. It is shown in Fig. 3 that the

amplified spontaneous emission (ASE) has built up in the longer wavelength region but is still 20 dB weaker than the signal laser and has little effect on the amplifier's performance.

The output power measured at the incremental 1030 nm laser power is shown in Fig. 4. A stable maximum laser output of 4.5 W at 1083 nm is achieved when a 5.85 W 1030 nm laser is launched into the gain fibre through the WDM. There is no sign of power-roll, indicating the potential for higher output power scaling with the substitution of the pump source with more powerful ones. The optical to optical efficiency is 76.6%, which is comparatively high among the single clad YDF amplifiers. Because the absorption coefficient at 1030 nm is 50 times lower than that at 975 nm, we have used a long enough gain fibre. From the spectrum of the output light (Fig. 5), we can find that the 1030 nm pump

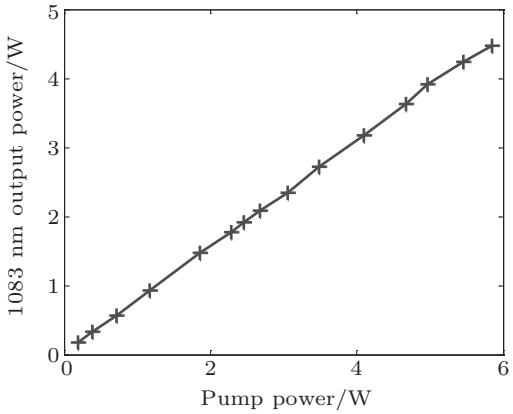


Fig. 4. Output power of the tandem pumped amplifier as a function of the incident pump power.

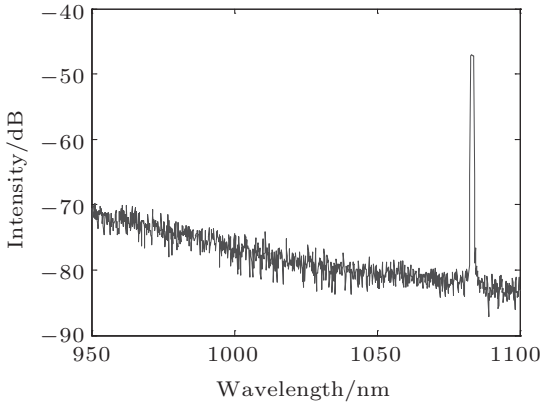


Fig. 5. Spectrum of the tandem pumped fibre amplifier.

laser has been absorbed completely and the ASE is very weak compared to that of the 1083 nm signal laser. It can be concluded that by choosing an optimal gain fibre length, the output power and the efficiency can be further increased.

3. Discussion

For a single clad YDF amplifier, the maximum output power is apparently limited. To achieve higher power scaling, the double clad YDF and the signal and pump combiners are ideal choices, which can operate at much higher power level than the WDM. Nevertheless, when it comes to the double clad fibre for the high power operation, the cladding absorption coefficient in the fibre core is always much lower for the resistance to the photodarkening[7] and the unwanted spectroscopic loss processes, such as the energy-transfer upconversion.[13] So the absorption would be a big problem in the double clad YDF tandem pumping. Enhancing the absorption coefficient of the gain fibre by varying the doped components may be the most promising method. However till now, there is no detailed report on the progress of this scheme. Another efficient approach to increase the absorption is with the fibre design. For the high brightness pump laser, it can be launched and guided in a smaller inner cladding, which can improve the pump overlap with the core and thus enhance the absorption. Our experimental results, to some extent, have shown the possibility of the high power tandem pumping with the commonly available YDF if the pump overlap with the core can be improved.

4. Conclusion

In conclusion, we have presented the detailed characteristics of a tandem pumped amplifier in an all-fibre configuration. The tandem pumping source is a 1030 nm fibre laser. The 1083 nm signal laser can be stably boosted to the 4.48 W maximum output limited by the pump power. The optical to optical efficiency is 76.6%. The output power and the conversion efficiency can still be raised by increasing the pump power and optimizing the gain fibre length. Our experimental results have demonstrated the possibility of the tandem pumping with the commonly available ytterbium doped fibre.

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