Simple and compact, all-fibre retro-reflector for cladding-pumped fibre lasers

Y. Jeong, S. Baek, J. Nilsson, and B. Lee

We propose an all-fibre retro-reflector that is realised via shaping a fibre end into a right-angled cone for a pump reflector in cladding-pumped fibre lasers. The conical-shaped, fibre-optic retro-reflector allows the folded, total internal reflections for pump beams that propagate in the inner cladding of a double-clad fibre. We applied the proposed scheme to a cladding-pumped ytterbium-doped fibre laser and readily achieved over 55% of reflection for the un-absorbed pump throughput, thereby generating 29% more signal output power than without the pump retro-reflector.

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

Introduction: Double-clad rare-earth-doped fibres (DCREDFs) combined with multimode pump diodes make excellent high-power laser sources. In this scheme, while the multimode pump beam propagates in the large inner cladding, the laser signal is generated in a much smaller doped core. Thus, a high-brightness or even diffraction-limited laser output beam is readily achievable. However, the pump absorption rate in a cladding-pumped scheme is much lower than the intrinsic core absorption because of the small overlap between the pump beam and the doped core. The low pump absorption rate can result in an excessive device length to the point where the accumulation of undesirable background loss and nonlinear scattering becomes problematic. The excessive device length leads to the degradation of output power and also limits the range of operating wavelengths insofar as ground-state absorption is significant (e.g., in Yb-doped fibre lasers). In particular the device length as well as the pump intensity (or the pump rate) is a crucial factor for three-level lasers, such as 980-nm ytterbium-doped fibre lasers, because a large amount of ground-state absorption must be overcome [1].

There have been a variety of attempts to improve the low pump absorption rates, and the pump rates, of DCREDFs by enhancing the effective interaction between the pump beam and the rare-earth doped core: The use of non-circularly symmetric fibres (D-shaped, rectangular-shaped, off-centred core, etc.) and mode mixing by bending fibres in a particular ways (kidney-shaped coiling, etc.) have widely been considered [2, 3]. On top of these schemes double-passed pumping can also be considered to increase the absorption within a fixed fibre length. For this purpose an external mirror can be used; however, this makes the setup bulky and, moreover, is not cost-effective. Recently, a pump-reflecting scheme on the basis of an inner-cladding fibre Bragg grating (FBG) was reported [4]. Although this could provide a compact all-fibre configuration, the inner-cladding FBG requires specialty fibres that must have a photosensitive inner cladding. Typically, however, inner claddings are made of pure silica, which is not photosensitive. In addition, the grating needs a very large reflection bandwidth in order to cover the bandwidth of pump beams that, in general, are highly multimode and spectrally broad. As a result, the maximum reflectivity was limited to ~46% [4]. This scheme is not applicable to normal DCREDFs that are not photosensitive in the inner cladding. Thus, a pump reflector that can easily be implemented with normal fibres is of importance for cladding-pumped fibre lasers of high-performance in which the pump rate and pump absorption rates need to be high.

In this letter we propose a fibre-optic retro-reflector that is realised via shaping the fibre end into a right-angled cone for a pump reflector in cladding-pumped fibre lasers. On the basis of this we demonstrate an improved cladding-pumped ytterbium-doped fibre laser. The experimental result demonstrates the usefulness of the proposed scheme.

Principle and experiment: The principle of the operation is that the pump beam undergoes two-folded, total internal reflections at the fibre end that has been shaped into a right-angled cone, as shown in Fig. 1. Under the paraxial approximation, the incidence angle of 45° for the pump beam is enough to ensure that total internal reflection occurs at the conical interface because the critical angle of the air-silica interface is approximately 43.6°. As a result the pump beam is readily reflected and again absorbed as propagates through the fibre in the opposite direction. This is a simple, compact, and cost-effective way to realise double-passed pumping of cladding-pumped fibre lasers.

The proposed scheme was experimentally investigated using a 6-m long double-clad single-mode ytterbium-doped gain fibre. The outer diameter of the fibre was 125 μm and it was coated with a low refractive index polymer. The inner-cladding absorption coefficient was ~0.43 dB/m at 915 nm. The experimental arrangement is shown in Fig. 2. Along with a straightforward arrangement with lenses and a broadband dichroic mirror for the pump and laser output coupling, a ~3-cm long, bare single-mode fibre (SMF) with an FBG inscribed in its core was fusion-spliced to the far end of the fibre, as seen from the pump-launching side. The FBG had peak reflectivity of 15 dB at 1058 nm and 3-dB bandwidth of 0.2 nm. Thus, an all-fibre laser cavity was formed between the perpendicularly cleaved fibre end at the pump launch side and the FBG as a high reflector at the rear end of the fibre.

We firstly characterised the fibre laser for the case that the fibre end after the FBG had a perpendicular cleave. This would lead to ~4% Fresnel reflection for the incident pump light. The maximum output was limited to 2.1 W at ~1058 nm with the launched pump power of 7 W. The pump power absorbed in the fibre was ~45% with respect to the launched pump power.

The proposed conical-shaped fibre end can be fabricated by a variety of ways, for example, by conventional wet etching, direct polishing, etc. Alternatively, a similar shape can more simply be obtained with an electrical arc as is used to splice and taper fibres. An image of the fibre end treated by an electrical arc is shown in the inset of Fig. 2. The resultant geometry resembles a right-angled cone and has a similar principle of operation on the whole. Thus, because of its simplicity, this technique was instead used to make a near-conical-shaped retro-reflector.

We used the fibre-optic pump-retro-reflector to the same setup used for the preliminary characterisation. The resultant output characteristics were significantly improved in comparison with those without the pump retro-reflector: The output powers of the fibre laser before and after implementing the fibre-optic pump reflector were shown in Fig. 3. The net pump absorption was increased to ~58% in total with respect to the launched pump power after treating the fibre end. The central part of the fibre end was likely to have a low incident angle because of the hemisphere-like shape, at which pump beam could escape from the total internal reflection. The resultant reflectivity was 55%. This is even higher than that previously obtained with an inner-clad FBG (46%) [4], even though the implementation was such simples and the fabricated fibre end was not optimized in shape. As a result, the maximum output power increased to 2.7 W (29% higher than the output power reached without the pump retro-reflector).

Conclusion: We have proposed and demonstrated a conical-shaped all-fibre pump retro-reflector for cladding-pumped fibre lasers, and experimentally demonstrated a reflectivity of 55% for the single-passed pump beam. This was obtained with a non-optimised reflector that was manufactured through a simple electrical arc treatment of a fibre end. The resultant reflector allowed for a double-passed pump in a compact alignment-free all-fibre configuration. The maximum output power increased by 29%. Further improvement is expected with optimised reflector shapes. The proposed pump retro-reflector along with the signal-reflecting FBG is readily applicable to normal DCREDFs in a simple, low-cost, compact, robust, and all-fibre configuration. While most Yb-doped fibre lasers can be made sufficiently long for efficient pump absorption even without a pump reflector, some fibre lasers such as Yb-doped fibre lasers at 980 nm and Nd-doped fibre lasers greatly benefit from the higher pump intensities and the higher pump absorptions that a pump retro-reflector can provide.

REFERENCES

1. D. B. S. Soh, C. Codemard, J. K. Sahu, J. Nilsson, V. Philippov, C. Alegria, Y. Jeong, “A 4.3W 977 nm ytterbium-doped jacketed-air-clad fiber amplifier,” ASSP 2004, New Mexico, 1-4 Feb., 2004, paper MA3.
2. A. Liu and K. Ueda, “The absorption characteristics of circular, offset, and rectangular double-clad fibers,” Opt. Commun., vol. 132, pp. 511-518, 1996.
3. H. Zellmer, A. Tünnermann, H. Welling, and V. Reichel, “Double-clad fiber with 30 W output power,” in OSA TOPS: Proc. OAA, vol. 16, pp. 137-140, 1997.
4. S. Baek, D. B. S. Soh, Y. Jeong, J. K. Sahu, J. Nilsson, and B. Lee, “A cladding-pumped fiber laser with pump-reflecting inner-cladding Bragg grating,” IEEE Photon. Technol. Lett., vol. 16, pp. 407-409, 2004.

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FIGURE CAPTIONS

Fig. 1. Principle of the pump retro-reflection from a conical fibre end.

Fig. 2. Experimental arrangement for a cladding-pumped ytterbium-doped fibre laser with a pump retro-reflector. Inset: image of the fibre end produced by an electric arc.

Fig. 3. Output characteristics of the cladding-pumped ytterbium-doped fibre laser with and without the conical-end pump retro-reflector. Inset: output spectrum. PRR: pump retro-reflector.

Fig. 1

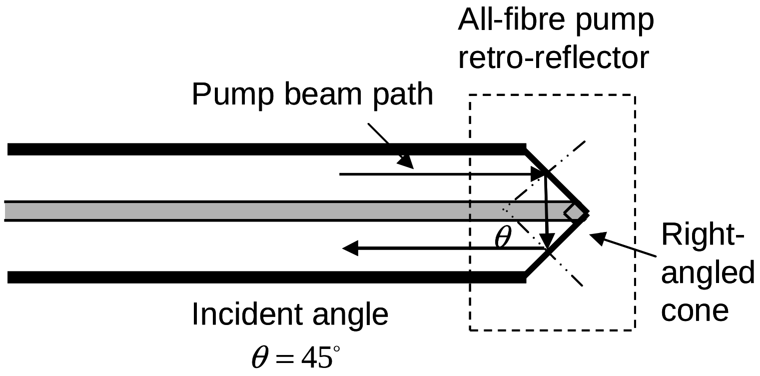
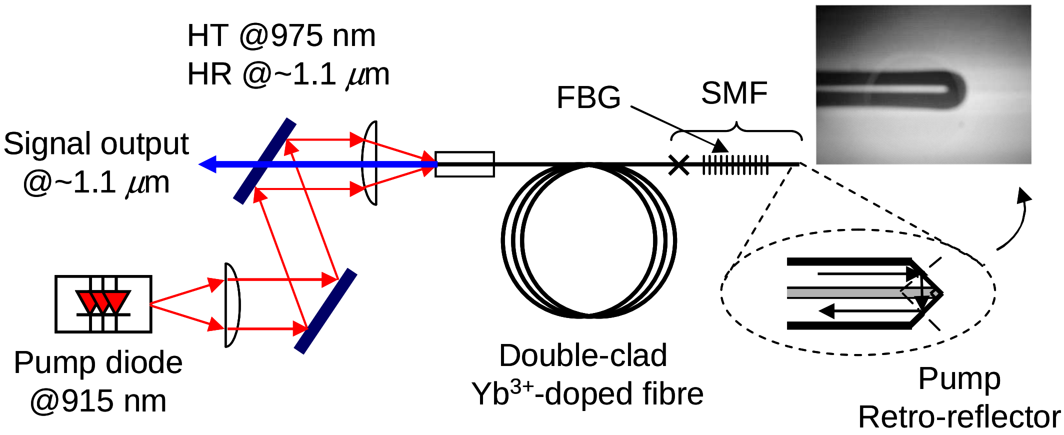
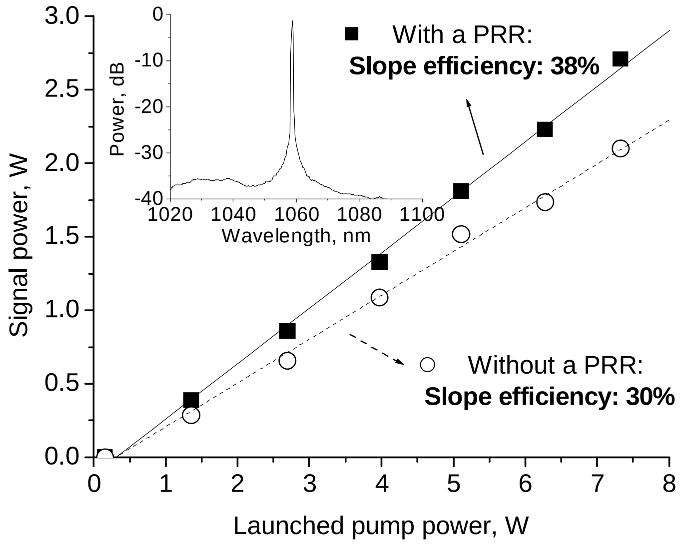

All-fibre pump
retro-reflector
Pump beam path
θ
Right-
angled
cone
Incident angle
θ = 45°

Fig. 2



HT @975 nm
HR @~1.1 μm
Signal output
@~1.1 μm
FBG
SMF
Pump diode
@915 nm
Double-clad
Yb3+-doped fibre
Pump
Retro-reflector

Fig. 3


With a PRR:
Slope efficiency: 38%
Without a PRR:
Slope efficiency: 30%
Signal power, W
Launched pump power, W
Power, dB
Wavelength, nm
0
-10
-20
-30
-40
1020
1040
1060
1080
1100
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
1
2
3
4
5
6
7
8