AN ERBIUM DOPED HOLEY FIBER AMPLIFIER AND RING LASER

Taichi Kogure (1,2), Kentaro Furusawa (1), Ju Han Lee (1), Tanya M. Monro (1), David J. Richardson (1)
1: Optoelectronics Research Centre, University of Southampton, Southampton SO17 1BJ, UK
Email: djr@orc.soton.ac.uk Tel: +44 23 8057 3139 Fax: +44 23 8059 3142
2: Information Technology R&D center, Mitsubishi Electric Corporation,
5-1-1 Ofuna, Kamakura, Kanagawa 247-8501, Japan
Email: tkogure@isl.melco.co.jp Tel: +81 467 41 2441 Fax: +81 467 41 2486

Abstract *We demonstrate an all-fiber erbium-doped holey fiber amplifier providing upto 44 dB of internal gain. Incorporating this amplifier within a ring laser we demonstrate a 0.5mW laser threshold and tuning range in excess of 100nm.*

Introduction

Holey fiber technology provides a powerful way to make fibers with new waveguide properties and parameter ranges well beyond those that can be achieved with conventional fiber fabrication processes [1]. For example, by making use of the high index contrast between silica and air, it is possible to make silica fibers with a high effective numerical aperture and correspondingly small core dimension of the order of the optical wavelength. Similarly, by making use of the wavelength dependence of average index guiding effects in the limit of small air holes and large hole spacings it is possible to design fiber with large mode areas that are effectively single-mode for all wavelengths.

Although most work so far has focused on the development of passive fibers there is a growing appreciation that this technology is also of great interest for the development of active fibers and devices [2-7]. To date the majority of work has focused on the development of Yb-doped, cladding-pumped fiber lasers based on large mode area fiber designs and that have recently demonstrated output powers as high as 280W [3]. However, small-core, high-NA, holey fiber designs also have much to offer. For example; the HF preform stacking procedure allows for ready positioning of the rare-earth dopant relative to the pump and signal mode fields and thus control of the associated overlap factors [4], ultra-high-NA cores allow for tight pump and signal mode confinement thereby allowing for high small-signal gain efficiencies and low laser thresholds [5], and the introduction of structural asymmetry into the core design allows for high values of fiber birefringence and thus PM device variants [6]. Such fibers can also possess extreme nonlinear and dispersive properties which can be useful for many pulsed amplifier and laser applications [7,8].

To date all laser/amplifier results presented on active small core holey fibers have used impractical end-pumping schemes and have again been Yb-doped variants. In this paper we present results on the realization of a compact fully-fiberized erbium doped holey fiber gain block and show that doped-HF can be properly integrated with standard fiber componentry into useful, high-performance, functional fiber laser and amplifier devices. We highlight this fact, and the unique properties offered by HF technology, by demonstrating the use of the gain-block in a tunable ring laser arrangement. The laser exhibits an ultra-low laser threshold (0.5mW) and broadband tunability over 100nm (from 1497-1601nm).

Erbium doped Holey fiber amplifier

Fig.1 shows a schematic diagram of the erbium doped holey fiber amplifier (EDHFA). The amplifier consisted of 4.5 m of aluminosilicate-erbium doped holey fiber (EDHF) with a hole spacing Λ and diameter d of 2 µm and 1 µm, respectively. Er^{3+} ions, at a doping level of ~1000 ppm within an aluminosilicate glass host, were confined to a region of ~1µm diameter at the centre of the HF core. The HF preform used to produce this fiber was fabricated using the conventional stacking approach with an appropriate dehydration stage. An SEM picture of the EDHF is shown in the inset of Fig.1. Both ends of EDHF were spliced to conventional fiber amplifier components (isolators and a pump coupler) using high NA fibers to achieve good intermediate mode matching. The input and output splicing losses were measured using the cut back method to be 1.6 dB and 1.8 dB, respectively. Up to 225mW of counter propagating 980nm pump power could be launched into the EDHF through the WDM coupler.

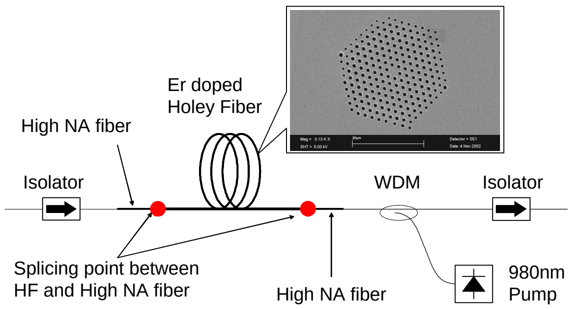

Fig.1 Schematic diagram of EDHFA. Inset shows the SEM picture of the EDHF core.

Fig.2 shows the gain saturation characteristics of the EDHFA at various operating wavelengths. A maximum small signal internal gain of 47 dB at 1533nm was achieved. No evidence of unwanted end facet lasing due to potential stray reflections from the EDHF to conventional fiber splices was observed as evidenced by Fig.2 (inset) which shows the ASE spectrum at 1560 nm under high gain operating conditions. The external noise figure was about 8 to 13 dB, depending on a wavelength, which is fairly reasonable value.

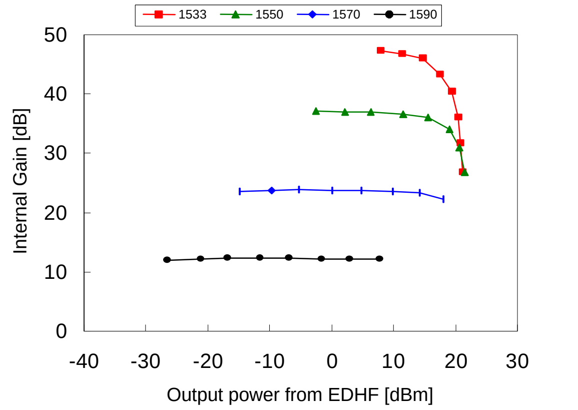

Fig.2 Single channel gain saturation characteristics of the EDHFA at various wavelengths. Inset shows the ASE spectrum with small signal gain conditions at 1560 nm.

Erbium doped Holey fiber ring laser

Fig.3 shows a schematic diagram of the EDHF ring laser (EDHFRL) using the gain block shown in Fig.1. The EDHFA input was connected to a 95% port of a 13 dB coupler, and the output was connected through a fiber Bragg grating (FBG) based tunable narrowband filter to a common port of the coupler thereby closing the cavity. The output coupling for the EDHFRL was thus 5%. Two FBG tunable filters with a 3 dB bandwidth 0.6nm were required to investigate the laser tuning range. The first filter, Filter 1, which had tuning range from 1525 to 1620 nm had a minimum loss of 3dB. The second filter, Filter 2, had a tuning range from 1470 to 1575 nm and a lower minimum loss of 1.5dB. The loss of both filters rose steadily at the extremes of the tuning ranges to ~5dB.

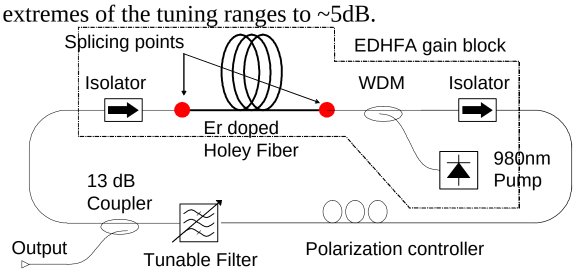

Fig.3 Schematic diagram of EDHFRL.

The output power versus pump power was first measured at a wavelength of 1550nm (using Filter 2 within the cavity). The result is shown in Fig.4. We obtained a laser threshold of 0.48 mW of pump (measured at the EDHF input) at the optimum 1550 nm operating wavelength. This ultra-low threshold, which is 5-10 times lower than that for erbium lasers based on conventional doped fibers, results from the tight physical confinement of the rare earth dopant and the pump/signal optical fields. The resulting optical spectrum (under maximum pump power conditions) is shown in the inset (a) of Fig.4. We have not yet confirmed whether truly single-frequency operation is obtained, however an extremely clean, narrowband spectrum, is clearly achieved. Fig.5 shows the results of our experiments on wavelength tunability of our EDHFRL. We obtained a tuning range of more than 104nm. This tuning range, which is comparable to the best ever achieved with conventional EDFs [9], was limited by the increased cavity loss due to tunable FBG filters used and further improvement should be expected with improved filters and further fiber length optimisation.

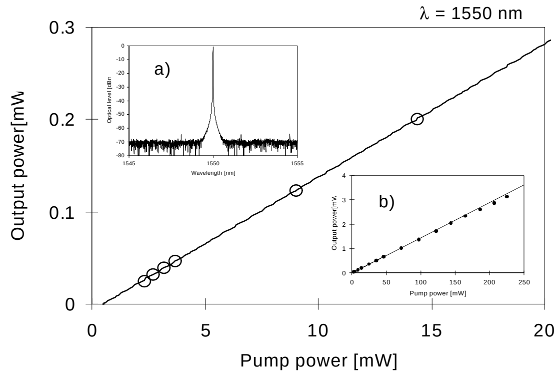

Fig.4 Output characteristics of the EDHFRL at 1550 nm near the threshold. Inset a) shows the corresponding spectrum and b) the output characteristics over the full range of pump power.

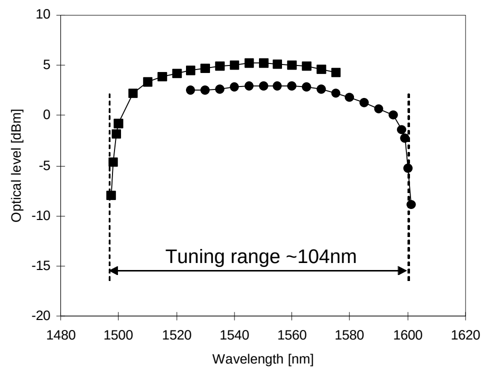

Fig.5 Output power as a function of emission wavelength of the EDHFRL at a maximum pump power. (squares: using Filter2, circles using Filter 2).

Conclusions

We have optimized the splicing process between small core holey fiber and conventional fiber and developed a practical erbium doped holey fiber gain block. The gain block has been shown to give good amplifier performance and used to demonstrate a high performance fiber ring laser with an ultra low threshold and extended tuning range. Our results highlight some of the unique device possibilities of active holey fiber technology and establish its practicality.

References

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