Fibers for High-power Lasers and Amplifiers

Jayanta Sahu*, Seongwoo Yoo, Alex Boyland and Andrew Webb
* Optoelectronics Research Centre, University of Southampton, Southampton – SO17 3RD, UK
Tel: 44 2380593162 and Fax: 44 2380593142
Email: jks@orc.soton.ac.uk

Abstract
We review design and fabrication of active fibers suitable for power scaling.

1. Introduction

Over the recent years, the power of fiber based sources has been significantly increased and is now competing with conventional bulk solid-state lasers in applications such as micro-machining, welding and other material processing. In particular, ytterbium -doped fiber lasers have been power-scaled to multi kW level at ~1.1 μm with a nearly diffraction-limited beam [1]. We review here the progress in active fibers suitable for power scaling mainly for continuous wave (CW) operation, highlighting the advances in the active fibers in 1.1 μm region and also in other wavelengths.

2. Double clad large mode area fiber

Power scaling in a fiber laser relies on a double clad fiber (DCF) structure. The conventional DCF comprises of 3 layers. The inner-most layer, which is the fiber core, possesses the highest refractive index. The refractive index decreases in radial direction away from the core. The inner cladding next to the core has a refractive index higher than that of the outer cladding, which endows the inner cladding with a waveguide characteristic for the pump beam. The large cross-sectional area of the inner cladding allows a multimode laser diode as a pump source in the DCF structure, which is great advantage compared to the core pumping counterpart. The pump light travels within the inner cladding with the help of the index contrast between inner cladding and outer cladding. Rare-earth ions, doped in the core, are excited by the pump beam and generate a signal wavelength in the stimulated beam while propagating the core. Therefore the core parameters, *i.e.* core size and numerical aperture (NA), determine signal beam quality and are usually controlled for single-mode operation. Hence, the DCF geometry itself works as an excellent brightness converter.

In addition to the DCF structure, large mode area (LMA) fiber design is a preferred choice in realization of high power fiber lasers as the LMA design increases power handling capacity of the fiber by minimizing the threshold of undesired nonlinear scatterings such as stimulated Raman scattering and stimulated Brillouin scattering. The LMA design features large effective core area and low core numerical aperture (NA) to reduce V-parameter of the core and allow only small number of modes in a core for near single-mode operation of high power fiber lasers. The single mode operation can be fulfilled by confining the core parameters to place the second mode cut-off wavelength shorter than laser operating wavelength. For example, single-mode rod-type fiber laser in Yb-doped microstructured fiber with core index close to silica and 60 μm core size was demonstrated at 1.1 μm region with 320 W of maximum output power [2]. Alternative approach for near single mode operation is to utilize macro-bending loss. The bending loss is larger for higher-order modes than for fundamental mode. Thus, precise control of bending diameter filters out the higher modes while the fundamental mode is intact. A Yb-doped LMA fiber with V-parameter of ~5.7 (0.05 of core NA and 40 μm of core diameter) exhibited M^2 of 1.41 and output power beyond 1 kW

[1].

3. Fabrication techniques

Most rare-earth doped silica optical fibers are drawn from preforms manufactured using modified chemical-vapor deposition (MCVD). An established rare-earth doping technique known as solution doping is used for fabricating active fibers but is impractical for realizing fibers with multiple layers and of complex design.

In-situ solution doping technique and chemical-in-crucible technique are two advanced fabrication techniques to provide flexible fabrication solution for dedicate fiber structures. The MCVD in-situ doping technique is similar to conventional solution doping, but the need to remove and reassemble the glass on the lathe is eliminated, making the process more efficient, reliable, and improving preform yield [3]. The flexibility of the in-situ doping technique makes it possible to realize complex rare-earth-doped preform geometries that are impractical to fabricate through conventional solution doping. An example is the Yb-doped polarization-maintaining fiber in a “pedestal” design that features a raised inner cladding ring around the core to offset its high numerical aperture (NA), ~ 0.12, caused by the high doping concentration of rare-earth ions. The inner cladding is raised by alumino-silicate through the in-situ technique, which makes it possible to insert stress rods in the pedestal layer [4]. In addition to in-situ solution doping, the chemical-in-crucible technique is designed for the vaporization and subsequent incorporation of relatively low-volatility precursors. The high volatility of the lanthanide-based chelate complexes in conjunction with MCVD offer excellent opportunities to dope preforms with rare-earth ions both in the gas phase and to very high concentrations at moderately low temperatures around 200ºC. Since the incorporation of the rare-earth and modifier ions such as aluminum and phosphorus, for example, takes place simultaneously with the silica deposition, there is the additional benefit of significantly reduced rare-earth clustering for the equivalent doping level when compared with the solution-doping technique [5]. This novel chemical-in-crucible preform fabrication technique offers potential for gas-phase deposition of a wide range of precursors, with the capability of heating them to several hundreds of degrees centigrade if necessary to produce sufficient vapor.

4. New gain medium

Optical gain around 1.16 – 1.50 μm from Bi-doped silicate glasses is attractive as it can bridge the gap unfilled by rare-earth ions in low-loss window of silica and also of great interest for various applications, e.g. telecommunication, medical imaging, and laser guide star, to name a few. Since Fujimoto and Nakatsuka reported broadband near infrared luminescence in Bi-doped silica glass [6], there have been extensive studies reported on the infrared luminescence of Bi-doped glasses in bulk and fiber form. It is known that the emission characteristics of Bi heavily depend on glass composition. The peak position of the emission band shifts to longer wavelengths in presence of phosphorous co-dopant in the core and can cover 1.3 μm region, while in alumino-silicate host the luminescence peaks at 1130 nm. An unsaturable loss at pump wavelength is identified as a limiting factor for better efficiency [7]. An excited state emission at wavelength below 1 μm deters other pumping wavelength options than ~1.1 μm for Bi in alumino-silicate host [8]. Further fundamental studies are necessary to make a progress toward better efficiency in Bi-doped fiber.

5. References

1 Y. Jeong, et al., Opt. Express, 12, 6088-6092, 2004.
2 J. Limpert, et al., Opt. Express, 14, 2715-2720, 2006.
3 A. S. Webb, et al., J. Non-crystalline Solids, 356, 848-851, 2010.
4 S. Yoo, et al., Laser Phys. Lett., 8, 453-457, 2011.
5 A. Boyland, et al., J. Lightwave Technol., 29, 912-915, 2011.
6 Y. Fujimoto, et al., Jpn. J. Appl. Phys., 40, L279-L281, 2001.
7 M. P. Kalita, et al., Opt. Express, 16, 21032-21038, 2008.

8 S. Yoo et al., Opt. Lett., 34, 530-532, 200