Impact of Axial Profile of the Gain Medium on the Mode Instability in Lasers: Regular Versus Tapered Fibers

V. Filippov[1], V. Ustimchik[2], Yu. Chamorovskii[2], K. Golant[2]; A. Vorotynskii[1], O. G. Okhotnikov[1]

1. *Optoelectronics Research Centre, Tampere University of Technology, 33101 Tampere, Finland*
2. *Institute of Radio and Electronics of the Russian Academy of Sciences, Mokhovaya 11, bld.7, 125009 Moscow, Russia*

Mode instability in fiber lasers and amplifiers represents the temporal variations of mode content with typical bandwidth of few kHz. This detrimental phenomenon leads to the degradation of M^2 and to substantial growth of intensity noise observed after spatial filtering. The modal instability thus prevents the scaling of output power with high beam quality. The basic mechanism behind this instability originates from the mode coupling in the periodic grating in a fiber core formed owing to intermodal interference. Among the techniques proposed for instability suppression, it should primarily be mentioned an efficient thermal management of the gain fiber combined with dynamic modulation of excitation [1].

This study describes the new concept for suppression of mode instability in high power fiber lasers and amplifiers based on tapered (i.e. axially non-regular) double-clad few-mode gain architecture. Since the bandwidth of the grating induced in the tapered fiber is larger due to core diameter variation, the contrast of a recorded grating would be relatively low and, therefore, resulted in a reduced a mode coupling efficiency.

It should be noted that adiabatically tapered fibers exhibit negligible mode coupling [2], and, consequently, allow a truly single mode regime of propagation with core diameter up to 120 µm (NA=0.11) to be achieved. The improved immunity to modal instability of tapered fiber is confirmed here by the comparative experimental study of powerful fiber lasers with regular cylindrical and tapered double clad fibres.

The impact of axial fiber geometry on the modal instability was experimentally investigated in a schematic shown in the Fig.5b in Ref.[2].

The light from 915 nm laser diode bars was coupled into an active fiber through the dichroic beam splitter. The laser cavity was formed by Fresnel reflections from the input end of ytterbium active fiber (outcoupling mirror) and by highly reflective fiber Bragg grating (FBG) at another end of the gain medium (Fig.5b, Ref.[2]). The FBG was imprinted in a section of passive fiber with core and cladding diameters of 20 µm and 400 µm, respectively. The near-field image of fiber core has been formed using lens system. The spatial filter has been used to convert the time-spatial modulation of near field pattern into the light intensity modulation. The aperture of a spatial filter (pin-hole) was similar to that of a single mode fiber.

The onset of mode instability was investigated in two laser configurations. The first laser uses as a gain medium Yb doped fiber (Yb1200-20/400 Liekki) with length 25 m, 20 µm core diameter and NA=0.08. The second laser employs a 22 m-long active tapered fibre with parabolic shape and tapering ratio of T=1:5 described earlier [2]. The highly reflective FBG has been spliced to the narrow end of the ytterbium doped tapered fiber. The core diameter of tapered fiber is 20 µm and 100 µm at the narrow and wide sides, respectively. Therefore, the core diameter of narrow end of tapered fiber is identical to the core diameter of cylindrical ytterbium fiber (20 µm).

The mode instability was investigated in regular and tapered fiber lasers in continuous-wave regime. Output radiation exhibits a nearly single mode behaviour for both fibers. The characteristics of the laser radiation were studied using two techniques. First, we observed the temporal mode beating pattern for different levels of output powers. The noise level of radio-frequency spectra of the spatially filtered output beam have been detected at the load of the photodetector. Next, we measured the degradation of beam quality parameter M^2 versus output power. Comparison of experimental results shows that the onset of mode instability occurs at much lower output power in the laser with regular fiber. Particularly, the modal instability in the laser with tapered gain medium has not been observed up to output power of 480 W which was limited by available pump power. It was found that the beam quality factor M^2 shows no measurable degradation with output power for laser with tapered fiber demonstrating an attractive potential of this concept for power scaling.

We have shown experimentally that lasers with tapered active fibers as the gain media exhibit considerable increase of the threshold of mode instability and thus offer potential for power scaling.

References

[1] H.-J. Otto, C. Jauregui, F. Stutzki, F. Jansen, J. Limpert, and A. Tünnermann, "Controlling mode instabilities by dynamic mode excitation with an acousto-optic deflector," Opt. Express **21**, 17285-17298 (2013)

[2] V. Filippov, Yu. Chamorovskii, J. Kerttula, K. Golant, M. Pessa, and O. G. Okhotnikov, "Double clad tapered fiber for high power applications," Opt. Express **16**, 1929-1944 (2008)

978-1-4673-7475-0/15/$31.00 ©2015 IEEE