Photodarkening in large mode area fibers

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Introduction

Ytterbium (Yb) doped fiber devices are an interesting and viable choice for many applications ranging from wavelength conversion to materials processing in the 1.0-1.1µm wavelength region. Such devices, particularly using fibers with double cladding structures, are often realized with a large core diameter (large mode area, LMA) fiber. LMA fibers are of interest since the length of the doped fiber may be considerably shortened by increasing the core/cladding area ratio and/or by increasing the Yb concentration, which result in higher pump absorption. For many applications, shortening the length of the Yb doped fiber is considered highly beneficial, for example, in reducing non-linearities in high peak power amplifiers. On the other hand, higher concentrations and/or higher pumping rates have been known to result in certain deleterious effects, the most troublesome of which is the phenomenon of photodarkening (PD), generally acknowledged as a parameter potentially limiting both the efficiency and the lifetime of Yb doped fiber devices. Such PD, attributed to the formation of color centers, manifests as a time dependent broadband absorption at visible and near IR wavelengths.

Measurement of photodarkening from LMA fibers

Our previous experiments [1] revealed that the initial PD rate is determined by a single variable, the excited state Yb concentration (i.e., the Yb concentration multiplied by the inversion level). Furthermore, the PD rate was found to have an extraordinarily high (7th-order) dependence on inversion, which implies vastly different PD rates for a given fiber employed in different device configurations (e.g., laser vs. amplifier, cw vs. pulsed, core pumped vs. cladding pumped), as shown in Fig. 1. The measurement technique we proposed for benchmarking single-mode Yb doped fibers relied on saturating the inversion of a fiber to a flat and repeatable level across the sample by high intensity core pumping [2]. PD is measured either with monochromatic or white light source coupled to the core of the fiber. As the area of the core of the fiber increases, the inversion in the core becomes harder to saturate using a single-mode pump diode, and other means of inducing the flat and repeatable inversion in the fiber sample must be introduced. For a 10cm fiber sample with approximately 1200dB/m peak Yb absorption at 976nm the saturation of inversion requires approximately 300 to 1000kW/cm^2 of pump intensity at pump wavelengths 976nm and 920nm, respectively. Such high intensity core pumping can however be easily attained up to 7-14µm core diameters for 10cm samples using a 500mW single-mode pump. For larger core diameters the flat and reproducible inversion is possible by cladding pumping. An example of such cladding pumped flat inversion in a sample as a function of pump power is shown in Fig. 2. The standard deviation of inversion over the 10cm fiber sample indicates that the inversion across the sample length is quite uniform. Note that in order to know the inversion the pump wavelength and coupled pump power must be known to a certain precision.

Conclusions

Meaningful comparison of photodarkening properties from different fibers is possible by having the same excited state Yb concentration between samples. We found that for example it is sufficient to use the same inversion level for different samples with similar dopant concentrations. We have shown that the measurement technique can be used effectively even for LMA fibers by employing cladding pumping rather than the more standard core pumping.

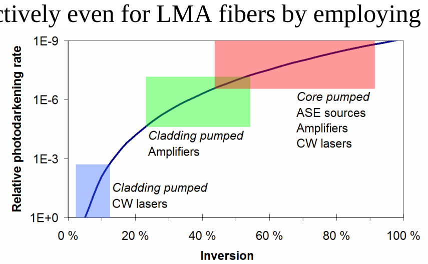

Fig. 1. Normalized photodarkening rate as a function of inversion, assuming a 7th-order power law. Device application regions with different inversion levels are highlighted.

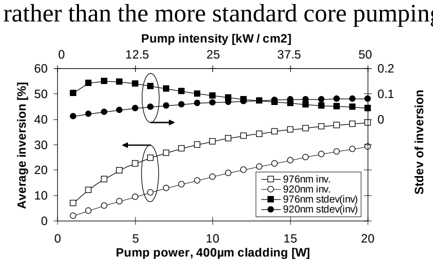

Fig. 2. Simulated inversion as a function of pump power. 10cm sample of 20/400µm (core/clad) fiber, cladding pumped, no signal feedback.

[1] J. Koponen, M. Söderlund, S. Tammela, D. Kliner, and J. Koplow, Photonics West LASE, LBD3, 2006

[2] J. Koponen, M. Söderlund, S. Tammela, and H. Po, CLEO/Europe Conference, CP2-2-THU, 2005