# Experimental Verification of Spatial Distribution of Photodarkening in Large Mode Area Ytterbium Doped Fibers

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**Abstract:** We experimentally demonstrated that photodarkening is not uniformly distributed in the cross-section of bent LMA fibers. Photodarkening distribution depends on coiling diameter, and affects the use of fibers in applications and their photodarkening propensity measurement.

OCIS codes: (060.2270) Fiber characterization; (060.3510) Lasers, fiber

## 1. Introduction

Ytterbium doped fibers are widely used for fiber amplifier and laser applications in the range of 980-1100nm due to their high efficiency and the relatively high level of dopant concentration of commercially available fibers. However, these advantages are shadowed by photodarkening, a phenomenon that decreases the ytterbium doped fiber efficiency under certain conditions.

As previously reported in [1], the photodarkening rate in ytterbium doped silica glass is proportional to the population density of the ytterbium ions on the upper laser level. For that reason, the rate of photodarkening is dependent on application type. A lot of efforts are currently focused on understanding the causes of photodarkening and reducing its effects [1-5]. One of the main challenges in this process is to develop reliable measurement techniques that would allow a proper fiber characterization and prediction of the fiber application lifetime.

In this paper we present an experiment that demonstrates that the photodarkening is not uniformly distributed in the cross-section of the LMA fibers. The degree of photodarkening follows the inversion distribution and, because of that, it is bend sensitive.

## 2. Experiment and results

In our experiments we used ytterbium doped fibers having a 30µm core diameter and 250µm cladding diameter. The fibers were 3m long and the coiling diameter was 5cm. The fiber was straight cleaved and placed in power conversion efficiency (PCE) setup where the pump power (920nm) was free-space coupled through one end of the fiber. The system freely lased at approximately 1035nm. The slope efficiency was measured by sweeping the pump power from 9 to 17W. The output power was measured from both ends of the fiber. The setup was not optimized for the best PCE but to ensure the single mode operation for higher measurement accuracy.

In our experiment we performed the following steps.

- The first slope PCE was measured for reference.
- The fiber was pumped with 17W at 920nm for >60 minutes, resulting in cw lasing of the coiled fiber sample (i.e. the fiber was photodarkened).
- The second PCE measurement was performed to verify that the coiled fiber cavity had not seriously degraded due to photodarkening.
- The fiber was recoiled in order to change the bending direction of the fiber.
- The third PCE was measured to observe the photodarkening induced degradation of the fiber cavity outside the volume that was lasing in cw mode.
- The fiber was re-cleaved, recoiled and the fourth PCE was measured (to double check the third PCE measurement).

It was assumed that the PCE measurement was fast enough not to affect the degree of photodarkening in the fiber.

The experiment was performed on three different fiber samples. The results are presented in Figs. 1 and 2. In Fig. 1 (fiber sample 1) the grey bars are the four PCE measurements with their corresponding error bars. The small graphs above the bars display the simulated photodarkening rate - as the excited state ion density - and mode field distribution across the fiber (calculated using LAD 4.0 [6]). The mode field position of the fiber is significantly shifted due to bending of the fiber. Due to this we expected the rate (and degree) of photodarkening to also be unevenly distributed. After >60 minutes of pumping, the photodarkening degree is lower where the mode has the highest power density and then increases as the mode field power density decreases. Because of this, the second measured PCE is - within the accuracy of the measurement - the same . After the fiber recoiling, the overlap between the peak mode field and the less photodarkened area is not maintained and thus the PCE measurement indicates a significant degradation.

Similar behavior was observed in the three samples under test. The level of PCE degradation after recoiling varies as we could not ensure that the recoiling is performed exactly in the opposite direction.

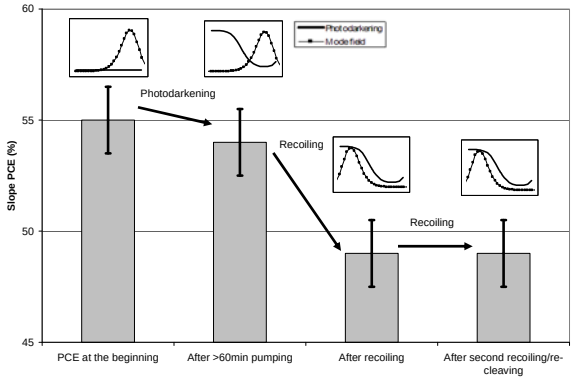


Figure 1: PCE measurements for fiber sample 1.

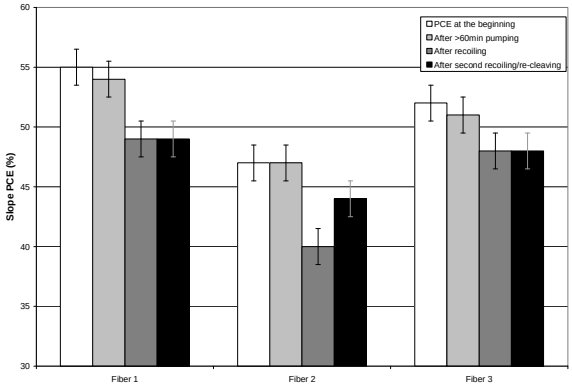


Figure 2: Summary of PCE measurements for 3 fiber samples.

## 3. Conclusions

We demonstrated that photodarkening in bent LMA fibers is not uniformly distributed in the fiber cross-section. This important effect needs to be considered in the development of correct photodarkening measurement procedures and also in engineering of fiber lasers and amplifiers.

## 3. References

[1] J. Koponen, M. Söderlund, S. Tammela, D. Kliner, and J. Koplow, “Photodarkening rate in ytterbium doped silica fibers,” Photonics West LASE, LBD3 (2006).
[2] J. Koponen, M. Söderlund, S. Tammela, and H. Po, “Measuring photodarkening from Yb-doped fibers,” CLEO/Europe Conference ’05, No. CP2-2-THU (2005).
[3] J. J. Koponen, M. J. Söderlund, H. J. Hoffman, and S. K. T. Tammela, " Measuring photodarkening from single-mode ytterbium doped silica fibers," Opt. Express **14**, 11539-11544 (2006).

[4] J. Koponen, M. Söderlund, H. Hoffman, D. Kliner, J. Koplow, “Photodarkening in large mode area fibers,” Proceedings of EPS-QEOD Europhoton Conference, ThB1 (2006).
[5] J. Koponen, M. Söderlund, H. J. Hoffman, D.A.V. Kliner, and J.P. Koplow, “Photodarkening measurements in large mode area fibers,” Proc. SPIE **6453** (2007).
[6] Mircea Hotoleanu, Per Stenius, William Willson, “Fiber Laser Simulators: Challenges and Opportunities,” Photonics Spectra, May (2007).