MODELING THE PHOTODEGRADATION OF LARGE MODE AREA Yb-DOPED FIBER POWER AMPLIFIERS

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INTRODUCTION / INO is a world-class R&D center specializing in optics and photonics solutions. INO's expertise covers laser systems, specialty optical fibers, fiber optic sensors, microfabrication, LIDAR, and biophotonics. This poster focuses on our model of photodarkening and photobleaching in Yb-doped fibers for laser and amplifier systems.

UNDERSTANDING PHOTODEGRADATION

The output power stability of Yb-doped fiber lasers and amplifiers is affected by photodarkening and photobleaching processes. Photodarkening causes excess loss in the core doped area through Yb ion assisted color center formation. Photobleaching deactivates color centers through photon excitation.

MODEL FUNDAMENTALS (Figure 1)

The model is based on a rate equation that includes photodarkening and photobleaching processes. Our characterization method allows each parameter to be determined separately, providing reliable simulations. Output power loss is calculated by integrating a time-dependent excess loss in a laser system simulator.

Rate equation

$$\frac{d\alpha_E(z,t)}{dt} = \beta t^{\beta-1}\underbrace{\left(k_d N_{Yb}^m n^m(z,t)\right)^\beta}_{\text{PD rate coefficient}}\left(\alpha_{E,\max}-\alpha_E(z,t)\right) - \kappa t^{\kappa-1}\underbrace{\left(k_b I^p(z,t)\right)^\kappa}_{\text{PB rate coefficient}}\alpha_E(z,t)$$

- α_E: Excess loss coefficient at λ
- β: PD dispersion parameter
- m: PD effective # of Yb ions
- k_d: PD efficiency constant
- $\alpha_{E,max}$: Max. excess loss coefficient
- N_{Yb}: Yb ion density
- n: Normalized inversion
- κ: PB dispersion parameter
- p: PB effective # of photons
- k_b: PB λ-dependent efficiency constant
- I: Laser intensity

Model solution w/o photobleaching

$$A(t) = \alpha_{E,\max} L\left\{1-\exp\left[-\left(k_d N_{Yb}^m n^m t\right)^\beta\right]\right\}$$

Slope of $\ln(A)$ vs $\ln(t)$ → β (argument of exp<<1)
Slope of $\ln(A)$ vs $\ln(n)$ → m (argument of exp<<1)
$\alpha_{E,max}L(k_d N_{Yb}^m)^\beta$ = constant → $\alpha_{E,max} = f(k_d)$
Fit with one unknown → k_d

Model solution w/o photodarkening

$$A(t) = A_0 \exp\left[-\left(k_b I^p t\right)^\kappa\right]$$

Pre-darkened fiber
Slope of $\ln(-\ln(A/A_0))$ vs $\ln(t)$ → κ
Slope of $\ln(-\ln(A/A_0))$ vs $\ln(I)$ → p
High inversion w/ signal amplification → k_b

Figure 1

MODEL FEATURES

- Rare-earth-doped LMA and single-clad fiber amplifiers and lasers
- CW, ns, ps, and fs laser systems
- Simulation of long-term time-dependent output power
- Prediction of the fiber lifetime for given operating conditions
- Assist system design by dictating how to operate the fiber to obtain the desired performances with an acceptable photodegradation
- Quickly assess the true quality of a fiber in terms of photodarkening

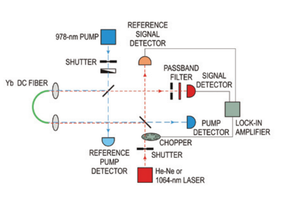


Figure 2

CHARACTERIZATION METHOD (Figure 2)

Uniform Yb population inversion is achieved by clad pumping at 978 nm a 14-cm long fiber with cleaved angles to hinder ASE. The fiber transmission is measured at 633 nm over time with a signal power of 1 μW. Pump and signal are alternated to have no interaction between them. Excess loss at 633 nm is calibrated for 1064 nm.

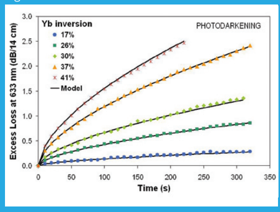
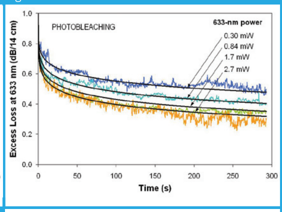
Figure 3


Figure 4


RESULTS (Figure 3-4-5-6)

- Yb-doped triple-clad fiber, 20/200 μm, core NA 0.066, MFD 14.5 μm @ 1064 nm
- Photo-induced excess loss through an effective 5-ion assisted color center formation
- Excess loss bleaching through a 1-photon excitation
- Maximum excess loss of 178 dB/m at 633 nm or 5.9 dB/m at 1064 nm
- Photodarkening rate constant of 19.8 h^{-1}
- Photobleaching rate constant of 0.0072 m^2/W-h
- Photodarkening dispersion parameter of 0.6
- Photobleaching dispersion parameter of 0.2

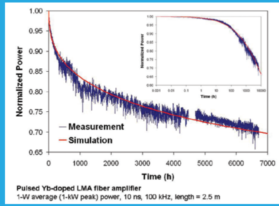


Figure 5

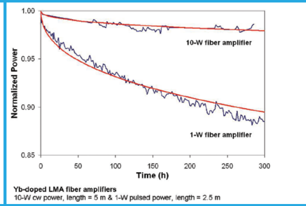


Figure 6

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CONCLUSION / Our photodarkening characterization method of Yb-doped fibers allows to acquire very important information about a given fiber amplifier system. Our model can predict the maximum excess loss of a fiber amplifier with regards to the pumping conditions and the fiber used. Consequently, fiber characteristics can be optimized for a given application and the amplifier power loss can be predicted as a function of operating time. It is a very interesting engineering tool when system lifetime needs to be evaluated.