Infrared light power transmission limitation of optical fibers

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Abstract: Luminescence from silica defects is associated with a multiphoton absorption mechanism, responsible for strong nonlinear losses in graded-index multimode optical fibers. Our experiments reveal the existence of a fundamental limitation to the power transmission capabilities of optical fibers.

Silica is the most common material of which optical fibers are made, thanks to its abundance in nature, as well as for its transparency over a wide spectral range, covering the whole near infrared (IR) and visible (VIS) regions. On the other hand, silica becomes lossy at ultraviolet (UV) wavelengths, where its intrinsic defects and possible impurities absorb light, giving rise to photoluminescence in the VIS [1]. Absorption by silica defects is not considered as a mechanism affecting optical fiber power transmission capabilities at telecommunication wavelengths, and in the VIS/IR spectrum in general. Such widely recognized consideration works very well when the peak power of the propagating optical pulses is low enough, to not incur in extreme nonlinear effects, such as light filamentation [2]. Here, we experimentally demonstrate that an intrinsic limitation to pulse propagation in the VIS-IR still exists, and it becomes significant when operating close to the fiber damage threshold. Differently from the continuous wave regime, where Brillouin scattering establishes the power transmission limitation, multiphoton absorption (MPA) mechanisms turn out to be relevant when intense ultrashort pulses propagate: they have been recently shown to affect the dynamics of highly energetic Raman solitons [3].

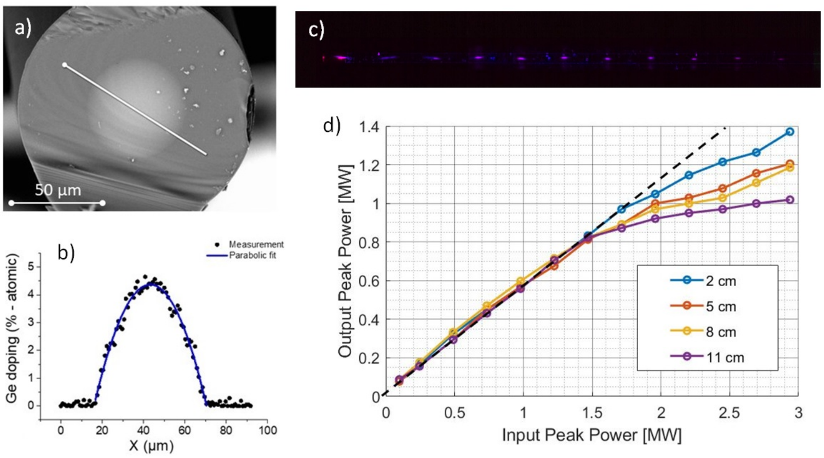

Fig. 1. a) Scanning Electronic Microscopy image of the GRIN 50/125 fiber. b) Measured germanium doping atomic concentration along the line traced in a). c) Luminescence of Ge-related defects appearing as blue spots at points of peak intensity generated by self-imaging. d) Nonlinear losses: output peak power vs input power, for several fiber lengths. The dashed line is a linear fit of all data for input peak powers below 1.5 MW. In all experiments, the input beam diameter is 30 μm.

In our experiments, we study the transmission properties of a standard 50/125 graded-index (GRIN) multimode fiber in the normal dispersion regime, at λ = 1030 nm. A scanning electron microscope image of the fiber section is shown in Fig.1a. Index grading is obtained by Germanium doping, whose concentration has a parabolic shape (see Fig.1b). Germanium atom inclusions provide an increase of silica defects luminescence at blue/violet wavelengths, making it excitable by the simultaneous absorption of multiple IR photons [4]. In Fig.1c, we report a true-color image of the fiber, when pulses with 2 MW peak power are injected. The luminescence signal appears as an array of emitting points, due to the spatial self-imaging effect, which consists of a periodic modulation of the beam diameter [5]. Here, we report the observation of fiber power transmission downfall, which accompanies the appearance of luminescence. In Fig.1d, we show the dependence of output peak power upon input power, as measured in a cutback experiment. Here the fiber length was reduced down from 11 to 2 cm. As can be seen, nonlinear losses occur when the input peak power exceeds 1.5 MW: at larger powers, experimental data no longer follow a linear trend. Although the nonlinear losses can be due to several mechanisms, we demonstrate that an effective N-photon absorption term is sufficient, in order to quantitatively reproduce the transmission drop. Considering such a term leads to nearly step-wise transmission drops at points of minimum beam diameter, which oscillates because of spatial self-imaging. These points correspond to local maxima of the beam intensity, as shown in Fig.2a. The agreement between the experimental data and the fitting curve is rather good, as shown in Fig.2b, where we obtained a fitting value of $N = 2.68$. Details about the modelling and fitting method will be given in the presentation. However, being the most important fitting parameter, N represents an average number of photons involved in the nonlinear absorption process.

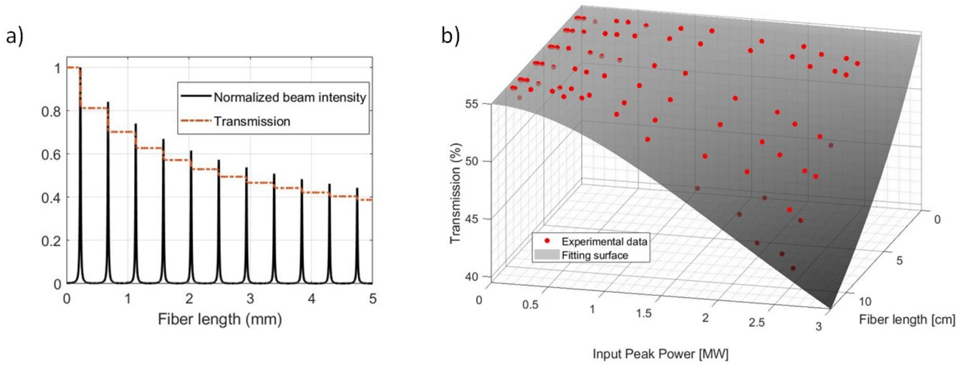

Fig. 2. a) N-photon absorption model: Beam intensity (normalized to its maximum value) and transmission trends along the first 5 mm of propagation. b) Fit of the transmission experimental data as a function of both input power and fiber length.

In conclusion, we reported the observation of nonlinear losses in GRIN fibers, and linked them to MPA-excited silica defects luminescence. We also fit transmission measurements with a model that involves a single N-photon absorption term in the propagation equation. Our results show and quantify an intrinsic limit to optical fiber transmission capabilities, which has an impact on the power scaling of spatio-temporal mode-locking with multimode fiber lasers, laser ablation and micromachining.

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