Fiber Fuse Effect: New Results on the Fiber Damage Structure

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Abstract

Interference of the fiber modes in the process of optical discharge propagation along the fiber enables one to influence the parameters of the process and to produce sequences of bubbles with a period of \(~10-1000\mu m\).

Introduction

During optical discharge (OD) propagation along the silica-based fiber under the action of laser radiation (known as fiber fuse effect), changes of most parameters of the fiber core (index profile, dopants distribution) and the formation of voids were observed [1-3]. However, up to now some essential features of this process, e.g. the nature of the voids formation, remain unclear. We report novel results of experimental investigation of the optical discharge propagation in optical fibers, which can shed light on the process of fiber damage. In contrast to the previous investigations, we varied the radial distribution of the laser radiation intensity in the fiber core by employing the mode interference phenomenon. In addition, a large mode area fiber was used, which allowed us to enhance the spatial resolution in measuring radial distributions of the refractive index and of the dopants concentration.

Experiment and results

A GeO$_2$- and F-doped silica fiber with a W-index profile ($\Delta n_{\text{max}} = 2 \times 10^{-5}$) and a mode-field diameter of 12 $\mu$m was used in the experiments. The refractive index profile (RIP) of this fiber is shown in Fig.1, the profile of germania concentration is shown in Fig.2. A peculiarity of this type of fibers is that it is single-moded at long length of fiber and supports several modes (LP$_{01}$, LP$_{11}$, and LP$_{02}$) at length \(\sim 0.5\) cm. The combined propagation of LP$_{01}$ and LP$_{02}$ modes was used in our experiments. We circumvent excitation of LP$_{11}$ mode owing to the cylindrical symmetry of the light-launching scheme.

The phenomenon of interference of fiber modes LP$_{01}$ and LP$_{02}$ results in modulation of light intensity distribution along a fiber core. In the conditions of our experiments, the intensity of laser radiation at the forefront of optical discharge was varied in a range of \((2.3-18) \times 10^6\) W/cm$^2$ along the fiber length of about 340 $\mu$m (period of interference pattern). Mode interference resulted in a large scale periodic structure of the core damages (Fig.3). Such a fiber damage structure allows to make accurate measurements of index profile and dopants distribution in various cross-sections of damaged fiber.

An order of magnitude increase of the maximal refractive index in the core cross-section (up to $2 \times 10^{-2}$) was observed (Fig.1). Essential modification of the germania distribution along the fiber radius and along the fiber length was revealed (Fig.2). It is shown that the index increase in the fiber core is due to a mechanical stress in the core region and to a redistribution of the dopants. Longitudinal modulation
of the mechanical stress in the fiber core after optical discharge propagation was observed. The maximal values of mechanical stress in the core were found to be located between the voids.

Fig. 2 shows the increase of the germania concentration at the fiber axis in comparison with the initial profile. The increase of the GeO₂ concentration can be understood because the process of optical discharge propagation is a kind of zone melting process. The comparison of GeO₂ profile and RIP after the process enable us to conclude that the upper part of RIP is formed by the GeO₂. But there is the lower part of RIP (at the level of ∆n around 7×10⁻³) that can be considered as stress-induced pedestal. Such assumption is confirmed by the results of optical polarization measurements.

It is well known that voids in periodical structures formed in the core of the ordinary fiber after optical discharge propagation frequently have the shape of bullets (or triangles in a plane figures) directed from the laser [1]. But in the case of MFD modulation along the fiber the picture changes drastically. Together with triangle-shape voids we observe large drop-like voids (denoted by 2 in Fig. 3). And these voids look like droplets also flying from the laser side (Fig. 3). And bullet-shape voids are oriented in this case not obligatory in the direction away from the laser. In Fig. 4 the laser radiation propagated from left to right, and the void 1 is directed in the “ordinary” way. But the most of other voids are oriented in the opposite direction. Such a phenomenon can be explained if we suppose that the triangle form of voids is determined by the direction of the movement of a cooling front wave in the heated region after the optical discharge propagation.

Conclusions
The large-scale periodic structure of the fiber damage was observed in the case of two-modes excitation. This structure allows accurate measurements of parameters of the damaged fiber. Such measurements were fulfilled for RIP and dopants concentration profiles at different cross-sections of fiber.

It is possible to prepare periodic structures of voids in the fiber core with a preset period in a range of 10-1000 µm by varying the fiber parameters and radiation wavelength. Moreover, the picture of damages of the fiber offers us the possibility for direct measurement of propagation constant differences for fiber modes.

References