Quantum Electronics **32** (6) 476 – 478 (2002)

PACS numbers: 42.81.Cn; 42.70.–a
DOI: 10.1070/QE2002v032n06ABEH002226

Catastrophic destruction of optical fibres of various composition caused by laser radiation

E.M. Dianov, I.A. Bufetov, A.A. Frolov, V.G. Plotnichenko, V.M. Mashinskii, M.F. Churbanov, G.E. Snopatin

Abstract. **The threshold intensities of the radiation required for sustaining the optical discharge waves in various silica fibres for different wavelengths of laser radiation are measured. It is shown that over a wide range of experimental conditions, the threshold intensity is determined mainly by the diameter of the mode field in the fibre. The destruction of chalcogenide and fluoride fibres upon exposure to laser radiation of power ~ 1 W is studied for the first time. The optical discharge wave is not formed in such fibres, and the destruction occurs due to thermal decomposition of the fibre material over the entire cross section of the fibre. The destruction of these fibres is characterised by much lower threshold intensities of laser radiation than in the case of silica fibres.**

Keywords: *optical fibre, optical discharge, laser-induced damage.*

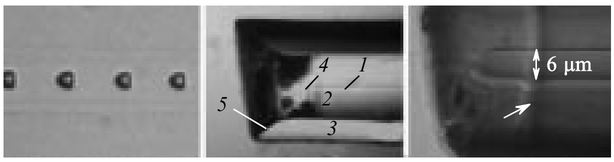
1. Introduction

Owing to the use of optical fibre amplifiers at present, the radiation power transferred through an optical fibre in communication systems achieves ~ 1 W. This power is sufficient for sustaining the propagation of a destruction wave through optical fibres made of different materials, including silica fibres used in modern communication systems. It is also interesting to study the laser-induced destruction of chalcogenide and fluoride glass fibres, which can be used (or are already being used) for creating rare-earth ion optical amplifiers. We studied the process of destruction of fibres of all these kinds.

2. Silica fibres

The propagation of a laser-induced optical discharge wave through the core of a silica fibre was first observed in Ref. [1] (see also [2, 3] and review [4]). Such a process was studied earlier in bulk glass samples [5] and in gases [6]. This phenomenon is manifested as follows: under certain conditions (initiation), a bright region of white or bluish glow (a small star, or the optical discharge wave) is formed in the core of the fibre of size ~ 10 μm, and moves in it towards the laser radiation at a velocity of the order of 1 m s^{-1}.

After the passage of the optical discharge wave, the fibre appears undamaged, but voids (or bubbles) of the order of several micrometers are formed in its core. Sometimes, these voids may form a periodic structure along the fibre core (Fig. 1a). The process may be initiated by contamination of the fibre end, by contact of the fibre end with a metal surface, or by heating a part of the fibre in an electric arc.



a b c

Figure 1. Photographs showing the damage in fibres of various composition after termination of the destruction process: (a) voids formed in the silica fibre core (radiation at a wavelength of 1.21 μm propagated from right to left; the distance between the voids is ~ 14 μm); (b) destroyed end of a fluoride fibre after switching off the laser radiation (the total diameter of the fibre with cladding is 250 μm: (*1*) core, (*2*) cladding, (*3*) polymer coating, (*4*) fused fluoride glass, (*5*) damaged polymer coating; (c) end of a chalcogenide fibre after switching off the laser radiation (the diameter of the fibre core is 6 μm, and the arrow indicates the boundary of the fused region).

We measured the threshold values of the laser radiation power required for the propagation of a destruction wave through the fibre (the threshold corresponds to the power at which the propagation of the optical discharge wave through the fibre is terminated). Measurements were made for single-mode silica fibres of various compositions irradiated at different wavelengths.

Table 1 contains the compositions of the core material or its brand, the maximum difference Δn in refractive indices of the core and the cladding, and the cut-off wavelength λ_{cr} for the second mode. The results of measurements are presented in Fig. 2. We used in the experiments fibre lasers emitting at 1.06, 1.21, and 1.48 μm. All the experimental points in Fig. 2 fall on a straight line with a certain spread, which leads to the conclusion that the mode field diameter

E.M. Dianov, I.A. Bufetov, A.A. Frolov, V.G. Plotnichenko, V.M. Mashinskii Fiber Optics Research Center, A.M. Prokhorov General Physics Institute, Russian Academy of Sciences, ul. Vavilova 38, 119991 Moscow, Russia; Tel.: 7 (095) 135 05 66; fax: 7 (095) 135 81 39; e-mail: dianov@fo.gpi.ru
M.F. Churbanov, G.E. Snopatin Institute of High-Purity Substances, Russian Academy of Sciences, ul. Tropinina 49, 603600 Nizhnii Novgorod, Russia; Tel.: 7(831) 266 85 42, fax: 7 (831) 266 46 34, e-mail: churbanov@ihps.nnov.ru

Received 27 March 2002
Kvantovaya Elektronika **32** (6) 476 – 478 (2002)
Translated by Ram Wadhwa

Table 1. Parameters of investigated fibres.

Fibre No.	Core composition	$\Delta n \times 10^2$	$\lambda_{cr}/\mu m$
1	$SiO_2 - P_2O_5$	1.4	1.1
2	$SiO_2 - GeO_2$	2.6	1.12
3	Flexcor (Corning)	0.65	0.9
4	SMF28 (Corning)	0.41	1.3
5	$SiO_2 - GeO_2$	1.0	1.34
6	$SiO_2 - GeO_2$	0.15	0.9
7	$SiO_2 - GeO_2$	0.15	1.15
8	$SiO_2 - GeO_2(+B$ in core)	0.8	1.0
9	$SiO_2 - GeO_2(+F$ in core)	3.0	0.9
chalcogenide fibres	As_2S_3	–	~ 5
fluoride fibres	IR guide (LeVF)	–	1.2

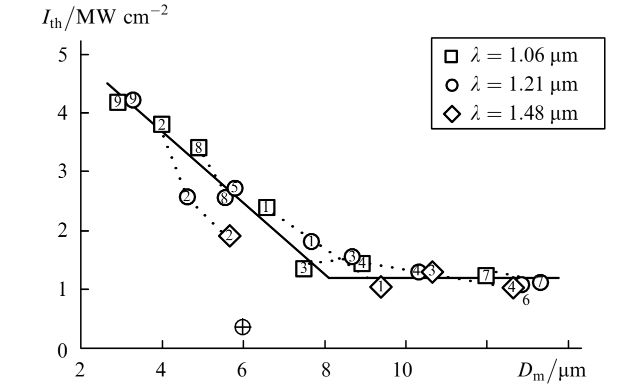


Figure 2. Dependences of the threshold intensity of laser radiation, required for sustaining the optical discharge wave, on the mode-field diameter for fibres of various composition and radiation at different wavelengths. The numbers correspond to fibres of different compositions (see Table 1). The dashed lines are obtained by connecting points corresponding to the same fibre irradiated at different wavelengths, while the solid line corresponds to the approximation of the experimental points. The encircled cross shows the approximate value of $I_{th}(D_m)$ for the investigated fluoride and chalcogenide fibres.

D_m in the fibre is the dominating factor in an analysis of the propagation of the optical discharge waves.

3. Fluoride and chalcogenide glass fibres

The destruction of chalcogenide and fluoride glass fibres takes place in an entirely different manner. We investigated fibres with a cladding of diameter 125 μm. The As_2S_3 fibre used in our experiments was a multimode fibre with the second mode cut-off wavelength of about 5 μm (for a core diameter of 6 μm), while the fluoride glass fibre was a single-mode fibre with $\lambda_{cr} = 1.2$ μm.

After the initiation of the process of destruction of these fibres, we did not observe the formation of optical discharge waves, and the fibres were destroyed completely (including the core, the cladding, and even the protective polymer cladding sometimes) over the entire cross section. The presence or absence of the protective polymer cladding affected the process of fibre destruction. For laser radiation powers close to the threshold values, the polymer cladding of fibres was not destroyed and the remnants of the core and cladding destruction remained in this polymer cladding. An increase in the laser radiation power leads to a destruction of the polymer cladding as well (Fig. 1b).

The initiation of the process of destruction in chalcogenide fibres led to melting and then to thermal decomposition of glass made of As_2S_3 with the formation of sulphur vapour and arsenic oxide (Fig. 1c). In some experiments with fluoride fibres, the glass simply melted under the action of laser radiation, resulting in the formation of drops at the fibre end.

The characteristic velocity of the destruction boundary was 3–4 mm s^{-1} for a 0.2-W radiation power at 1.06 μm in chalcogenide fibres and 1 mm s^{-1} for a 0.5-W radiation power at 1.21 μm in fluoride fibres. The threshold power for sustained destruction depends on the external conditions. Under normal conditions, the threshold power was about of 0.08 W for chalcogenide fibres at 1.06 μm (operation at several modes) and about of 0.1 W for fluoride fibres at 1.21 μm (single-mode operation with a mode-spot diameter about of 5.7 μm).

Optical fibres made of these materials may burn in air, but destruction under the action of laser radiation may also occur in gaseous nitrogen, water or liquid nitrogen, i.e., without access of oxygen. The nature of destruction (absence of an optical discharge wave) is preserved for fluoride fibres in the entire range of intensities accessible in the experiment (up to 10 MW cm^{-2} at 1.21 μm).

Because the propagation of a destruction wave in the fibre depends considerably on the temperature dependence of its optical losses, we performed the corresponding temperature measurements for chalcogenide and fluoride fibres (Fig. 3). For comparison, the same figure also shows the analogous data for a silica fibre obtained in Ref. [1].

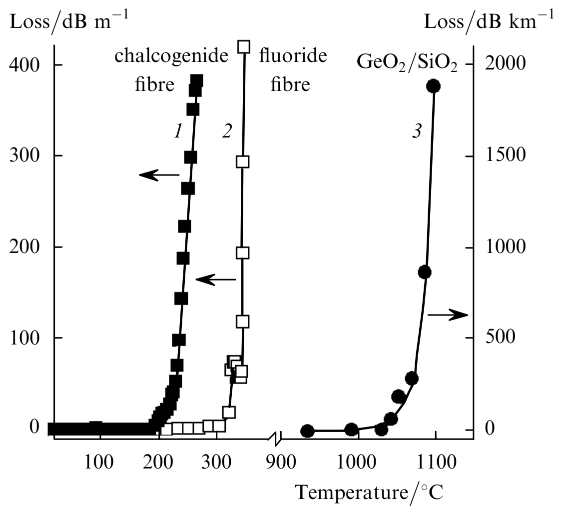


Figure 3. Dependence of the optical losses in fibres at a wavelength 1.06 μm on the fibre temperature for chalcogenide (*1*), fluoride (*2*), and germanium-silicate fibre (*3*) [1].

4. Discussion

Apparently, the optical discharge wave does not propagate in chalcogenide and fluoride fibres. Even if we assume that such a process does occur in such fibres, the temperature at the surface of the fibre attains the vitrification temperature for chalcogenide (185 °C) and fluoride glasses (265°C) according to Ref. [7], which results in a lowering of the mechanical strength of the fibre cladding and makes it impossible to sustain a high pressure in the optical discharge plasma required for the propagation of an optical discharge wave.

The observed dependence of the threshold intensity on the mode-field diameter of laser radiation in silica fibres (see Fig. 2) and the weak effect of factors like the core composition and the radiation wavelength on it is in accord, at least qualitatively, with the thermal conductivity model of propagation of optical discharge [6]: the threshold radiation intensity I_{th} decreases almost inversely proportional to the increase in the mode-field diameter D_m ($D_m = 3 - 8$ μm). The stabilisation of I_{th} observed for $D_m = 8 - 14$ μm may correspond to an optical discharge wave propagation regime in which radial heat losses from the discharge front are insignificant and I_{th} is determined from the condition of attainment of the plasma temperature required for absorption of laser radiation over a distance of the order of D_m.

5. Conclusions

The destruction of fibres by laser radiation limits the laser power that can be used in fibre communication systems. If silica fibres with $D_m > 10$ μm are used in the communication lines, the region of absolute stability to destruction by laser radiation (when the propagation of the optical discharge wave is not sustained) has an upper power limit of $1 - 1.5$ W. The boundary of relative stability is determined by the conditions of initiation of this wave and may be much higher. The destruction of chalcogenide and fluoride fibres differs qualitatively from the destruction of silicate fibres: no plasma formation is observed, and the entire fibre (and not just the core) is destroyed. The threshold radiation power for the propagation of destruction waves in chalcogenide and fluoride fibres is much lower – about of 100 mW for $D_m \approx 6$ μm, which is about an order of magnitude lower than for silicate glass fibres. This circumstance may limit the possibilities of using such fibres in optical fibre communication systems.

References

1. Kashyap R., in *Proc. Intern. Conf. Lasers'87* (Lake Tahoe, Nevada, 1987) p. 859.
2. Hand D.P., Russell P.St.J. *Opt. Lett.*, **13**, 767 (1988).
3. Dianov E.M., Mashinsky V.M., Myzina V.A., Sidorin Y.S., Streltsov A.M., Chickolini A.V. *Sov. Lightwave Commun.*, **2**, 293 (1992).
4. Davis D.D., Mettler S.C., DiGiovanni D.J. *Proc. SPIE Int. Soc. Opt. Eng.*, **2966**, 592 (1997).
5. Kask N.E. *D. Sci. Thesis* (Moscow: MSU, 1985).
6. Raizer Yu.P. *Lazernaya iskra i rasprostroneniye razryadov* (Laser-Induced Spark and Discharge Propagation) (Moscow: Nauka, 1974).
7. Kashyap R., Sayles A., Cornwell G.F. *Proc. SPIE Int. Soc. Opt. Eng.*, **2966**, 586 (1977).