Catastrophic destruction of fluoride and chalcogenide optical fibres


Catastrophic destruction of fluoride and chalcogenide optical fibres under laser radiation in the wavelength region 1.06–1.48 μm has been investigated for the first time. Different characteristics and much lower thresholds of catastrophic damage compared to silica-based fibres have been discovered.

Introduction: Catastrophic destruction (or fibre fuse) of silica-based fibres was observed and discussed in a number of papers (e.g. [1–3]). The fibre fuse can take place at the laser power of ~1 W continuous wave (CW), representing the propagation of plasma formed under the action of the laser radiation, i.e. propagation of optical discharge (OD) in the core of the fibre [4]. The main physical mechanism responsible for the OD propagation is thermal conductivity. OD in the core is readily initiated in most fibres by launching CW laser power into a fibre and ensuring contact of the exit endface of the fibre with an absorbing surface or by heating a part of the fibre. It appears as a bright visible spot of white light which propagates from the point of initiation towards a light source. The temperature of the OD plasma is ~5000–10 000 K. The speed of the OD propagation is ~1 m/s in typical fibres at the laser power of ~1 W. Examination of the fibre core after the OD propagation shows extensive damage in the form of voids which have the form of bubbles (sometimes periodic) or long non-periodic filaments.

The widespread application of fibre optical amplifiers in modern optical fibre communication systems has led to the increase in optical powers used in these systems to the level of ~1 W CW. Thus the catastrophic damage of fibres is of great concern to system designers since some incidents such as a sharp fibre bending, contact of a fibre end with absorbing substances, dust within couplers, electrical discharge, etc. can lead to the destruction of long lengths of fibres.

Over the years much interest has been shown in using rare-earth-doped fluoride and chalcogenide optical fibres as an active medium for fibre lasers and amplifiers (e.g. [5–7]). This is connected with more efficient operation of these devices owing to a smaller multiphonon quenching in these glasses. In particular, the recent work on Tm-doped fluoride fibre amplifiers has shown their great promise for the 1.5 μm spectral region ([8, 9]). However these glasses have a much lower melting temperature compared to silica-based glasses. Therefore one may expect different mechanisms of catastrophic damage in these fibres and lower damage thresholds.

Experimental results: We have investigated the catastrophic damage of a fluoride fibre (FF) and a chalcogenide fibre (CHF) at the wavelengths 1.06, 1.21 and 1.48 μm. The parameters of the fibres are shown in Table 1. The data on a silica-based fibre (SF) are also shown for comparison. In the Table λc is the cutoff wavelength, dcore and dclad the core and cladding diameters, dplast the diameter of a fibre with plastic coating, Tg the glass transition temperature, Pa the minimal power (at the wavelength in parentheses) necessary for maintaining the destruction process in the fibre, Vth the corresponding light intensity in the core, and V is the velocity of the destruction region propagation along the fibre (the corresponding light power is given in parentheses).

![Fig. 1 Destruction of chalcogenide and fluoride fibres under laser radiation (laser radiation propagating left to right in all frames)](image1)
a Picture of ‘burning’ of CHF fibre (side of squares 0.5 cm)
b End of CHF fibre after laser power turned off (core diameter 6 μm)
c Drop of the fluoride glass at end of FF fibre (fibre diameter 125 μm)
d End of damaged polymer coated FF fibre (fibre diameter 250 μm)

![Fig. 2 Dependence of fibre losses on temperature](image2)

In the case of CHF and FF destruction under laser radiation differs essentially from that of SF. In the case of CHF and FF we have not observed the formation of hot highly absorbing plasma in the core, unlike SF. The measured velocities of the destruction wave propagation was three-orders lower than in SF (~1 mm/s, see Table 1). In these fibres the process of destruction takes place not only in the core of the fibre (as for SF) but embraces the whole cross-section of the fibre.

In our experiments the process of fibre destruction was initiated in most cases by contacting the end of the fibre with an absorbing surface in ordinary laboratory conditions. In the case of CHF the initiation of the damage led to the thermal decomposition of the As2S3 glass (see Fig. 1a, in which 1 is the fibre, 2 the flux of the destruction products, 3 the trace of condensed destruction products on the screen, and 4 the end of the fibre during the process of destruction; laser radiation propagating from left to right in all frames of Fig. 1). The bright point corresponds to the scattering of the laser radiation (the camera has sensitivity at laser wavelength). Fig. 1b shows the burned end of CHF after turning off the laser radiation (1 is the core). The white arrow shows the boundary of the melted region.

![Table 1: Parameters of fibres](image3)

<table>
<thead>
<tr>
<th>Composition</th>
<th>λc (μm)</th>
<th>dcore (μm)</th>
<th>dclad (μm)</th>
<th>dplast (μm)</th>
<th>Tg (℃)</th>
<th>Pth, mW (λ, μm)</th>
<th>Ith, (MW/cm²)</th>
<th>V, m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHF As2S3</td>
<td>~5</td>
<td>6.0</td>
<td>125</td>
<td>145</td>
<td>185</td>
<td>100 (~1.06)</td>
<td>~0.35</td>
<td>~0.002</td>
</tr>
<tr>
<td>FF Products</td>
<td>1.2</td>
<td>5.7</td>
<td>125</td>
<td>250</td>
<td>265</td>
<td>100 (~1.21)</td>
<td>~0.35</td>
<td>0.0028</td>
</tr>
<tr>
<td>LeVF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF SiO2–GeO2</td>
<td>0.9</td>
<td>6.8</td>
<td>125</td>
<td>250</td>
<td>1100</td>
<td>700 (~1.06)</td>
<td>~2.5</td>
<td>~1</td>
</tr>
</tbody>
</table>

In the case of FF, the melting of the glass takes place with the formation of a drop of the glass, if the polymer coating was removed (Fig. 1c, laser power ~0.6 W). In the case of the fibre with a polymer coating, the complete destruction of FF together with the coating was observed as that for CHF. Fig. 1d shows the burned end of FF after turning off the laser radiation (1 is the core, 2 the cladding, 3 the polymer coating, 4 the melted fluoride glass, and 5 the end of the destroyed polymer coating). The laser power necessary for propagation of the destruction wave in the uncoated FF was about five times as large as for the coated fibre. In all cases no essential dependence of process...
characteristics on the wavelength of laser radiation was observed. The process of fibre destruction under laser radiation takes place in fibres submerged into nitrogen atmosphere and in water.

Since the temperature dependence of the laser radiation absorption is the starting point for the damage process [2–4], we measured attenuation of 1.06 μm light in CHF and FF fibres against temperature. Lengths of fibres, ~5 cm long, were placed in an oven. The temperature rise velocity was 2 to 3 °C per min. The data obtained are plotted in Fig. 2 (similar data for germanium-doped silica fibre [1] are shown for comparison). Though the temperature dependencies of the attenuation are similar for all fibres, a rapid increase in the attenuation occurs for CHF and FF at much lower temperatures, ~250 and 350 °C, respectively. It should be noted that this increase in the attenuation in CHF and FF was irreversible (lowering the temperature did not restore the initial attenuation). In the heated length of the fibres the diminishing up to vanishing of the index difference between the core and the cladding was observed.

The main differences between the CHF and FF from one side and the SF from another can be explained by the low glass transition temperature of CHF and FF glasses. Loss of mechanical solidity of these glasses at increased temperatures prevents formation of the highly absorbing plasma. As a result, a fibre absorbs only a small part of the laser power, which is nevertheless sufficient for fibre melting and destruction. The absorbed power can be estimated as ~10 mW at the velocity of destruction wave ~1 mm/s. For this reason the threshold of the process of fibre destruction is strongly dependent on environmental conditions. Different pictures of the destruction for uncoated and coated FF (Figs. 1c and d) demonstrate this fact.

**Conclusion:** The character of the destruction of CHF and FF under laser radiation differs strongly from that in SF. The destruction of a whole fibre takes place in contrast to silica-based fibres where only the core is damaged. There is no plasma formation. The speed of the destruction wave propagation is ~1 mm/s, i.e. ~1000 times slower than that in SF. The threshold laser power necessary for the destruction propagation along the fibre is about 10 times lower compared to SF. The destruction depends strongly on external conditions.