Optical fuse by carbon-coated TeO_2 glass segment inserted in silica glass optical fiber circuit

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Excessive-light-induced melt down was observed in a carbon-coated TeO_2 glass segment formed between a pair of optical fiber end-faces. This structure was made by splicing single-mode silica fibers through TeO_2 glass melt to form a necked bridge, which was coated with carbon-containing paint after quenching it. Optical fusing action was induced by 0.3–1.5 W of CW light (1.54μm) and its output power dropped by 12 dB on average. Optical decoupling seems to be induced by not only deformation but also crystallization of the glass bridge. Its quite a high insertion loss of about 2dB can be reduced by introducing some refractive index modulations into the present structure.

KEYWORDS: optical fiber, tellurium oxide glass, carbon, optical fuse, hybrid device

Recent development of high power light source over several watts brings about a potentially dangerous situation for optical components to be damaged by excessive incident beam. Just as almost all the electric appliances contain "fuse", every optical system is desired to be installed with "optical fuse" at low cost. Although several optical fuses have been proposed before, most of them need some external electric power to monitor the incident light intensity and close the circuit. The first "passive" optical fuse, that is, without any external power supply, was announced to be on sale by KiloLambda IP Ltd. on 17th March 2003, but its technology has not been disclosed yet.

We propose a previously unknown device structure of passive optical fuse realized by a pair of silica glass optical fibers spliced through low-melting glass and light absorbing material. In this report, the fusing action of this device is demonstrated and its mechanism is discussed.

Several samples were fabricated by the following procedures, some of which are described in detail elsewhere.[1–3] Two commercial single-mode bare fiber pigtails were placed on fiber holders so that their ends face each other. A droplet of TeO_2 melt on a gold plate with a small electric heater was set between them. Then, the end of the fibers were inserted into the glass melt from its side and the plate is lowered to leave a small amount of the melt between the two ends. The fibers were immediately moved to an appropriate position to form a necked segment before the melt was solidified (see Fig. 1(a)).

Among 7 samples, the lengths of the glass segment varied 0.097–0.179mm (0.145mm on the average), which were measured by a high-resolution reflectometer (AQ7410A, Ando Electric), and the insertion losses, 1.43–2.88dB (2.24dB ave.) compared with that of the physical contact between

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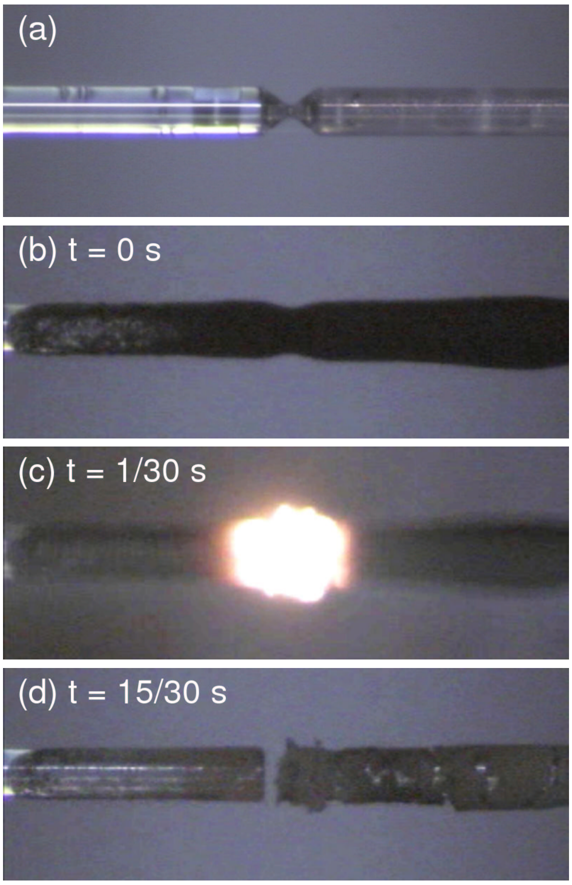

Fig. 1. Captured video images of an optical fuse (a) before and (b) after the carbon-coating on TeO_2 glass segment inserted in a silica glass optical fiber circuit, (c) at the beginning and (d) at the end of the burning of the coating. Each elapsed time is shown in the images of (b), (c) and (d). The diameter of the fiber is 125μm.

the end-faces before splicing. These variations are due to the varieties in the volume of captured melt and the necking width of the segment. This fiber circuit was connected to an Er-doped fiber laser (ELD-33-1540, IPG Laser, 2W max.) and an optical multimeter (AQ-2140, Ando Electric). We confirmed that this bare glass bridge withstand transmitting of the laser power up to 2W, which was increased by 0.1W in every 30 sec.

In the next place, the glass bridge was coated with commercial black watercolor, which consists of fine carbon powder and gum arabic in general (Fig. 1(b)). Then the laser light was entered to the device in the same way described above and its appearance was recorded as a video movie whose sampling rate was 30 images per second. A flush suddenly appeared from the glass segment as shown in Fig. 1(c), and subsequently the coated carbon burned completely and the glass bridge was disappeared (Fig. 1(d)). This flush burning is brought about by the leaked light from the adjacent glass segment which has no waveguide structure.

Among the 7 trials, so-called fiber fuse was not observed. This phenomenon is triggered by strong

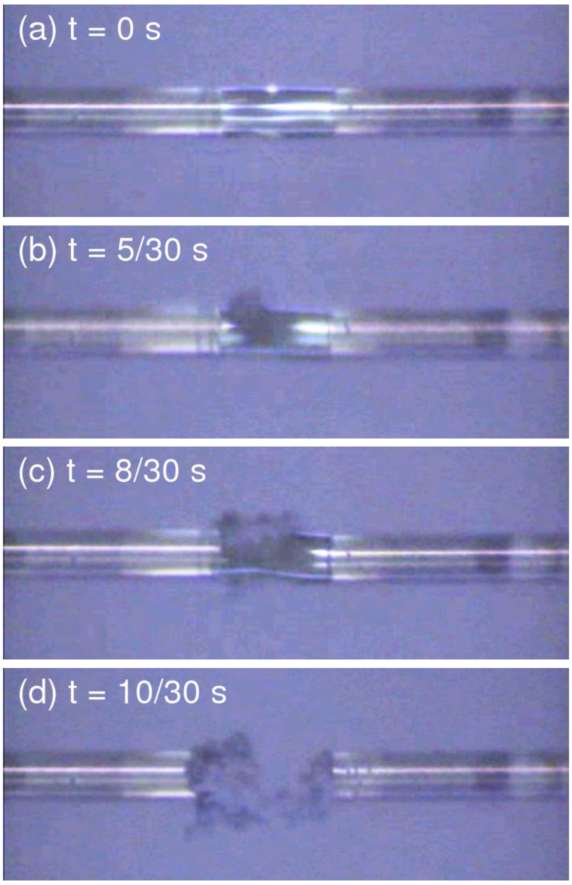

Fig. 2. Captured video images of an annealed TeO_2 melt inserted between a pair of silica glass fiber end-faces. Each elapsed time is shown in each image. The diameter of the fiber is 125μm.

light absorption at the end-face of the fiber to melt the core region and the damage propagates along the core toward the light source until it is shut down.[4] The absence of fiber fuse is because the fiber core is shielded from the carbon particles by the inserted glass segment.

The threshold input power of burning varied 0.3–1.5W (0.8W ave.) among 7 samples. At the present stage, we have a difficulty to relate between these threshold values and the device-configuration parameters such as their sizes and insertion loss values of the glass segment. This is probably because the critical value is also affected by small eccentricity of the glass segment and slightly bended light propagation due to a little tilted cut at the fiber pigtail. Further discussion for the threshold value should be done after the reproducibility of this fabrication process is established.

The output power from the device dropped by 12dB on the average. Two factors are considered to be responsible for this drop; reduced viscosity and crystallization of the glass segment. As the coated carbon absorbs the leaked light to generate heat, the viscosity of the adjacent glass decreases to lead self-deformation under the influence of its surface tension and gravity. In addition, since pure TeO_2 glass is known to be thermally unstable and very easy to crystallize,[5] the temperature raise also induces crystallization which scatters the propagating light.

We directly observed the crystallization of TeO_2 melt in a separate experiment. A small amount of TeO_2 melt was captured within a pair of silica fiber end-faces and annealed in the vicinity of a heater. As far as annealed at an appropriate position, the melt survived for a long time ($\sim$ few minutes) without devitrification. Once the melt was moved to a point at a short distance far from the heater to reduce its temperature and put back to the original position, the melt began to crystallize immediately. This is because of the nucleation occurred in the cooling period, which promoted the crystal growth in the following heating period.

Most of the crystallization phenomena observed in this experiment completed within one frame of video recording, i.e. 1/30 sec. Figure 2 shows the slowest phenomenon among the present experiment. These pictures clearly show that crystallization process also deforms its original shape and breaks the fiber linkage. Moreover, it is expected that the glass materials easy to crystallize is favorable for optical fuse with rapid action. This requirement is completely opposite to that for fiber drawing.

In the present stage, we can not determine which factor dominates the output power drop in the present optical fuse, since we can't see the inside of carbon-coated glass segment during the fusing action and could not know whether or not the power drop occurs before the light flush by the present experimental setup.

The insertion loss of the present structure is quite a high, about 2dB, because of (1) low coupling efficiency due to a lack of waveguide structure in the glass segment and (2) Fresnel reflection loss at the interface of silica fiber and TeO_2 glass, which is estimated as 0.18 dB per an interface. These losses can be reduced by introducing refractive index modulation at the interface and/or the glass segment. The former loss can be reduced by using TEC (Thermally Expanded Core) fibers, which is formerly demonstrated by the authors,[1)] and/or direct waveguide writing by focusing fs-laser pulse.[6)] The latter loss is suppressed if the refractive index gap at the interface is reduced by introducing refractive index gradient coating at the end-face of the fibers.[7)]

In summary, passive optical fusing action was demonstrated in a previously unknown structure, that is, carbon-coated TeO_2 glass segment inserted between silica glass optical fiber end-faces. The threshold input power ranges 0.3–1.5W, which was very sensitive to the shape of the necked glass segment. Its optical power drop is brought about heat-induced deformation of the glass segment, which is considered to be due to a reduced viscosity and enhanced crystal growth. Further reduction of its insertion loss is expected by introducing refractive index modulation at the interface and/or the glass segment.

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