In-situ observation of fiber-fuse ignition

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ABSTRACT

Ultrahigh-speed video recording of fiber-fuse ignition was reported for the first time. Fiber fuse was initiated in a glass ferrule in which the fiber end was in contact with cobalt oxide powder. Optical discharge emerged from a slowly moving darker radiant at about 300μm distance from the fiber end. Absence of void in the trajectory of the dark radiant implies that there is no glass-plasma interface at the radiant. Two other types of fused damage on ignition were also reported.

Keywords: Fiber fuse, Ultrahigh-speed videography, Laser-induced damage

1. INTRODUCTION

Fiber-fuse effect was discovered in late 1980s,[2,3] initiated by local heating of optical fiber to generate an optical discharge running along the fiber to the light source (~W) resulting in catastrophic destruction of core region. Ever since, nearly 40 papers has been published concerning this phenomenon. The list of these papers is available elsewhere (The author's another paper[4] in this volume, and his web page; its URL is printed below).

Recent growth of available laser power (>kW) gives rise to an urgent need for fiber fuse termination.[5–8] It is more important, however, to recognize this initiation mechanism. Most of the works on fiber-fuse ignition up to now are based on indirect experimental results, such as required pumping power density and the methods for initiaton. This is due to the difficulty in direct observation of this phenomenon. Usually, the ignition is accomplished by one of the following ways; bringing the fiber output end into contact with absorbent materials, or heating the fiber with a flame, a fusion arc, or in a furnace. Each of these makes us hard to observe the phenomenon directly and microscopically.

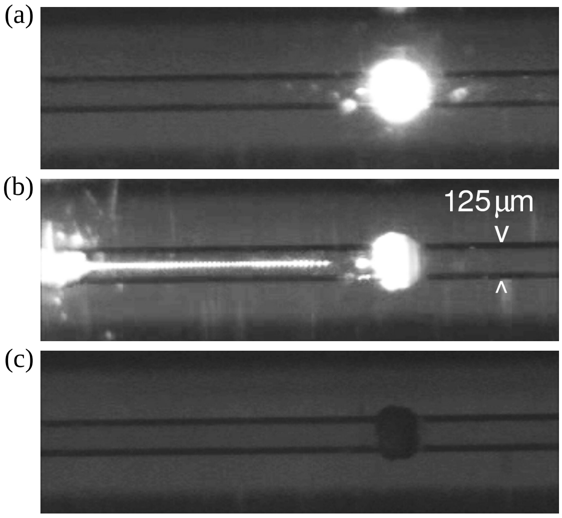

Figure 1. Successive captured video images of fiber-fuse ignition taken by a normal video recorder.[1] The shooting speed is 30 frames per second.

Recently, the author succeeded to take a photograph of the igniting moment using a normal video camera (see Fig. 1).[1,9] This paper presents further investigation of this topic using ultrahigh-speed videography.

2. EXPERIMENTAL

Figure 2 shows the experimental setup in this study. One end of a commercial single-mode silica glass optical fiber (SMF-28, Corning, core diameter: 9μm) was connected to a Raman fiber laser (PYL-10-1480, IPG Laser, 1.48 μm, 9 W). In order to initiate a fiber fuse in a observable configuration, the other end of the fiber was inserted into a glass ferrule with a small amount of cobalt oxide powder, as shown on the right of Fig. 2. The ignition was observed through a CCD camera (ultima APX-RS, monochrome version, Photron Ltd., sensitivity range: 380-790 nm) with an appropriate zoom lens. Pictures with a resolution of 256×32 were taken every 10 μs with 1-μs-exposure time through ND (neutral density) filters (x64). Damaged sites were examined by an optical microscope.

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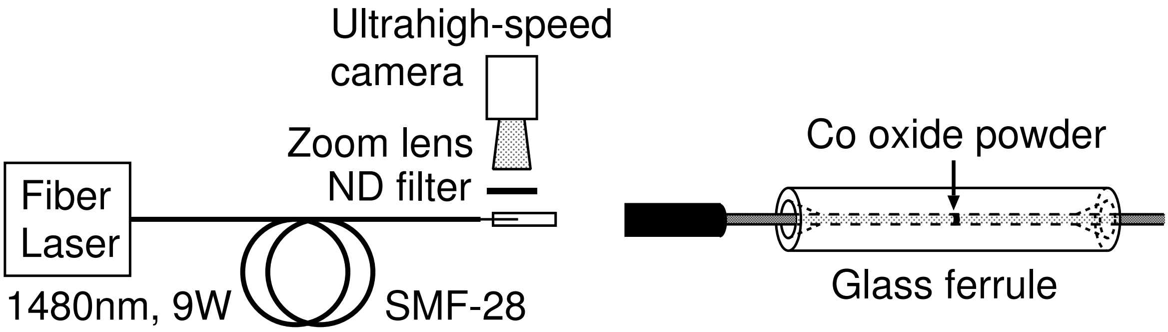

Figure 2. Experimental setup for observing fiber fuse ignition (left) and configuration for self-ignition by laser pumping (right).

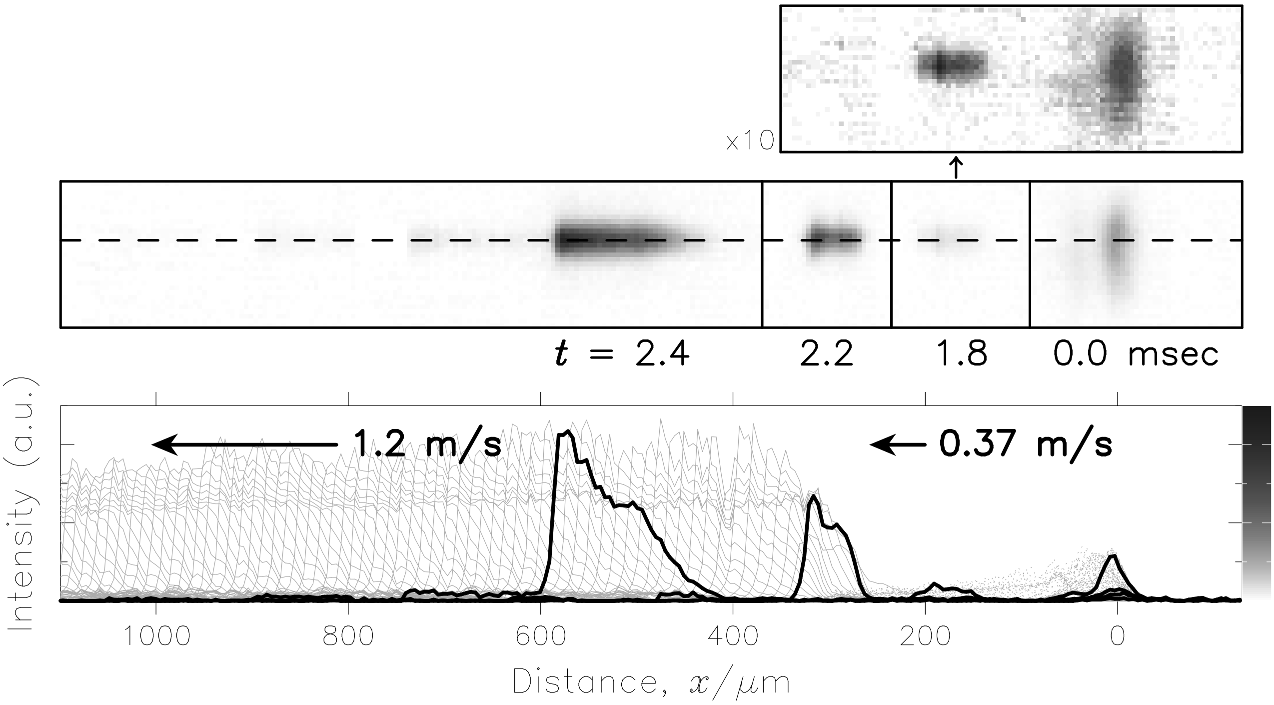

Figure 3. Photographs of visible light emission around fiber-fuse ignition (upper) and their intensity profiles along the dashed lines on the photos at every 10 μsec (lower). The fiber end is located near $x = 0$. The laser pumping started several seconds before $t = 0.0$ ms.

3. RESULTS

Five takes of fiber-fuse ignition were recorded. A typical result is compiled in Fig. 3. The upper half shows photographs of visible light emission around fiber-fuse ignition (t=2.2 ms). The laser pumping started several seconds before t=0.0 ms. The fiber end is located near x=0. Thus, the photo at t=0.0 ms represents heated area of the Co oxide powder. Lower half of Fig. 3 and Fig. 4 show time-varying intensity profile of the radiant along the dashed line shown in the upper photos. These trajectories clearly show that a dark radiant emerged at t = 1.55 ms and x= 90 μm (see upper arrow in Fig. 4) and moved slowly along the fiber. Then, an fiber fuse occurred from the radiant at t = 2.2 ms near x= 300 μm. Averaged speeds of the discharge and radiant are calculated to be 1.2 m/s and 0.37 m/s, respectively. Other four cases showed similar tendency.

Bottom of Fig. 4 shows the voids generated by the ignition. Periodic voids appears in the region of x >300 μm, at which the optical discharge appeared. A thin void extends from the fiber end to the depth of about 100 μm, where the dark radiant appeared. Thus, it is reasonable to conclude that the thin void and the periodic voids were generated after the optical discharge emerged and before the dark radiant emerged, respectively. For all the five cases recorded, similar damages are generated. It is, however, not the only mode of ignition. In some rare cases, different types of damage were

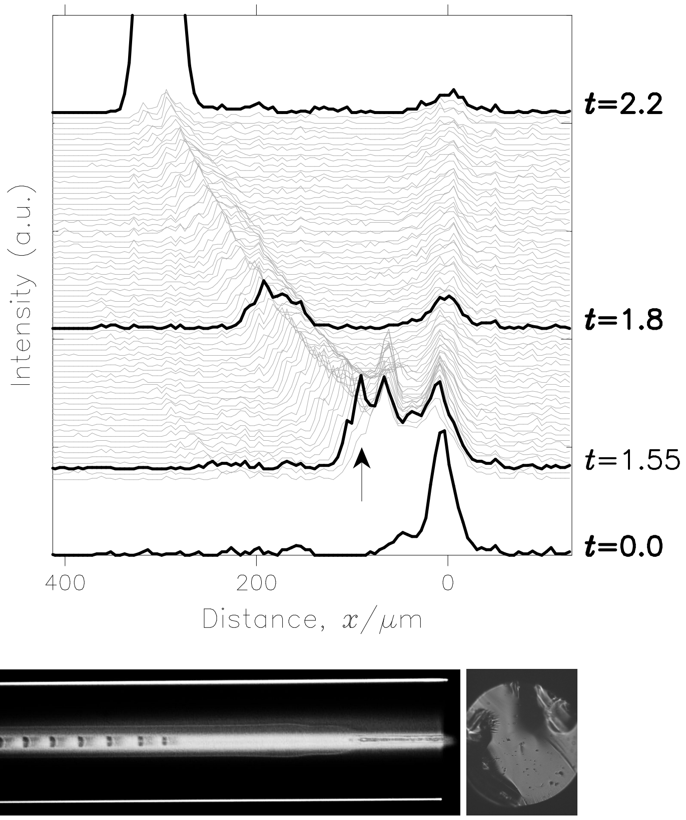

Figure 4. Upper: Time-varying intensity profile of visible light emission before fiber-fuse ignition (t=2.2 ms) along the dashed lines on the photos shown in Fig. 3. Lower: Optical micrograph of damaged fiber.

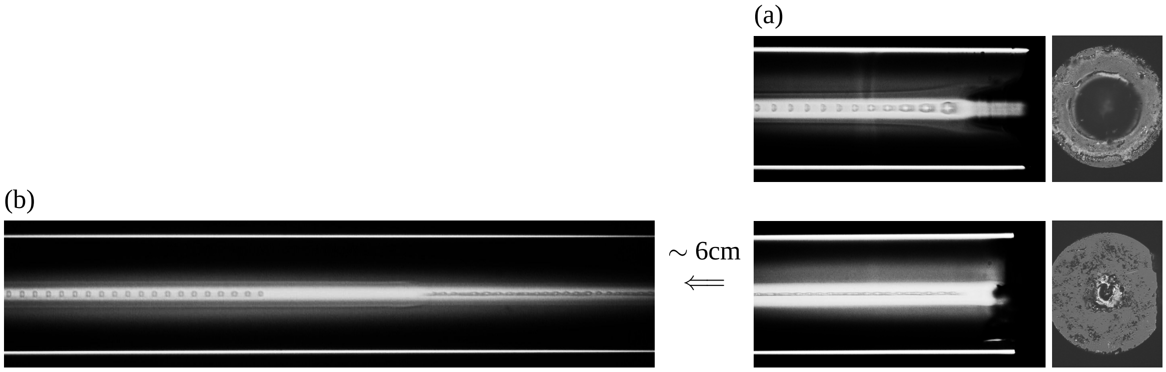

Figure 5. Optical micrographs showing two types of ignited tail.

observed as shown Fig. 5(a) and (b). In either case ultrahigh-speed video shooting have not succeeded yet.

4. DISCUSSION

A trajectory of the dark radiant is also recorded in the captured video image shown in Fig. 1(b), as an absence of light filament. After emerging the optical discharge, light filament appears because the light intensity is large regardless of its high speed. Before emerging the dark radiant, it appears due to long staying time in spite of lower light intensity.

The speed of dark radiant is as fast as that of optical discharge pumped by 1.5 W light,[4] 0.33 m/s, where other experimental conditions are the same as this study. These two phenomena are, however, completely different because only the latter leaves a thin continuous void. Absence of void in the trajectory of the dark radiant implies that there is no glass-plasma interface at the radiant. Thus, it can be called a transient propagation mode of energy without gas plasma.

It is interesting to find such a void-free section in another case of damage (see Fig. 5(b)) at about 6-cm-distance from fiber end. The 6-cm-long thin void looks like thin voids generated by less than 2.0-W-pumping.[4] The pumping energy in this case was, however, more than 2.0 W. It seems to be also different from the thin void shown in Fig. 4 because of the presence of large hole on the fiber end surface. Thus, it must be another propagation mode of energy with gas plasma. Further investigation including ultrahigh-speed videography is needed.

The last case of damage shown in Fig. 5(a) is likely to be brought about by an ignition without any fore-running phenomenon. In other words, light-induced heating of Co powder could accidentally give enough heat to make an immediate ignition. A huge hole at the fiber end and a gradual increase of void size toward the fiber end are likely to be due to the heat generated there. Similar void expansion has been reported in an ignition by fusion arc.[10]

5. CONCLUSION

Fiber-fuse ignition was observed by an ultrahigh-speed video camera. Optical discharge was found to be generated after a fore-running phenomenon in which a darker radiant moved slowly along the fiber and left no void. It must be a trangent propagation mode of energy without gas plasma.

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