Heating and burning of optical fiber by light scattered from bubble train formed by optical fiber fuse

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Abstract: We investigate in detail for the first time the scattering properties and heating characteristics in an optical fiber when a bubble train forms in the middle of the fiber as a result of the fiber fuse phenomenon that occurs when a high power signal is launched into the fiber. We found that almost all the optical light is scattered at the top of the bubble train. The scattered light heats UV coated fiber and nylon jacketed silica fiber to around 100 and over 250 °C, respectively, and finally the fiber burns and destroyed at a launched optical power of over 3 W.

OCIS codes: (060.2400) Fiber properties; (120.6810) Thermal effects; (350.1820) Damage

1. Introduction

Recently the optical power in optical fiber is being increased to achieve an efficient transmission network by increasing the optical signal channel number and by maintaining a suitable SNR at a high transmission speed by using a high power optical fiber amplifier and Raman amplification. This has led to increased concern about the damage caused by the fiber fuse phenomenon [1], which can occur in single mode optical fiber delivering a high optical power of over a few watts when there is localized heating in the fiber core caused by defects in the fiber or dust at the fiber endface. Once the phenomenon is initiated, a bubble train forms in the fiber core after the fiber fuse, and it propagates towards the high optical power source and continues until the optical power in the core falls below the threshold fiber fuse power. Optical signals cannot be transmitted through fiber damaged in this way. There have been several studies regarding the generation mechanisms [1-5], the bubble formation mechanism and the emission properties from the plasma discharge that occurs when bubbles are formed [6-9]. Recently, passive prevention methods employing a tapered core structure [10, 11] and a hole assisted fiber structure [12-15], and active prevention methods in which the high power light source is turned off by monitoring the RF signal of the reflected light from the bubble train [16], have also been proposed to prevent a transmission fiber from suffering damage over a long distance. However, there have been no reports on the scattering and heating characteristics of fiber where the train is formed in the middle of the fiber when high power light is launched again into the fiber, although the characteristics are very important for safety reasons.

In this paper, we describe in detail for the first time the scattering characteristics of a bubble train formed by the fiber fuse phenomenon, and the heating and burning of UV coated and nylon jacketed optical fiber by the scattered light.

2. Scattering properties of light from bubble train

A fiber laser operating at 1550 nm with a maximum output power of 4.5 W was used to initiate a fiber fuse and to measure the scattering characteristics of light from a bubble train, as shown in Fig. 1. The scattered optical light was

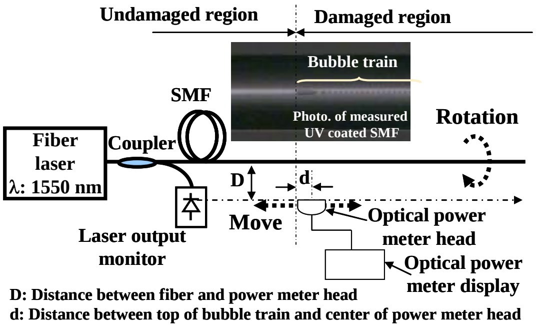
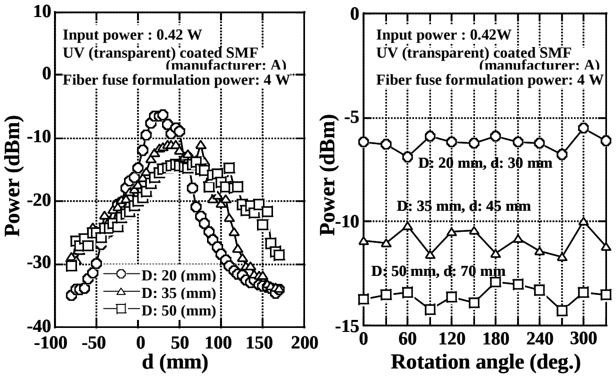


Fig. 1 Setup for measuring scattering characteristics



(a) (b)

Fig.2 Typical scattering properties

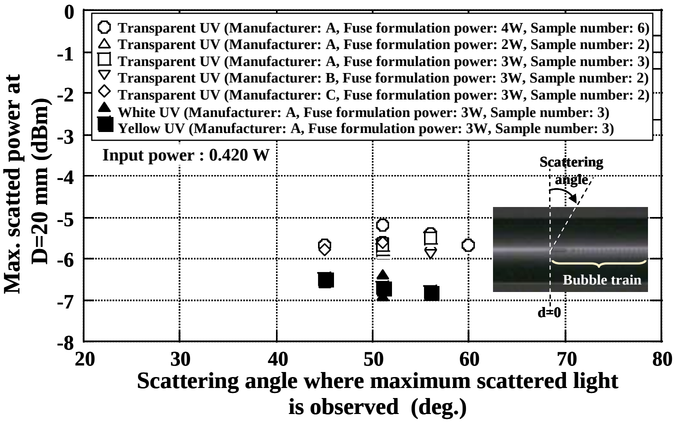


Fig.3 Relationship between angles where maximum scattered light is observed and maximum scattered light powers

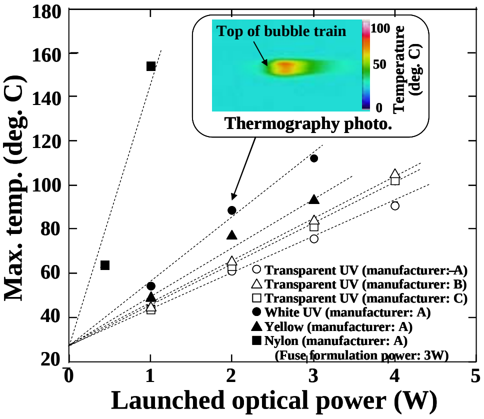


Fig.4 Maximum fiber temperature as a function of launched optical power

measured with an optical power meter with a 2.5 mm square active area. The measured fiber section in which the bubble train was formed in the middle of a fiber was straight and the optical power meter head was moved along the measured fiber section. The fiber section was also rotated while the rotation angle dependence of the scattered light was being measured. We measured various UV coated silica fibers fabricated by three different manufacturers.

The relationship between d (the distance between the fiber and the power meter head) and the scattered power for various D values (the distance between the top of the bubble train and the center of the power meter head), and the relationship between the rotation angle and the scattered power for various d and D values are shown in Fig. 2 (a) and (b), respectively. The fiber fuse formation power, which we defined as the power at which the bubble train is formed, is 4 W. The launched optical power was 0.42 W. Figure 3 shows the relationship between the scattering angle where the maximum scattered light is observed and the maximum scattered power for various UV coated silica fibers fabricated by three different manufacturers. The fiber fuse formation powers were 2, 3 and 4 W. The UV coating colors were transparent, white and yellow. From these results, we found that the light was scattered cylindrically and almost all the light was scattered at the top of the bubble train, i.e., the boundary between the undamaged and damaged regions of the fiber. The scattering angle from the vertical axis of d=0 (as shown in Fig. 3), where the maximum scattered light is observed, was around 51 degrees, independent of the fiber manufacturer and UV coating color. And the maximum scattered light power for the transparent UV coated fibers was higher than that for the white and yellow UV coated fibers.

3. Heating and burning of UV coated and nylon jacketed optical fiber

We used infrared thermography to measure the temperature of a fiber in the middle of which a bubble train had formed when a high power light was launched into it. The measurement temperature range was -20 to 250 °C.

Figure 4 shows the maximum fiber temperature as a function of launched optical power for various UV coated silica fibers and a nylon-jacketed optical fiber. The fiber fuse formation power was 3 W. The nylon jacketed optical fiber was white. The temperature was observed in less than a minute after a high power light was launched into the

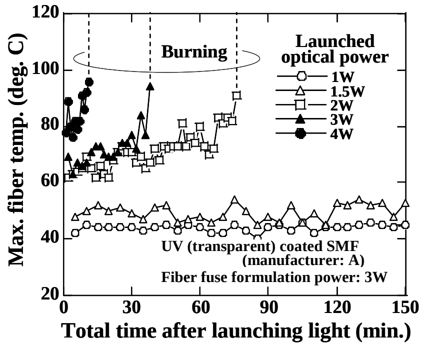
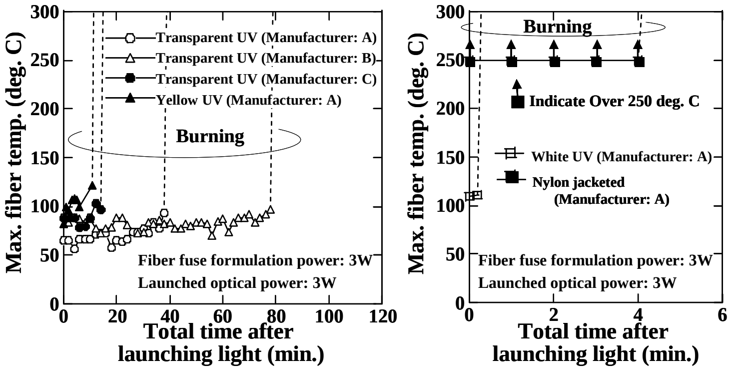


Fig.5 Maximum fiber temperature as a function of total time after launching light at various powers



(a) (b)

Fig.6 Maximum fiber temperature as a function of total time after launching light at various fibers

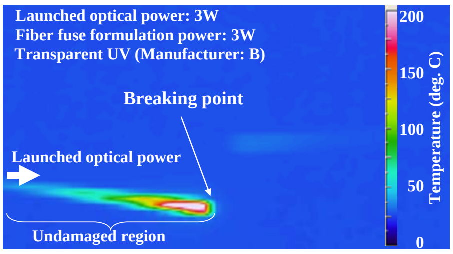


Fig.7 Typical thermography photography after UV coated fiber was burned and destroyed

fiber. We confirmed that a high temperature area appeared around the top of the bubble train, i.e., the boundary between the undamaged and damaged regions where the bubbles formed, as shown in the inset thermography photograph in Fig. 4. Furthermore, the maximum fiber temperature is proposed in relation to the launched optical power for all of the fibers, and the temperature of the nylon jacketed fiber is higher than that for the UV coated fibers, and the temperature of the colored UV coated fibers is higher than that for transparent UV coated fibers.

Figure 5 shows the maximum fiber temperature as a function of total time after launching light at various powers, and Fig. 6 (a) and (b) show that for various UV coated fibers and a nylon (white) jacketed fiber, respectively. The fiber fuse formation power was 3 W. We found that the fiber temperature increased as we increased the time for launching the light, and all of the UV coated fibers and the nylon jacketed fiber were burned and destroyed within 120 min when the launched optical power exceeded 3 W. Burning occurred at around 100 °C for the UV coated fibers and at over 250 °C for the nylon jacketed fiber. Figure 7 shows a typical thermography photograph taken after the UV coated fiber was burned and destroyed.

4. Conclusions

We reported in detail for the first time, the scattering properties and thermal characteristics of fiber with a bubble train formed in its center by the fiber fuse phenomenon when a high power light was launched again into the fiber. We found that the almost all the optical light launched into the fiber was scattered at the top of the bubble train, i.e., the boundary between the undamaged and damaged regions of the fiber. And UV coated fiber and nylon jacketed silica fiber were heated to around 100 °C and over 250 °C, respectively, by the scattered light, and were finally burned and destroyed when the launched optical power exceeded 3 W.

These results clearly warn of the high risk of burning and burn injury when high optical power light is launched into UV coated silica fiber and nylon jacketed silica fiber with a bubble train in its center.

5. Acknowledgment

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