Appendix A
Comparison with Bulk Silica Glass Modification by Continuous-Wave Laser

Extremes meet.

In 2006, an interesting phenomenon was reported by researchers in precision engineering, in which bulk silica glass is modified with a continuous-wave laser beam focused on a thin copper foil that covers the backside of the glass [10] (see Fig. A.1). The modification starts with heat-induced generation of plasma (or optical discharge) on the foil. Then, it moves to the light source, that was clearly recorded by high-speed photography [2, 4, 6]. Finally, it disappears when the power supply is exhausted due to the laser beam defocusing at the plasma [2]. This resembles the fiber fuse initiation, propagation, and termination processes discussed in Chap. 1.

Sometimes, the modified area contains hollow voids [2, 4, 6]. Figure A.2 describes one example of this modification process reported in Hidai et al. [4] where a void train of $\sim$5.5 mm was left. The void shape varies with the depth from the copper foil; (a) periodic bullet-like voids near the foil, (b) quasi-periodic voids with a smaller interval and irregular shape in the middle of the train, and (c) a long void ($>$400 μm) with a slight periodic necking at the end of the train. This trend is driven by the pump power density reduction at the plasma front. It also reminds us of the following fiber fuse behaviors; the reduction of periodic void interval with the pump power in the cylindrical mode as shown in Fig. 3.1a and the long void generation in response to a rapid power reduction as shown in Fig. 4.5d.

Hidai et al. [4] analyzed the modified area through fictive temperature determined by Raman and IR spectroscopy, Vickers hardness and etching rate. They revealed that the area consists of two layers. The inner zone is mainly modified by laser heating and the outer by tensile stress caused by the densification of the inner area. It is reasonable to expect that this structure is also left after a passage of a fiber fuse.

In this connection, it should be noted that the CW-LBI method triggers another interesting phenomenon where a metal particle in a glass block is pumped to move, radiate light/heat, and modify the surrounding [3]. One example is shown in Fig. A.3.

S. Todoroki, *Fiber Fuse*, NIMS Monographs, DOI: 10.1007/978-4-431-54577-4,

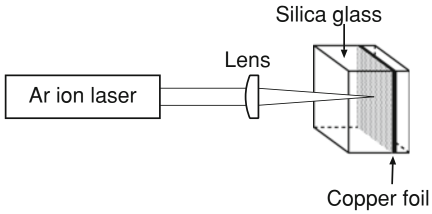

Fig. A.1 Experimental setup for continuous-wave laser backside irradiation (CW-LBI)

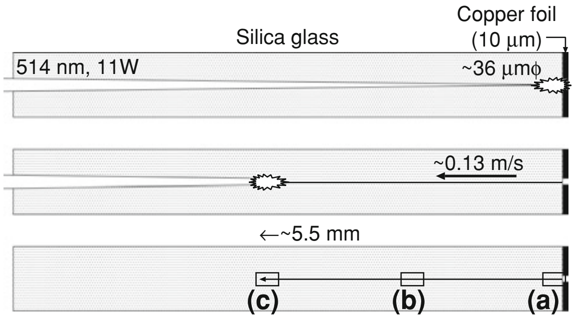

Fig. A.2 Modification process of bulk silica glass by CW-LBI; (*top*) initiation, (*middle*) propagation, and termination, and (*bottom*) the positions of damage photographs are shown in Fig. 3 in Hidai et al. [4]

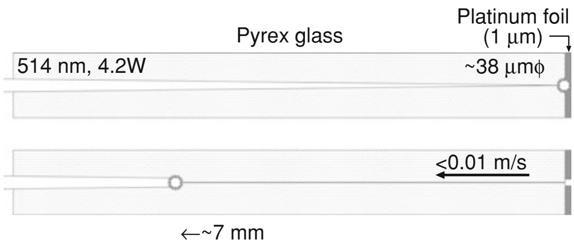

Fig. A.3 Migration process of platinum particle (diameter:∼5 μm) in borosilicate glass by CW-LBI [3]; (*top*) initiation, (*bottom*) propagation and termination

A metal particle is introduced from the platinum foil on the backside of a borosilicate glass piece and moves until the power supply is exhausted due to defocusing. The driving force of particle movement is considered to be the gradient of surface tension that is introduced by the poor thermal conductivity of the metal, i.e., a thermal gradient between the fore and rear of the particle [5]. Compared with the case of copper foil on silica glass shown in Fig. A.2, the propagation speed is slower by an order of magnitude at least.

Appendix B
Fiber Fuse in Materials Other than Silica Glass

Never judge by appearances.

B.1 Soft Glass Fibers

As described in Sect. 1.2, a distraction wave without plasma is known to occur in chalcogenide and fluoride fibers and to decompose the entire cross section of the fiber [1].

B.2 Polymer Optical Fiber

In January 2014, it was reported that a fiber fuse phenomenon occurs in a polymer optical fiber (POF) [8]. Its macroscopic appearance is in perfect analogy to what we have seen in silica glass fibers except its slow propagation speed, $\sim$0.02 m/s. A bright spot runs through a perfluorinated graded-index POF having a core of 50 μm diameter pumped with $<$0.2 W, 1,546-nm light. The most striking feature is found in its microscopic behavior. The damage left behind the spot looks like a black wavy line oscillated at the wavelength intrinsic to its graded-index profile as shown in Fig. B.1. A unique termination method is presented thanks to the high elasticity of the polymer. A fiber fuse stops at a point pressed with an outer metal attachment. These facts suggest that its propagation mechanism is completely different from that in silica glass fibers.

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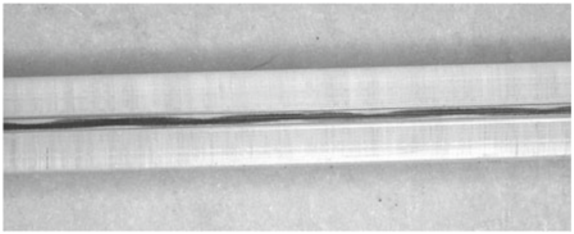

Fig. B.1 An oscillatory curve of fiber fuse damage in a polymer optical fiber with graded-index profile. The outer diameter is 750 μm. Courtesy of Dr. Yosuke Mizuno, Tokyo Institute of Technology

Box B.1 Video providing macroscopic view of polymer optical fiber fuse.

- Fiber fuse propagating along a polymer optical fiber at an extremely slow speed (~ 0.02 m/s).

http://www.youtube.com/watch?v=t0k_B6EOQhg
Duration: 1:11
Fiber: Perfluorinated graded-index polymer fiber
Pump laser: 1546 nm, 75 mW
Speed: 30 fps

B.3 Yb-Doped Bismuthate Glass Waveguide

Fiber fuse phenomenon is also observed in active devices made of silica glass fibers including laser emitters [11] and optical amplifiers [9]. In addition, it was recently reported that an active waveguide laser device fabricated in a Yb-doped bismuthate glass was destroyed by this phenomenon leaving a bullet-shaped void train [7].

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