Zr inclusions revealed by microcomputed tomography observations on the CO_2 laser fusion splicing interface between single-mode optical fibers

Throughout the communications equipment hierarchy from cabinet-level to board-level interconnection, optical interconnection technologies have recently attracted much attention as the solution for the interconnection bottleneck [1], such as the limits of the interconnection density in future high-performance computing systems, routers and servers. In applying many optical fiber interconnections to board-level interconnections, the technical difficulties related to entanglement of optical fibers wired on circuit boards need to be solved.

We have proposed the laser fusion splicing technology for fiber buckling (Ref. [2]). The technology has advantages in terms of efficient integration of a large number of optical fibers on circuit boards, because it does not require the same complicated optical fiber positioning mechanism and large electrodes for melting down fibers as in the currently used electric arc discharge method [3].

Figure 1 shows the experimental setup for CO_2 laser fusion splicing for single-mode silica optical fibers with the external diameter of 125 micrometers using the fiber buckling. The single-mode optical fiber cores (about 10 μmϕ) inside both fiber#1 and fiber#2 are aligned by inserting the optical fibers into the conventionally used zirconia-ceramics V-shaped grooves and by closing the arms attached to the plate, as shown in Fig. 1. After butting both optical fiber end faces, the optical fiber buckling force can be generated by making optical fiber#1 go forward with a small offset of Δy. The adjustment to the buckling force results in the splicing interface with the suitable volume of silica optical fiber material, when the spliced interface of silica is melted by CO_2 laser irradiation. Thus, the laser system installed at the remote position from the circuit board and the fiber buckling force can replace the large fiber fusion splicing system. However, new characteristics of the laser-fusion-spliced optical fiber, such as mechanical fracture strength and splicing loss distribution, have not yet been fully elucidated [4].

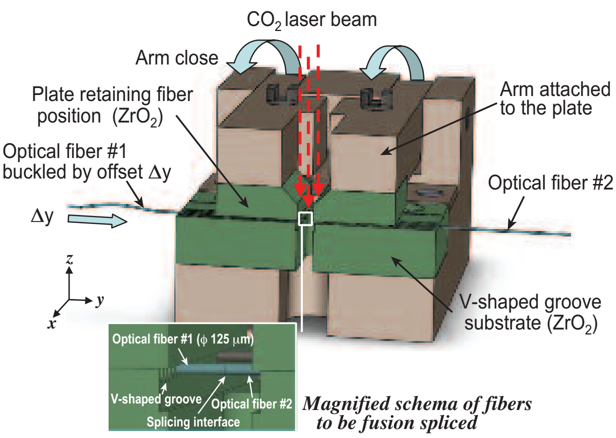

Fig. 1. Isometric cross-sectional view of experimental apparatus for stabilizing optical fibers to be laser-fusion-spliced for fiber buckling.

SPring-8 microcomputed tomography (SP-μCT) installed at beamline **BL47XU** is a powerful method of nondestructive investigation that enables even the cross-sectional structure of the spliced optical fiber with a high signal-to-noise ratio to be visualized with the proper choice of X-ray energy and an intensive photon dose using a ring accelerator and an undulating magnet field system [5]. It also enables the precise linear absorption coefficient (LAC) distribution with one-micrometer-space resolution that is suitable for observing optical fiber structure changes to be obtained. The SP-μCT clarified the existence of some inclusions with high LAC at the interface between optical fibers spliced using a CO_2 laser. The observation results implied that the laser fusion splicing losses increased with the volume of the inclusions lying behind the fusion splicing interface.

Figure 2 shows the fluorescent X-ray spectroscopy results obtained at the splicing interface and at a position away from the splicing interface. Fluorescent X-ray spectroscopy measurement was carried out with a germanium single-element solid-state detector (Ge SSD) installed at beamline **BL19B2**. As shown in this experimental result, detection of Zr K_α fluorescence at the interface implies that the inclusions were the material including zirconium. After this analysis, the newly proposed cleaning process using micro-polyester nylon fiber textiles and air blowing with a microstatic eliminator have been introduced to clean up the V-shaped groove substrate and the plate retaining the fiber position as shown in Fig. 1 [6].

Figure 3 shows the effect of the zirconium inclusions on the structural changes of the optical fiber core and cladding observed from the classification of LACs. The structural relationship between the zirconium inclusions, optical fiber core and optical fiber external structure was successfully visualized by SP-μCT. We could observe clearly a large volume of zirconium inclusions in the sample fabricated before the introduction of the cleaning process as shown in this figure, whereas only a small volume of zirconium inclusions could be observed in the sample fabricated after the introduction of the cleaning process [6].

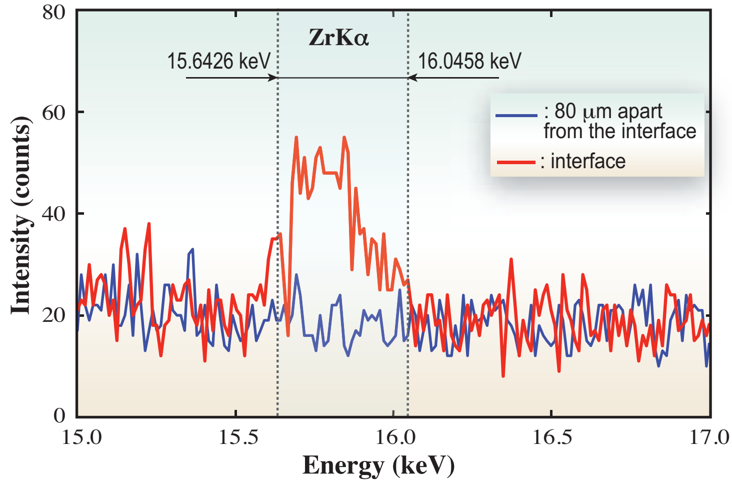

Fig. 2. Results of fluorescent X-ray spectroscopic microbeam analysis at the interface of the laser-spliced fiber and a position away from the interface.

Thus, the proposed cleaning process is considered to enable the reduction of the volume of zirconium inclusions at the fusion-splicing interface [6]. On the other hand, the observation results implied that the large volume of zirconium inclusions caused defects on the optical fiber external structure and core-structure changes as shown in Figs. 3(a) and 3(b). These structural changes would affect the laser-fusion-spliced fiber qualities including the mechanical fracture strength and splicing loss distribution.

On the basis of the described analytical results of having unveiled the laser-fusion spliced optical fiber structure, the analytical performance of SP-μCT for observing optical fiber devices' structures is expected to be clarified further with the deployment of optical microdevices.

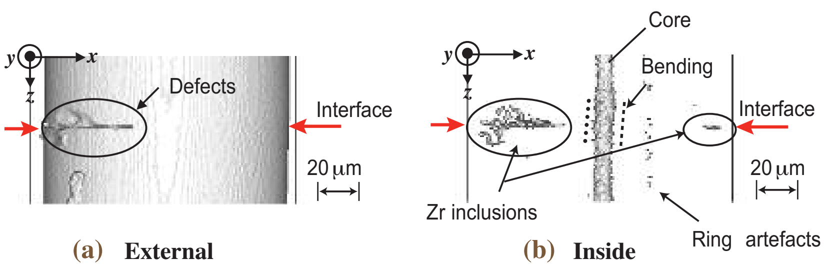

Fig. 3. Structural changes of the optical fiber external structure and the core due to Zr inclusions revealed by SP-μCT at the laser-fusion-spliced interface. ((**a**) External structure of a spliced optical fiber reconstructed from SP-μCT images. (**b**) Optical fiber core and Zr inclusions revealed after the extraction calculation. The x-y-z coordinates and scale in (a) correspond to those in (b).)

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