Precise measurement of diffraction structures in capillary laser sight for ion microbeam irradiation to mammalian cells

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Glass capillary optics has been utilized in emitting ion microbeam (μm-order diameter) irradiation to single mammalian cells and *Escherichia coli* cells at the RIKEN Pelletron accelerator facility in the Nishina R&D Building.[1)] The typical ion energy is a few MeV whose range in water is from 10 to 100 μm for a H ion and approximately 10 μm for a He ion. The ranges are close to cell sizes, and are controlled with 1 μm resolution by selecting an appropriate initial energy. To avoid mis-hitting the target area in ion irradiation, a laser sighting operation will be performed[2)] prior to the ion shooting, which is realized by a dual-microbeam capillary optics method. However, the micrometer-sized spot of the laser-sight encompasses not only the center spot but also surrounding ring structures, which causes a larger laser spot and increases the mis-hitting probability. Here, we report a new precise laser spot mapping method and analyze the decomposition of the diffraction pattern. Figure 1 shows the experimental setup implemented at Toho University. A laser beam from an Ar^+ laser source enters the glass capillary optics. A digital camera equipped with a transmissive screen or power meter probe was located at a distance of 65–70 mm downstream of the capillary outlet. Figure 2(a) depicts a typical ring pattern taken by the camera, showing the center spot, thin rings, and bright ring groups. We aim to investigate (1) the origin of the thin rings, (2) dependence of the diameters of the 1st and 2nd bright ring groups on capillary outlet size a, and (3) power ratio of each group. Accordingly, a power meter probe with a 70 $\mu m\phi$-aperture was newly installed to measure the absolute value of power density driven by a 2-dimentional high position-resolution (0.5 μm) stage. The green curve with dots connected by lines depicted in Fig. 2(b) denotes the measured power density along a horizontal line including the

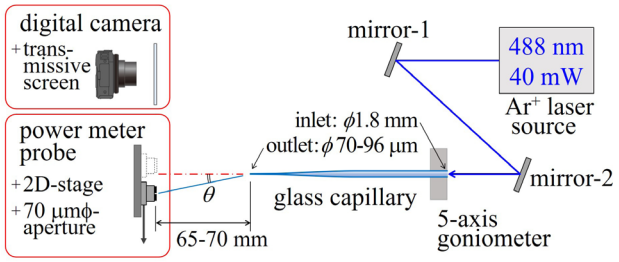

Fig. 1. Setup of the laser microbeam profile measurement.

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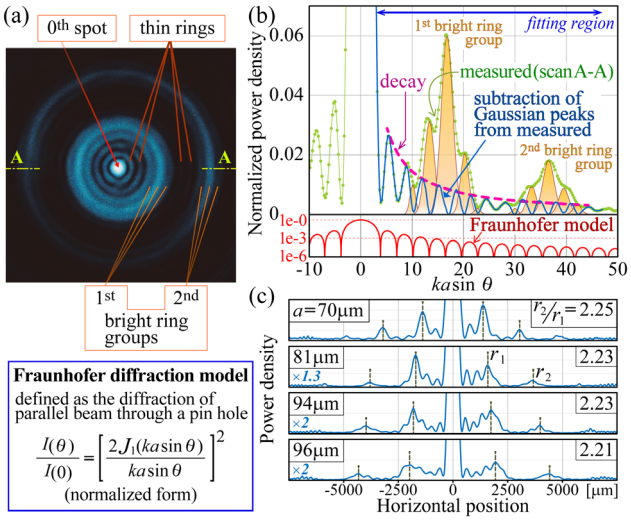

Fig. 2. (a) Photo of typical ring pattern. (b) Power density as a function of $ka\sin\theta$, showing measured (green) and fitted Gaussian peaks (orange), as well as Fraunhofer diffraction model in a logarithmic scale (red). (c) Comparison of the ring diameters according to the outlet size a.

spot center defined in Fig. 2(a) for a capillary with $a = 94$ μm. Horizontal axis is in the unit of $ka\sin\theta$, where k is wave number and θ is the probe angle in Fig. 1. Each Gaussian peak comprises more than 10 measurement points, which are large enough to use fitting methods. The thin rings in Fig. 2(a) are assumed to extend beyond the 2nd bright ring group. However, the spread is hidden behind the bright rings. To remove the bright rings from the green curve, they were expressed as 5 and 3 Gaussian peaks, and the shapes were determined by fitting. The solid blue curve represents the result of subtracting of the Gaussian peaks (orange) from the green curve. The fitting did not impose a Fraunhofer condition; however, the oscillation period of the blue curve is the same as that of the Fraunhofer model (red). Although the decay of the (dashed) curve seems to be slower than that of the red curve, the behavior of blue curve including the center spot is similar to a Fraunhofer model. The slow decay might be due to the focused light beam inside the capillary body. Using the precise peak positions of the bright ring groups, it was found that the diameters of the groups increase with a (Fig. 2(c)), while the ratios of the diameters of 2nd to 1st groups remains constant with respect to a. The power ratios of 0th, 1st, and 2nd groups were also obtained. The

ratio of the 0th spot was 37% of the entire spot for $a = 96$ μm. However, a ratio of 62% was achieved for smaller $a = 70$ μm. This means a smaller microbeam has less power of bright ring groups. In conclusion, the thin rings originate in the Fraunhofer diffraction at the outlet. To obtain a high-contrast laser microspot with smaller bright ring groups, it is necessary to use the capillaries with smaller outlets.

References

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