Analysis of diffraction patterns of laser spots in dual-microbeams generated by glass capillary optics for future biological use

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We have developed an ion microbeam irradiation system employing tapered glass capillary optics for biological use in the RIKEN Pelletron accelerator facility in the Nishina R&D Building. Glass capillary optics is a simple and reliable tool to generate ion/laser microbeams,[1–3] where both the ion and laser can be extracted from the capillary outlet simultaneously. When an end window is installed at the outlet, the microbeams can be applied to targets in the liquid/gas phase. At the microbeam irradiation port, cultivated living cells in a liquid medium or parts of small living insects in air are targets.[4] The corresponding irradiation lengths are expected to be a few micrometers or submillimeters for liquid and air, respectively. The ion species are H and He ions with energies of a few MeV so that the range in water (approximately 100 and 30 μm for H and He ions, respectively) approximately corresponds to the sizes of the biological targets. The maximum linear energy transfer (LET) is selected to be 80 or 240 keV/μm for H or He ions, respectively, which is sufficiently high to cause serious damage to DNA. In this ion irradiation, any mishits should be avoided because such a single ion hit may cause an undesirable effect on the living target. To realize precise ion targeting, a laser microbeam extracted from the same capillary is used as a laser sight of a μm-order scale. The laser microspot on the target consists of a center spot and higher order rings of diffraction, which are different from those of Fraunhofer diffraction. The higher order rings deteriorate the sharpness of the laser spot, which then reduces the accuracy of the laser sight. In this study, to understand the mechanism of ring generation, the brightness of each ring was measured according to the distance from the capillary outlet so that the results could be discussed based on ray tracing simulations. For this purpose, the distance range was selected to be in the order of 100 mm because larger ring images can provide detailed information of light trajectories. The end window was not introduced to obtain clear ring images.

Figure 1 shows the setup at Toho University. A visible light laser with a wavelength $\lambda = 488$ nm from a source (Photochemical Research Associates Inc. LA15R) entered a glass capillary with an outlet diameter of 62 μm, as shown in Figs. 2(a)–(c). The width of the input beam was approximately 570 μm at the full width at half maximum (FWHM).[2] Laser spots on a transparent screen were recorded by a digital camera for a distance L ranging from 120 to 300 mm, where L was defined as the distance between the capillary outlet and the screen. An ND filter was used to reduce the intensity of the input beam so that rings of a lower brightness were clearly

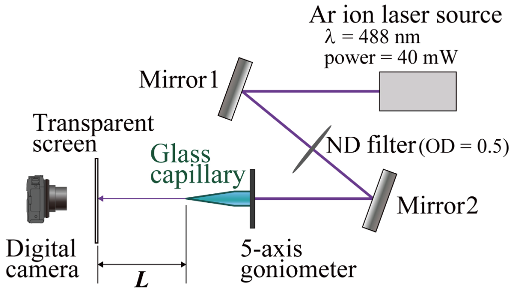

Fig. 1. Experimental setup to obtain diffraction patterns of laser spots. The distance L ranged from 120 to 300 mm.

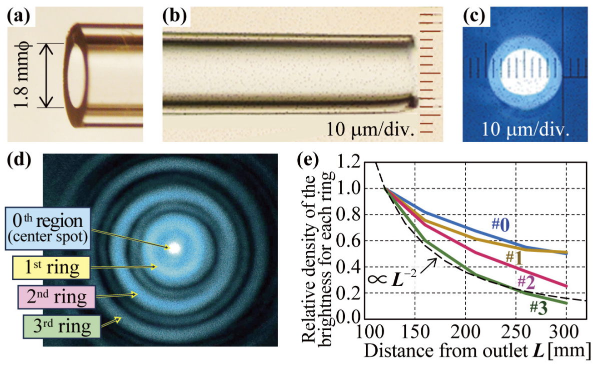

Fig. 2. (a) Capillary inlet, (b) capillary outlet with a diameter of 62 μm, (c) the downstream view of the outlet, (d) a typical laser spot on the screen, and (e) relative density of the brightness as a function of L.

recorded with an 8-bit dynamic range of the image files. A typical laser spot image is shown in Fig. 2(d) along with the definition of the center spot (0th region) and higher order rings (1st, 2nd, and 3rd rings). The total brightness of each component (0–3) was obtained by integrating over the area, and the brightness density was calculated by dividing by the area. To compare the L-dependence of each density, the density was normalized by that at $L = 120$ mm, as shown in Fig. 2(e) with a dashed line corresponding to L^{-2}. The density for the 3rd ring (#3) was found to follow the L^{-2} curve; that is, #3 was emitted from a point-like source, which may be owing to reflection at the inner surface around the outlet. Although curve #0 was expected to be constant because it was the component without any reflection inside the capillary, the curve was found to depend on L. The obtained behaviors of the curves will be compared with ray tracing simulation results.

References
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