Spot size estimation for laser aiming system of ion microbeam irradiation using a tapered glass capillary optics

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In order to investigate the response of living cells to radiation, micrometer-sized beams are used to shoot a small structure inside the cell. A microbeam irradiation system has been developed at RIKEN, employing MeV H/He ions generated by the Pelletron accelerator and tapered glass capillary optics, whose beam inlet and outlet diameters are ∼1 mm and several micrometer, respectively.[1)] HeLa cells[2)] and *E-coli.* cells[3)] were irradiated using this system. Since the high accuracy needed to shoot the targets should be achieved easily, the installation of an aiming system utilizing laser micro spot has been scheduled. The capillary can transmit both ions and laser at the same time. The aiming system provides the laser microbeam needed to spotlight the target prior to ion irradiation. When the excitation light of a specific fluorescent protein or fluorescent dye is selected as the spotlight, only the labeled target in a microscopic view will be irradiated by the ion microbeam.

The laser transmission experiments have been carried out with tapered glass capillary optics in Toho University. The power of the transmitted beam was well-reproduced by a simulation with a precisely measured capillary shape.[4)] The beam power was measured by using a power meter based on a photodiode whose sensitive area was 10 mm × 10 mm. In order to determine the laser spot size, a microscopic imaging technique is needed. Figure 1 shows our method, which records the spot shape on a fluorescent-bead screen located L mm-downstream of the capillary outlet; it was set up at the Quantum Electronics Lab. in Toho Univ., using a laser beam from an Ar^+ laser source (wavelength $\lambda = 488$ nm, CW power = 15 mW). The screen consists of fluorescent beads, 2 μm in diameter, which can shift the λ from 488 nm (input laser) to around 508 nm (fluorescence). A band pass filter attached at the eye piece suppresses the input laser intensity by 10^{-6}, except for $\lambda = 510$ with a width of 20 nm. The spot images were taken by a digital camera and analyzed for $L > 1$ mm in a previous work.[5)]

This year, we introduced another microscope to determine L precisely and succeeded in achieving measurements of L down to 17 μm, which is short enough to spotlight the cell targets in the range of 4 MeV He^{2+} ions in water. The spot shape for $L > 1$ mm was similar to that of a Fraunhofer diffraction pattern, which is known as the ring images for a parallel laser beam entering a small aperture. Although a finite beam divergence during transmission does not follow the Fraunhofer formula, the obtained similarity for $L > 1$ mm inspires Fresnel pattern for $L < 100$ μm, where higher-order outer rings

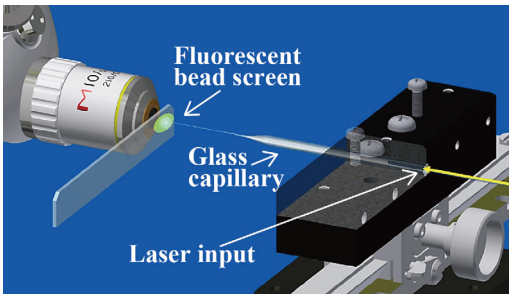

Fig. 1. Fluorescent beads, 2 μm in diameter, shift the wavelength from 488 nm (input laser) to around 508 nm (fluorescence) in order to observe the spot shape at a specific distance.

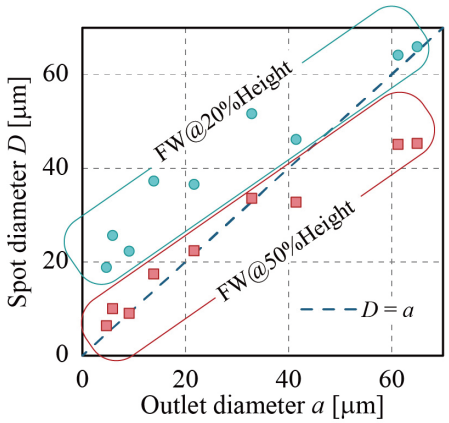

Fig. 2. The spot size as a function of the capillary outlet diameter at $L = 17$ μm and $\lambda = 488$ nm.

are strongly suppressed. This is highly advantageous for spotlighting a small target. We succeeded in performing spot size estimation, for the first time, using the precise L-determination system. Figure 2 shows the results of spot size as a function of outlet diameter at $L = 17$ μm. The full spot width at half (or 20%) maxima for each spot is represented by a square (or circular) symbol. The dashed line is a guide to show the case when the spot size is equal to the outlet size. We confirmed that smaller spots are obtained for smaller outlet capillaries without any higher-order rings. The estimation included the calibration of non-linearity of light intensity at the camera and the suppression of the halation effect due to cross-talk between the fluorescent beads. The installation of the system to a beam line of the Pelletron accelerator is in progress.

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