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Light Microbeams by Tapered Glass Capillaries for Biological Irradiation

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ABSTRACT

Microbeams of visible light were studied using a tapered glass capillary. Transmittance of laser light through capillaries with different inlet and outlet diameters was measured. About several % of the transmittance was obtained and larger than 80% was achieved in combining with an optical lens. It was found that the obtained transmittance considerably depended on the capillary shape, *i.e.*, the taper angle. Density enhancement of the extracted beam was derived and showed a strong focusing ability for the tapered glass capillary. Propagation of visible light through the capillary was discussed.

Keywords: Light Microbeam; Tapered Glass Capillary; Transmittance; Propagation of Light; Density Enhancement

1. Introduction

In micro-surgery of single living cell, fluorescent markers conjunct to the nucleus or an organelle are needed. Light microbeam provides a spot light so that the other part within a microscope view is free from the bleaching due to the undesired excitation light. If the microbeam is strong enough, the beam itself can serve as a pin-point knife. Although the conventional optical lens can focus light into even several mm, it is hard to control the beam size and the beam position on a living cell using the optical lens.

Using tapered glass capillaries, many studies have recently been reported on microbeam production of keV-MeV accelerated ions [1-3]. Microbeams by the capillaries have the advantages of low cost, easily positioning on the target and preferable sizes of beams. However, few studies about visible light with the glass capillary have been reported and propagation of light through the capillaries is not known. The capillary optics can be a new method with above advantages to produce focused microbeams of light in addition to optical lenses and further is applicable to the UV and X-ray microbeam production. The light propagation through the capillary is also interesting in terms of light-matter interaction.

In this paper, we report light-microbeam production using tapered glass capillaries for biological irradiation. Transmittance is obtained for capillaries with different inlet and outlet diameters, and results are discussed.

2. Experiment

Tapered glass capillaries were prepared using a puller (PE-21, NARISHIGE Co. Ltd) by heating a straight glass tube made of borosilicate and by pulling both ends with a constant force. Glass tubes with the inlet diameters of 1.8 mm and 0.8 mm were used. Outlet diameter was determined by cutting the capillary with a Microforge (MF-900, NARISHIGE Co. Ltd). Tens of images were taken by a microscope for the whole capillary in order to obtain the capillary shape and the taper angle.

Figure 1 shows the experimental setup for the transmittance measurements. We used an Ar^+ laser, a He-Ne laser, and a diode laser with a wavelength of 488 nm, 633 nm and 670 nm, respectively. The capillary was set on a

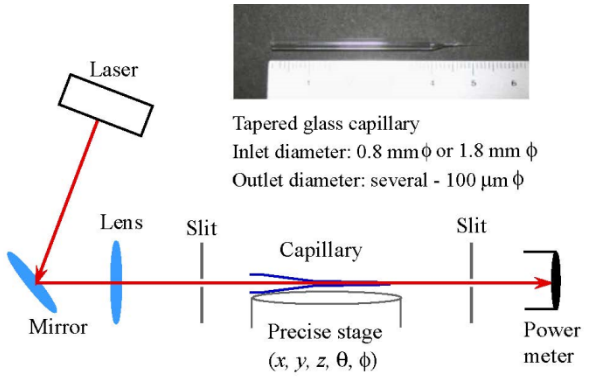

Figure 1. Experimental setup for transmittance measurements.

5-axis (xyzqf) precise stage and fine adjustment with the precision of mm could be made. In order to cut scattered light, slits were located both upstream and downstream of the capillary. The diffraction pattern of the transmitted beam was used to align the capillary respect to the initial beam direction. Powers of transmitted beams through both the tapered capillary and a straight glass tube were measured with a power meter.

In some measurements, an optical lens with a focal length of 20 cm was set upstream of the capillary. The lens together with the precise stage and the slits was set on a straight rail and, therefore, the lens could be moved along the beam direction in order to change the position of the focal point.

3. Results and Discussion

We measured the powers of transmitted beams through both the tapered capillary and a straight glass tube defined as "output power" and "input power", respectively. Therefore, the transmittance T is defined as follows

$$T(\%)=\frac{\text{output power}}{\text{input power}}\times 100. \quad (1)$$

3.1. Transmittance

Transmittance T was derived from the measurement for capillaries with different outlet diameters. Results of T for the 1.8 mm inlet diameter are shown in **Figure 2** as a function of the outlet diameter without the optical lens. Transmittance T increases from about 3% to about 10% when the outlet diameter rises from 17 mm to 100 mm and, however, no obvious dependence on the wavelength is found.

3.2. Combined with a Lens

The effect of an optical lens combined with capillaries was investigated. Changing the position of the lens, *i.e.*, the position of the focal point, we measured T for different capillaries. Dependence of T on the position of the focal point at 488 nm is show in **Figure 3** for the 1.8 mm inlet diameter capillaries with three typical outlet diameters of 28 mm, 37 mm and 67 mm. The origin of the x axis is set at the position of the capillary outlet and the position of the focal point moves to the inlet as x increases.

It can be seen from **Figure 3** that T strongly depends on the position of the focal point particularly for small outlet diameters and reaches maximum around $x = 2$ cm, *i.e.*, the region between the large taper angle and the small one [4]. The capillaries with the outlet diameters of 28 mm, 37 mm and 67 mm show a same trend. Similar behavior was also found for the wavelengths at 633 nm and 670 nm.

Dependence of T on the outlet diameter with the optical lens was measured as shown in **Figure 4**, where the

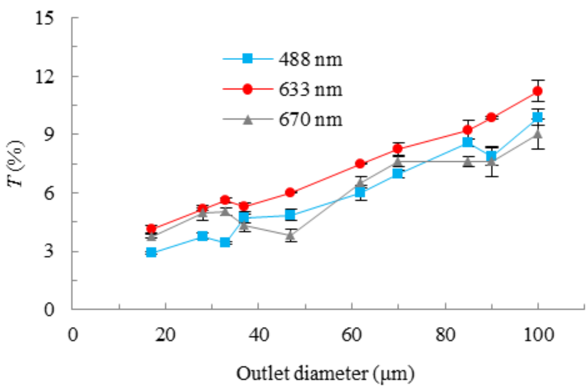

Figure 2. Transmittance of laser beam through the capillary of the 1.8 mm inlet diameter as a function of the outlet diameter without the optical lens.

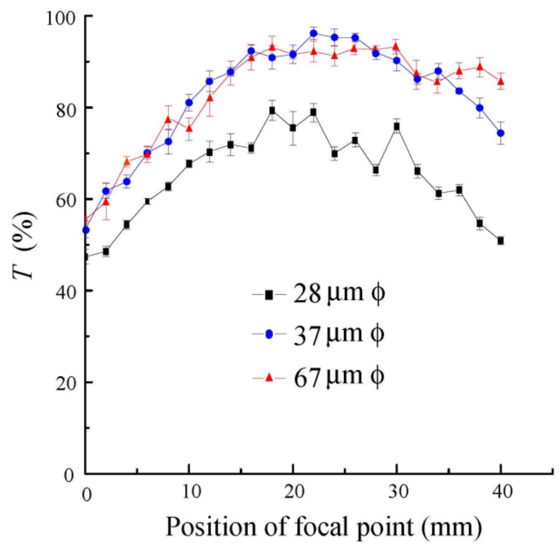

Figure 3. Dependence of transmittance on the position of the focal point for the 1.8 mm inlet diameter at 488 nm. The origin of the *x* axis is set at the position of the capillary outlet.

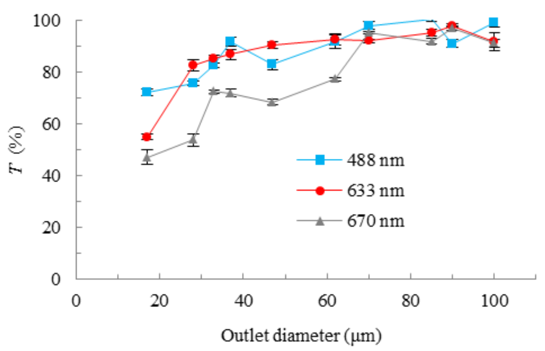

Figure 4. Transmittance of laser beam through the capillary of the 1.8 mm inlet diameter as a function of the outlet diameter with the optical lens.

position of the focal point is set at the region between the large taper angle and the small one, corresponding to the maximum *T*. Rapid increase of *T* with the outlet diameter can be found and *T* saturates to be larger than 80% in the region beyond 40 mm.

3.3. Transmittance for Different Inlet Diameters

Transmittance of light through the capillary is considered to be dependent on the capillary shape, *i.e*., the taper angle of the capillary. In order to study this effect, we measured transmittance of light through capillaries with the 1.8 mm and 0.8 mm inlet diameters. **Figure 5** shows a comparison of transmittance between these two inlet diameters at 633 nm. It can be seen from **Figure 5** that the transmittance for the 0.8 mm inlet diameter is considerably larger than that for the 1.8 mm inlet diameter. However, capillaries with the 0.8 mm inlet diameter have a same trend as the 1.8 inlet diameter concerning the dependence of the outlet diameter.

The capillary shape together with the taper angle was analyzed using the capillary images taken. **Figure 6** shows a comparison of the inner radius of the capillary for the 1.8 mm and 0.8 mm inlet diameters in a direction to the capillary outlet. The origin of the *x* axis is set to the position before the taper starting. It is clearly found from **Figure 6** that the inner radius for the 1.8 mm inlet diameter changes rapidly, corresponding a large taper angle, compared with the 0.8 mm inlet diameter. This is the reason of the small transmittance for the 1.8 mm inlet diameter.

3.4. Density Enhancement

In order to check the focusing ability of the capillary, the density enhancement was derived from densities at the outlet and inlet and is shown in **Figure 7** without the lens.

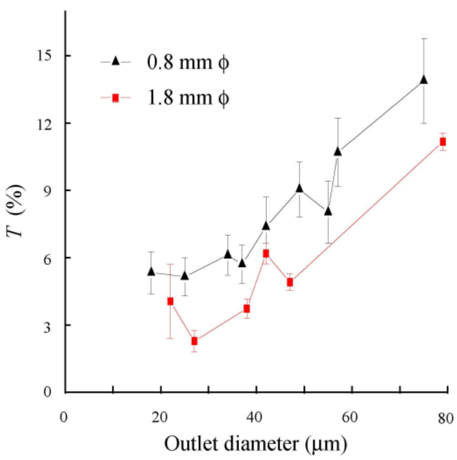

Figure 5. Comparison of transmittance through the capillary between the 1.8 mm and 0.8 mm inlet diameters at 633 nm.

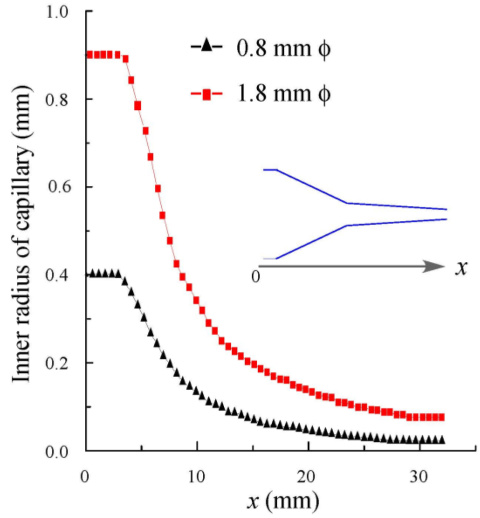

Figure 6. Comparison of the inner radius of the capillary between the 1.8 mm and 0.8 mm inlet diameters.

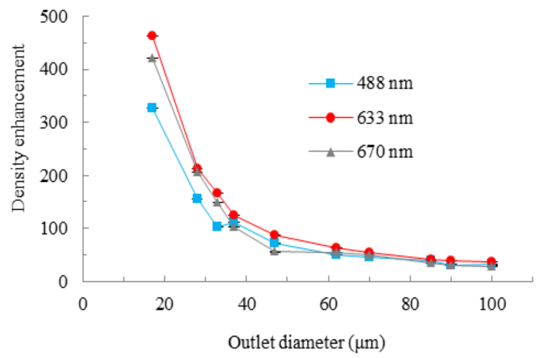

Figure 7. Density enhancement of the capillary for the 1.8 mm inlet diameter as a function of the outlet diameter without the optical lens.

The enhancement is about 30 at 100 mm, and reaches about 400 at 17 mm, increasing when the outlet diameter decreases. This shows that the capillary has strong focusing ability; the smaller outlet diameter the stronger focusing.

The obtained experimental results can be qualitatively interpreted. We introduce a model which divides a real capillary shape into two regions: region 1 with large taper angle of about 7˚ and region 2˚, near the outlet, with a small taper angle of about 0.2˚. It is known that reflectance of light by a glass surface strongly depends on the incident angle; several % for the incident angle of smaller than 60˚ while almost 100% for the incident angle close to 90˚ [5]. The region 1 has, therefore, almost no contribution to the transmission and reflection at the region 2 results in several % of the transmittance as experimentally obtained. In the case of the combination with the optical lens, however, light is focused by the lens directly into the region 2 and this yields the large transmittance.

4. Summary

Light microbeams were produced using tapered glass capillaries for biological irradiation. Propagation of visible light through the capillary was studied. Transmittance was measured for the capillaries with different inlet and outlet diameters. The transmittance was found to be about several % without the optical lens and larger than 80% with the optical lens, depending on the outlet diameter. Measurements with and without the lens provide information to find the optimum lens-free shapes of the capillaries. The transmittance for the 0.8 mm inlet diameter was measured to be considerably larger than that for the 1.8 mm inlet diameter, and was attributed to the difference of the capillary shape which was analyzed using the capillary images taken. Density of the extracted beam was found to be greatly enhanced and showed the strong focusing ability of the tapered glass capillary. The present study shows that the tapered glass capillary can be used to produce light microbeams for biological irradiation instead of the conventional optical lens system.

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