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Piezoelectric 2D Microscanner for Precise Laser Treatment in the Human Body

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Abstract- **Laser irradiation in the human body using an optical fiber is an effective method of minimally invasive laser treatment. For realizing precise laser treatment in the human body, a two-dimensional (2D) laser scanning micro tool has been developed. A laser is transmitted through an optical fiber and a micro rod lens. The laser is reflected and scanned by a 2D microscanner and focused on an objective area. The fabricated 2D microscanner has three piezoelectric unimorph cantilevers that have a ball joint at each tip and a mirror. The mirror is supported by a pivot from underside and is inclined by pushing down by three cantilevers on the top of the mirror. The maximum inclined angle of the mirror is 30 degrees. Using potasium-titanyl-phosphate (KTP) laser, a function of the laser scanning is confirmed. For insertion the 2D laser scanning micro tool into a working channel of a conventional endoscope, these components are assembled and packaged into a tube. In the future, this tool can be used not only for laser treatment but also for in vivo microscopic inspection. By combining the 2D microscanner and the microscopic inspection techniques, for example micro confocal laser scanning microscope or Endoscopic Optical Coherence Tomography (EOCT), the tool might be more effective for precise laser treatment.**

Keywords - **Laser scanner, piezoelectric, 2-dimentional, endoscopy, laser treatment**

I. INTRODUCTION

Recently, several treatments in the human body have been performed. In minimally invasive treatments, laser irradiation is widely used to cut, remove, shape and treat tissues of the human body [1]. By delivering laser to a local legion in the human body using an optical fiber, the beam is exposed from the tip of the optical fiber to a target. But there is a limitation to perform precise laser treatments in the human body because the diameter of the laser beam from the fiber end diverges and it damages collateral tissues [2]. Even if micro lenses are used, positioning of the small spot to the target is difficult.

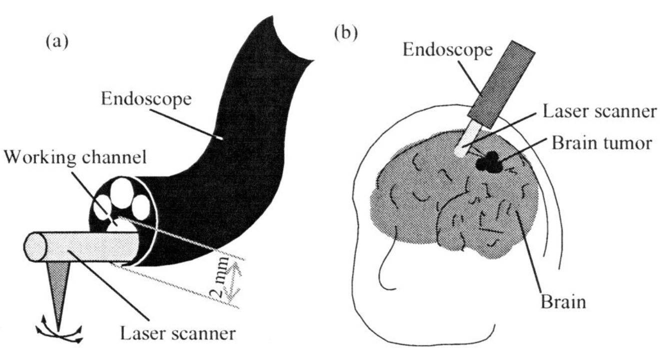

Fig. 1. Application of the 2D laser scanning micro tool in the human body
(a) Endoscopic laser treatment. (b) Laser ablation treatment of brain tumor.

To solve these problems, a 2D laser scanning micro tool using piezoelectric scanner has been developed. The tool has a micro rod lens to focus the laser beam from the fiber end and the 2D microscanner which has three piezoelectric unimorph cantilevers to scan the beam. If the external diameter of the tool is smaller than 2 mm, the tool can be easily delivered to the diseased area through a working channel of a conventional endoscope as shown in Fig. 1 (a). For example, by using the tool, treatment of a brain tumor (Fig. 1 (b)), a gastric cancer, or a laryngeal cancer can be performed without damaging the adjacent normal area.

II. DESIGN

Figure 2 (a), (b) shows the detailed structure of the 2D laser scanning micro tool. The laser beam from the fiber end transmits through the micro rod lens. The beam is reflected by a fixed mirror. Then, the beam is reflected by a scanning mirror of the 2D microscanner and the mirror scans the beam. The scanned beam is focused on the diseased area. By driving the 2D microscanner, precise positioning of a small laser spot can be performed. Moreover, the laser beam can be scanned in various shapes and sizes according to the diseased area.

Figure 2 (c) shows the detailed structure of the 2D microscanner. The 2D microscanner has three piezoelectric unimorph cantilevers which are arranged parallel to each other. Each cantilever has a glass ball joint at the tip as shown in Fig. 2 (b). A Si mirror is located under the ball joints and supported by a pivot under the mirror. When voltage is applied to the each piezoelectric unimorph cantilever, they push a mirror, which is supported by a pivot, and the mirror inclines two-dimensionally by pushing it down at 3 points. This 2D microscanner has five characteristics. Firstly, by arranging the piezoelectric unimorph cantilevers parallel to each other, it can be packaged in a small diameter tube. Secondly, the tips of the piezoelectric unimorph cantilevers have ball joints and the distortion between the cantilevers and the mirror is decreased by the ball joints and it enables large inclination angle of the mirror. Thirdly, a thick Si mirror can be inclined and the mirror can reflect high intensity laser beam because the power of the laser beam for treatment is relatively high and it damages a thin mirror. Fourthly, the mirror has a deep pyramidal indentation on the backside (Fig. 2 (b)) and it stabilizes the scanning motion of the mirror and this design reduces the defocusing of the laser beam because the change in optical length caused by the inclination of the scanning mirror is small. Finally, the mirror can be kept in required angle by piezo-actuation and it enables treatments with changing parameters of the laser beam, for example, pulse-width and intensity.

The tool has to be a tube-shaped device for insertion into the working channel of the endoscope. To assemble the required optical components and the 2D microscanner in a tube-shaped package, a 3D assembly method is used. For easy assembling of the optical components and the 2D microscanner, acrylic components are designed and fabricated. These components have V-grooves for precise arraignment of a GRIN (GRadient INdex) rod lens and a single mode optical fiber and a 30 degrees slope for the fixing mirror illustrated in Figure 2 (b). A polymer tube with an optical window is used as an outer tube.

III. FABRICATION

The 1-mm-diameter and 200-μm-thick scanning Si mirror is fabricated by the MEMS process. The mirror and a

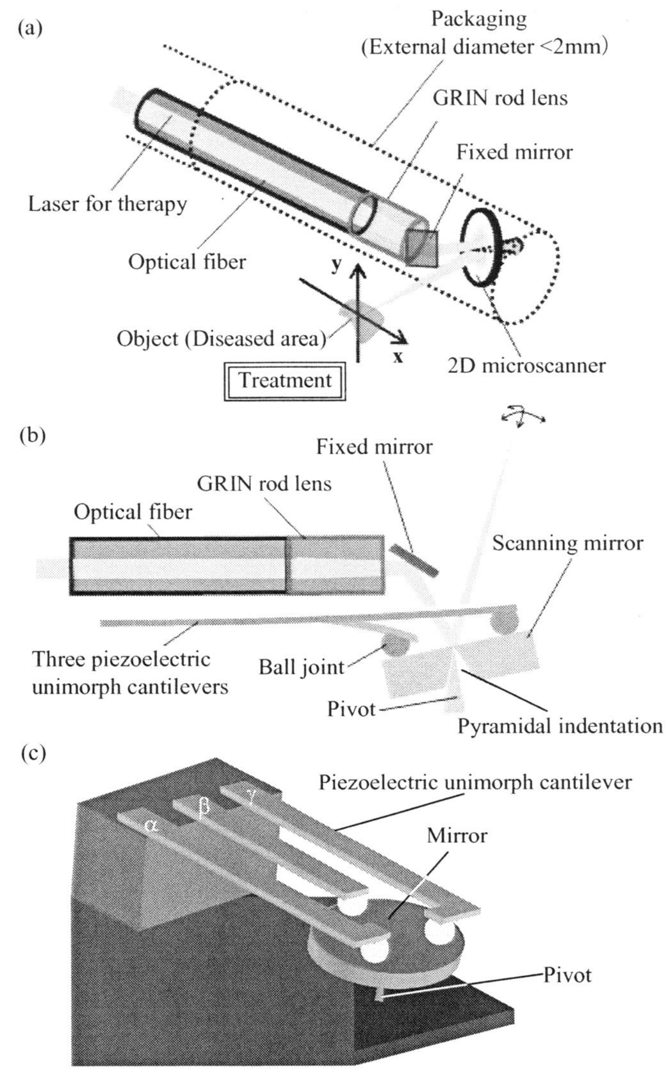

Fig. 2. Structure of the 2D laser scanning micro tool
(a) Schematic of the 2D laser scanning micro tool.
(b) Cross section of the 2D laser scanning micro tool.
(c) Schematic of the 2D micro scanner.

handling jig (Fig. 3 (a)) were shaped using a deep RIE (Reactive Ion Etching). A deep pyramidal indentation (Fig. 3(b)) was made on the backside of the mirror using anisotropic etching.

Three piezoelectric unimorph cantilevers were fabricated using femtosecond laser ablation from a piezoelectric unimorph plate which was fixed on the patterned electrodes on the substrate by conductive epoxy (Fig. 3 (d)). The thickness, width and length of the movable parts of the cantilevers were 0.06, 0.44 and 7 mm, respectively. The cantilevers had 100-μm-diameter through holes (Fig. 3 (c)) for positioning of the 250-μm-diameter glass balls. The glass balls were fixed by adhesive at the end of the cantilevers as shown in Figure 3 (d).

The 2D microscanner was assembled as following. First, a tungsten carbide needle was fixed on a substrate using adhesive as the pivot for the mirror. Tungsten carbide was used because it is wear resistant material. Second, the Si mirror with the handling jig was put on the pivot. Third, the piezoelectric unimorph cantilevers were put on the scanning mirror with handling jig, and the beams which support the mirror were cut using femtosecond laser abrasion and the handling jig was removed.

To install the optical components and the 2D microscanner in a tube of small diameter, acrylic components were fabricated using a high speed milling machine. The acrylic components were shown in Fig. 4; A: base for the optical components, B: cover plate and C:

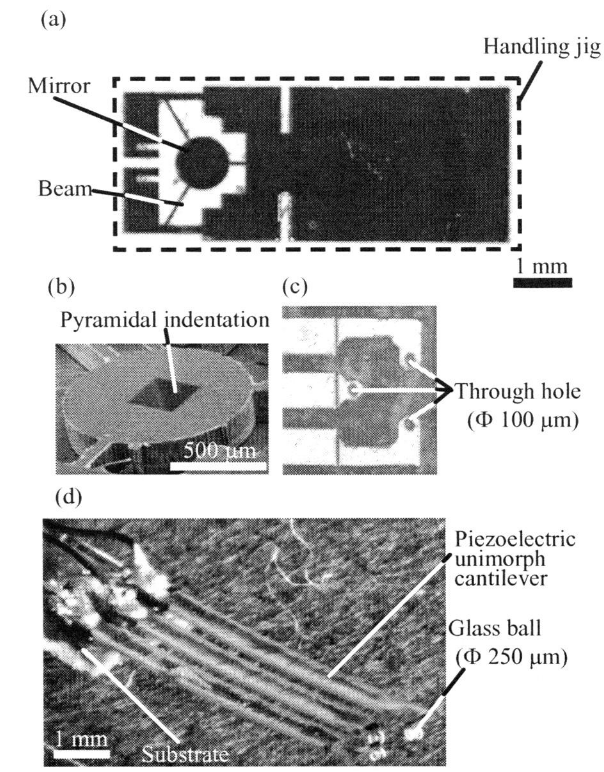

Fig. 3. Components of 2D microscanner
(a) Si mirror with handling jig. (b) Backside of Si mirror.
(c) Through holes of piezoelectric unimorph cantilevers.
(d) Piezoelectric unimorph cantilevers with glass ball.

base for the pivot and the 2D microscanner. Alignment holes and pins on the acrylic components were used when assembling the components. The size of the assembled components is 1.8 × 2.3 × 25 mm.

A 3.8-mm-external-diameter and 3.4-mm-inner-diameter Teflon tube was used as the outer tube. An optical window on the tube was fabricated using femtosecond laser ablation.

For packaging with the acrylic components and the outer tube, a new low-height 2D microscanner with 150-μm-diameter glass ball joints instead of 250-μm-diameter ones has been fabricated.

The tool was assembled as following. First, 2D microscanner was fabricated on the component C using almost same assembly method mentioned before as shown in Fig. 5 (a). Second, a 100-μm-thick Si reflecting mirror, a 125-μm- diameter single mode optical fiber and a 500-μm-diameter GRIN rod lens were fixed on the component A and the component B was fixed on the components A as a cover plate using adhesive as shown in Fig. 5 (b). The fixed mirror was fabricated using femtosecond laser ablation. Third, assembled component shown in Fig. 5 (b) was fitted and fixed by adhesive on the assembled component shown in Fig. 5 (a) as shown in Fig. 6 (5). Finally, the assembled components were inserted into the Teflon tube with optical window as shown in Fig. 5 (d).

IV. RESULT

Figure 6 shows the measured inclination angle of the scanning mirror of the 2D microscanner with 250-μm-diameter glass ball joints when voltage is applied to each piezoelectric unimorph cantilevers. The maximum inclination angle was about 30 degrees.

2D scanning of the therapeutic KTP (potasium-titanyl-phosphate) laser was also demonstrated using the 2D microscanner. A GRIN rod lens collimates the laser beam from the fiber as shown in Fig. 7 (a). At the center of the scanning mirror, the 2D microscanner reflects and scans the

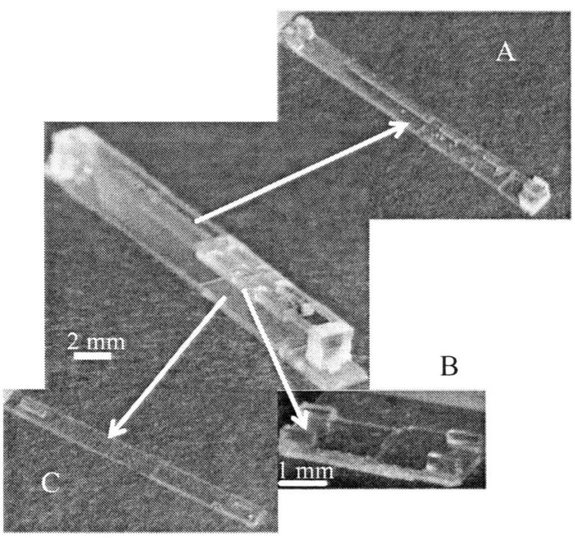

Fig. 4. Acrylic components
A: Base for the optical components. B: Cover plate.
C: Base for the pivot and the 2D microscanner.

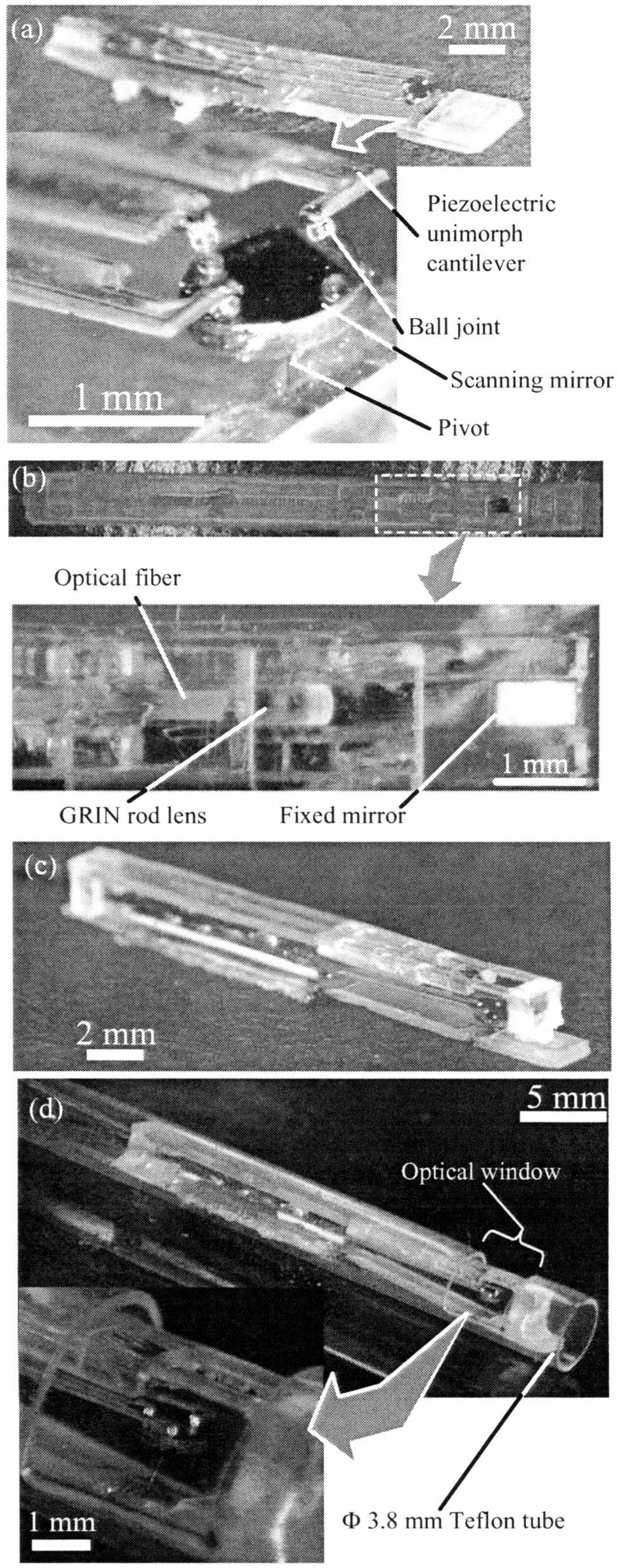

Fig. 5. 2D laser scanning micro tool
(a) 2D microscanner. (b) Fitted optical components and 2D microscanner. (c) Fitted 2D microscanner and assembled optical components. (d) 2D laser scanning micro tool.

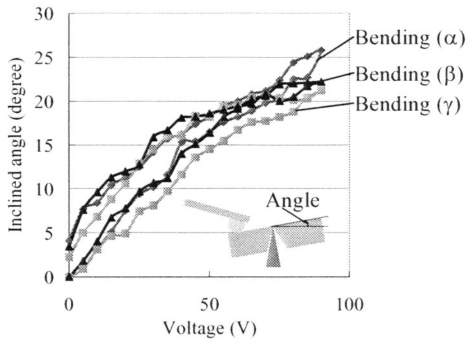

Fig. 6. Inclined angle of the scanning mirror
Each piezoelectric unimorph cantilever of the 2D microscanner is named as α, β and γ as shown in Fig. 2 (c).

laser beam. The laser beam was projected on tracing paper which is held above the 2D microscanner and recorded using a CCD microscope. Figure 7 (b) shows the scanning locus when the 2D microscanner is driven. Spot size of the laser beam on the tracing paper is about 100-μm-diameter and raster scanning is realized.

V. Conclusion

2D laser scanning micro tool for laser treatment in the human body has been developed. The tool is packaged in a 3.8-mm-external-diameter Teflon tube. The actuation of the tool is confirmed.

The inclination angle is measured using the 2D microscanner with 250-μm-diameter glass ball joints. The maximum inclination angle of the scanning mirror was 30 degrees. 2D scanning of the therapeutic laser was also demonstrated.

VI. Further studies

2D laser scanning micro tool smaller than 2-mm-external-diameter will be designed and fabricated.

For realizing a precise laser treatment, an observation system is important because a local legion should be precisely identified. Furthermore, laser ablation in the human body is relatively dangerous because there is not enough information about the structure and behind of the ablation area. In recent years, micro confocal laser scanning microscope [3] and EOCT (Endoscopic Optical Coherence Tomography) have been developed for *in vivo* microscopic inspections [4]. These techniques can identify exact location of borders of the local legion and the information is helpful for the laser treatment without damaging adjacent area. Our 2D laser scanning micro tool might be used not only for precise laser irradiation in the human body but also precise optical inspection. In the case of combining the EOCT system, 3D inspection can be realized because the tool can obtain a few mm depth images. These 3D and precise information will be effective for precise laser treatment in the human body. For example, even if there is a blood vessel behind the laser treatment area, undesired bleeding can be prevented.

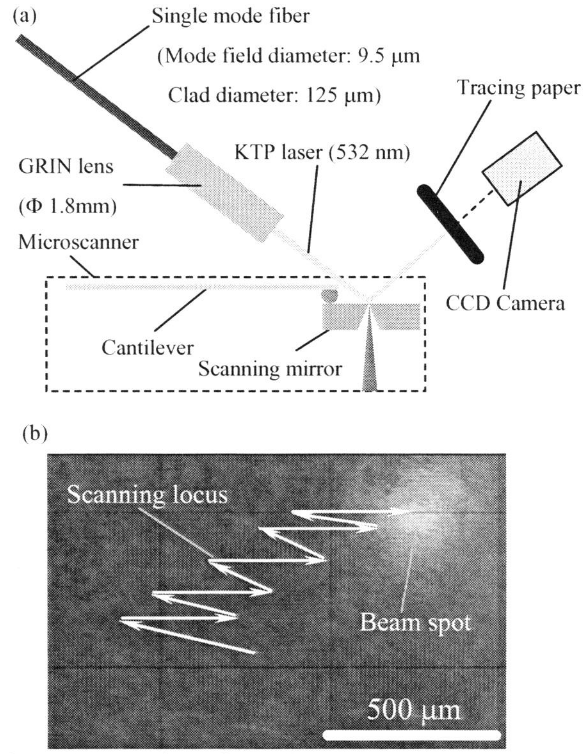

Fig. 7. 2D scanning of KTP laser
(a) Laser scanning system. (b) Locus of the 2D scanning.

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