# ACTIVE MICROMIXER USING A METALLIZED MICROTURBINE DRIVEN BY AN ULTRA-LOW POWER LASER

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## ABSTRACT

We propose an active micromixer using a metallized microturbine driven by an ultra-low power laser beam. The metallized microturbine is produced by two-photon microfabrication and electroless plating. Although conventional laser-driven micromachines need a high-power driving laser (~1 W), the metallized microturbine can be rotated at an ultralow power (< 1 mW). It is also demonstrated that the microturbine can be driven in a microchannel. The metallized microturbine will be applied to highly efficient laser-driven microfluidic devices such as active mixers and micropumps.

**KEYWORDS:** Two-photon microfabrication, Electroless copper plating, Optically driven metallic microrotor

## INTRODUCTION

Recently, a variety of micromixers have been widely developed in order to achieve highly efficient mixing in a microfluidic channel [1-3]. The mixing principles are divided in two classes: passive and active. Although passive devices do not require actuators for fluid mixing, relatively large, complicated three-dimensional microchannels are required. On the other hand, active micromixers are driven and controlled externally with magnetic forces, optical forces, ultrasound, electrowetting and so on [1-3]. In particular, optically driven micromixers using a tiny microrotor are suitable for miniaturization of mixing area, because the size of optically driven microrotors is much smaller than that of other mixing devices [3, 4]. In addition, since the use of optical force enables the driving of multiple components individually, optically driven microfluidic devices are suitable for highly integrated lab-on-a-chip applications including micromixers, micropumps and microvalves [5, 6]. However, since conventional optically driven microfluidic devices are made of polymers, a high-power laser beam is required to drive them due to the small magnitude of attractive optical forces. This is a crucial problem for practical use, because optical driving systems become large and expensive.

In order to overcome the above problems, we developed an optically driven micromixer using a metallized microturbine produced by two-photon microfabrication and electroless plating [7]. The metallized microturbine can be driven by an ultralow-power laser beam, so that the driving system of metallized micromachines is small and inexpensive. The optically driven metallized micromachines are suitable for practical use. In our experiments, we developed a highly-efficient optically driven microturbine. The optical force exerted on the blade of the microturbine was evaluated by two-dimensional electromagnetic analysis to determine the optimal angle of the blade. A prototype metallized microturbine was fabricated and driven by a He-Ne laser at a power of 0.7 mW. Finally, we fabricated a prototype of an active micromixer using a metallized microturbine to mix multiple reagents in a microchannel.

## AN ACTIVE MICROMIXER USING A METALLIEZD MICROTURBINE

We propose an active micromixer using a metallized microturbine (Figure 1). The active micromixer has multiple inlets and a single outlet. The microturbine is placed at the center of the chamber. Since the microturbine is rotated by repulsive forces imparted on the blades by a scanning a laser beam, the laser power required for driving a microturbine is one thousandth of that for a polymeric microrotor.

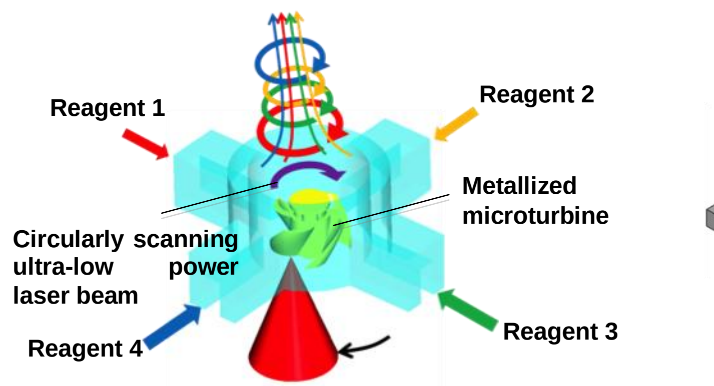



*Figure 1. Active micromixer using a laser-driven metallized microturbine. By scanning an ultralow-power laser beam, the microturbine can be rotated efficiently.*

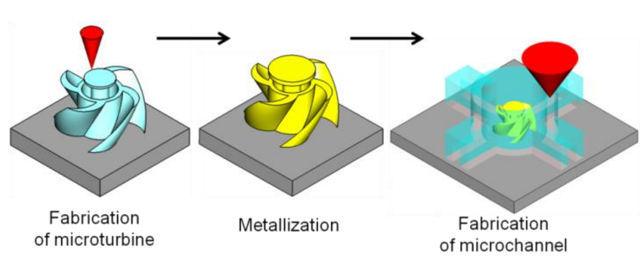
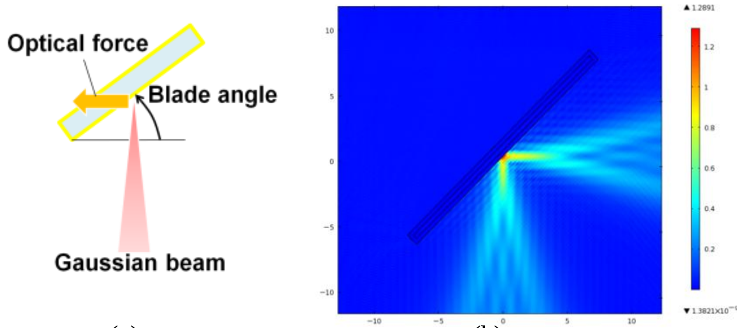



*Figure 2. Fabrication process of an active micromixer.*




(a) (b)

*Figure 3. Analysis of optical force exerted on a metallized blade. (a)Simulation model (b) Electromagnetic field around a metallized blade tilted at 45°.*

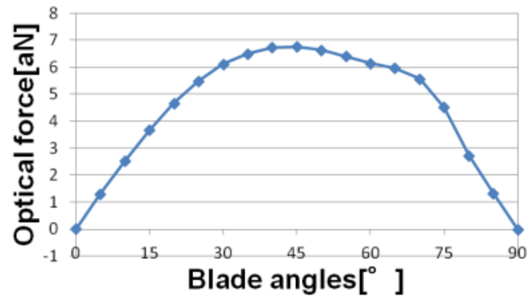
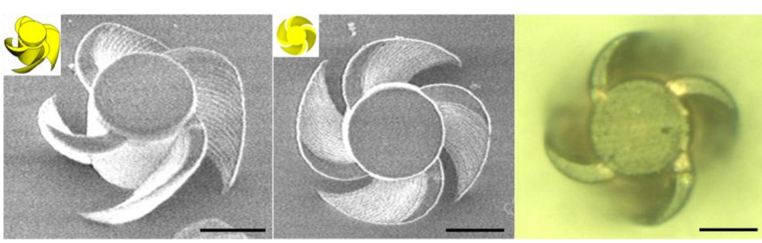



*Figure 4. Dependence of net lateral optical force on blade angle.*

Figure 2 shows the fabrication process of an active micromixer. The details of the process are as follows: (Step 1) A microturbine without any supporting parts is fabricated on a glass substrate by two-photon microfabrication. (Step 2) The movable micropart is metallized by electroless copper plating. (Step 3) A microchannel is fabricated on the glass substrate around the metallized microturbine by two-photon microfabrication. As a result, an active micromixer can be constructed. By rotating the metallized microturbine, multiple reagents are sucked from multiple inlets and then are mixed in the outlet channel.

## ANALYSIS OF OPTICAL FORCE EXERTED ON A METALLIZED BLADE

We investigated the optical forces exerted on microturbines with different blade angles by using two-dimensional electromagnetic analysis in order to maximize the rotation efficiency of the microturbine. Figure 3 (a) shows the side view of a tilted metallic blade irradiated by a Gaussian laser beam (wavelength: 633 nm, beam waist: 699 nm). In this model, a polymeric blade is coated with copper layer (thickness: 324 nm). Figure 3 (b) shows the electromagnetic field when a laser beam is focused on the blade tilted at a 45° angle. We calculated the net lateral force generated by repulsive force when a laser beam is focused on the center of the blades with different blade angles. Figure 4 shows the blade angle dependence of the net lateral force. From the result, we found that the maximum lateral force was obtained at a blade angle of 45°. Since the incident laser beam is totally reflected at the surface of the copper layer, the blade can be rotated efficiently.



(a) (b)

Figure 5. *Metallized microturbine produced by two-photon microfabrication and electroless copper plating. (a) SEM images (b) Optical image. Each scale bar is 10 µm.*

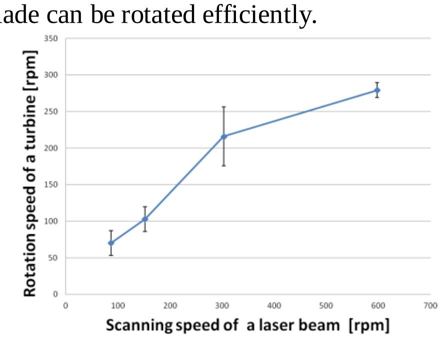



*Figure 6. Rotation speed of a microturbine vs. scanning speed of a laser beam (laser power : 0.7 mW).*

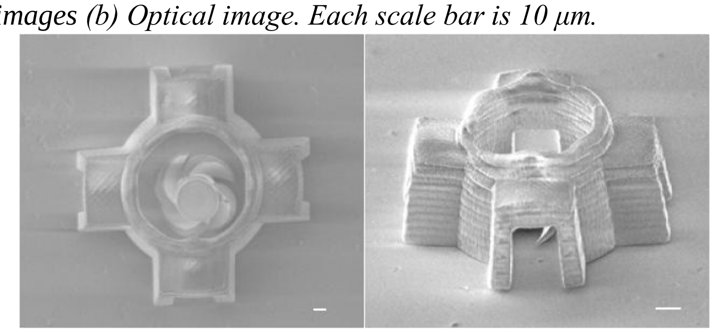


*Figure 7. SEM images of an active micromixer (a) Top view (b) Birds-eye view. Each scale bars is 10 µm.*

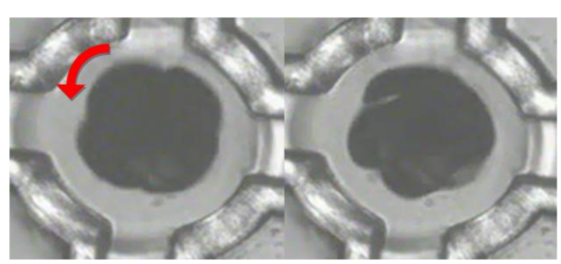


*Figure 8. Rotation of a metallic microturbine in a microchannel.*

## FABRICATION OF A METLLIED MICROTURBINE

A microturbine with blades tilted at a 45° angle was fabricated by two-photon microfabrication and electroless copper plating. Figure 5 shows SEM and optical images of a metallized microturbine (diameter: 40 μm). The tilted blade is curved so that a focused laser beam is reflected outside of the microturbine, enabling us to achieve highly-efficient continuous rotation of a microturbine owing to unidirectional optical torque.

## EXPERIMENTAL VERIFICATION OF THE ROTATION OF A METALLIZED MICROTURBINE

We rotated the metallized microturbine by scanning a He-Ne laser beam (wavelength: 633 nm). The microturbine was located in glycol ether ester. The metallized microturbine could be rotated at a laser power of 0.7 mW under the objective lens. The orbital radius of the scanning laser beam was 15 μm. We investigated the rotation speed of the microturbine with different scanning speeds of the laser beam. Figure 6 shows the dependence of the rotation speed of the microturbine on the scanning speed of a laser beam. The rotation speed of the microturbine is proportional to the scanning speed of a laser beam. The maximum rotation speed achieved at 273 rpm at a scanning speed of laser beam of 603 rpm. Use of repulsive force made possible to rotate metallized microturbines at a laser power of less than 1 mW.

## DEMONSTRATION OF AN ACTIVE MICROMIXER USING A METALLIZED MICROTURBINE

We fabricated an active micromixer consisting of a microturbine and a microchannel by two-photon microfabrication. Figure 7 shows SEM images of an active micromixer. The microchannel was fabricated around a metallized microturbine by two-photon microfabrication. The metallized microturbine was driven in the microchannel by scanning a He-Ne laser beam. Figure 8 shows the rotation of a metallized microturbine in the microchannel. To demonstrate fluid mixing, silica microparticles (diameter: 2 μm) were dispersed around the micromixer, and then the microturbine was rotated by scanning a laser beam. As a result, the microparticles quickly aggregated around the inlets of the mixer, demonstrating that the rotation of the metallized microturbine can generate flow inside the microchannel. We also observed thermal heating effects during laser irradiation. In the near future, we will analyze the mechanism of flow generation during rotating a microturbine by scanning a laser beam.

## CONCLUSION

We developed a metallized microturbine by two-photon microfabrication and electroless copper plating. The metallized micromachines can be driven by an ultralow-power laser beam (< 1 mW) because a large repulsive force is generated on the metallic blade due to the reflection of a laser beam. In addition, we succeeded in rotating the microturbine inside the microchannel, and generating flow around the microturbine. In the near future, optically driven metallized micromachines such as micromixers and micropumps will be applied to low-cost, high-performance, lab-on-a-chip devices.

## ACKNOWLEDGEMENTS

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## REFERENCES

[1] N.-T. Nguyen and Z. Wu, "Micromixers—a review," J. Micromech. Microeng. **15**, R1 (2005).
[2] V. Hessel, H. Lowe, F. Schonfeld, "Micromixers—a review on passive and active mixing principles", Chemical Engineering Science **60**, 2479 (2005).
[3] H. Ukita, "A shuttlecock optical rotator-its design, fabrication and evaluation for a microfluidic mixer," IEEE Journal of Selected Topics in Quantum Electronics **8**, 111 (2002).
[4] P. Galajda and P. Ormos, "Complex micromachines produced and driven by light," Appl. Phys. Lett. **78**, 249 (2001).
[5] S. Maruo, "Optically Driven Micromachines for Biochip Application," *Nano- and Micromaterials Series: Advances in Materials Research* , Vol. 9, Eds. K. Ohno, M. Tanaka, J. Takeda, Y. Kawazoe, (Springer 2008) 291.
[6] S. Maruo, A. Takaura, and Y. Saito, "Optically driven micropump with a twin spiral microrotor," Optics Express **17**, 18525 (2009).
[7] T. Ikegami, M. P. Stocker, K. Monaco, J. T. Fourkas, and S. Maruo, "Fabrication of three-dimensional metallized movable microstructures by the combination of two-photon microfabrication and electroless plating," Jpn. J. Appl. Phys., **51**, 06FL17 (2012).

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