The Formation of Micro-glass Ball and Its Applications

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Abstract

This paper demonstrates a novel way of forming high precision micro-sized spheres using surface tension. A glass fibre with a diameter of ϕ9µm and an optical fibre with a diameter of ϕ50µm were used. YAG laser (λ=1064nm) and CO_2 laser (λ=10.59µm) were used to irradiate the fibres. A processing system was constructed and the success rate of forming micro-glass balls at optimum conditions was 100%. We measured the roundness of the spheres and from the best result, glass fibres have a roundness of 43nm and optical fibres have a roundness of 81nm.

1 Introduction

In recent years, product miniaturisation has increased the need for high-precision micro-spheres as seen in the need for micrometre precision measuring probes in the measuring apparatus of MEMS parts. The conventional method of manufacturing spheres involves grinding, lapping, and finally polishing the glass. Additionally, to manufacture a micro-sphere probe, the process of accurately bonding the sphere to the stylus is required. Both processes are time consuming and require a high level of skill to obtain high precision finishes. Therefore manufacturing micro-sized spheres will be more difficult. In this paper, we propose a new laser processing method of forming high precision micro-glass sphere probes.

2 Formation Mechanism of Micro-glass ball

In the micro world, surface tension is more dominant than gravity [1]. To further understand this theory, a fibre's capillary length, κ^{-1} is calculated using equation 1;

$$\kappa^{-1} = \sqrt{\frac{\gamma}{\rho g}} \qquad (1)$$

Considering that the surface tension of silica glass at 1200°C is γ=356mN/m and the density, ρ is 2555kg/m^3, therefore capillary length is found to be 3.77mm. Hence by melting the tip of a micrometre-sized fibre (Figure 1), it is possible to form micro-sized spheres using surface tension.

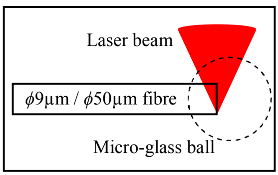

Figure 1: Micro-glass ball formation using laser

3 Formation of micro-glass spheres using YAG Laser (λ=1064nm)

3.1 Experimental setup and procedure

In this experiment, YAG laser was selected because its focused beam emits a high energy density beam which is ideal for high precision processing. Glass fibres with a diameter of ϕ9µm were used. Even if SiO_2 does not absorb the YAG laser, glass fibres does contain elements (e.g. Al_20_3=16wt%) which may absorb the laser. Experiment was done with and without an absorbent. The YAG laser was irradiated at the tip of the glass fibre to melt the fibre and form a micro-glass ball. Laser power was set at 2.4W and with an objective lens (NA=0.46), the beam spot size diameter at focal point was 26µm. After the fibre was irradiated, Scanning Electron Microscope (SEM) was used to evaluate the resulting sphere. We also measured the roundness of the micro-glass balls using a non-contact contour measuring instrument (MLP-2) provided by Mitaka Kohki Co., Ltd.

3.2 Results

Without an absorbent, the success rate of forming the micro-glass balls is a low 25%. This was probably due to the fibre not absorbing the laser enough to form a sphere. After the spheres were formed, we assessed the quality using SEM and the surface was found to be smooth. We then deposited an absorbent to increase the absorption rate and the success rate increased to 87.5%. Then, by controlling the amount of melted fibre, we were able to form micro-glass balls with different sizes (Figure 2). The roundness of the micro-glass balls were measured using a non-contact contour measuring instrument. A ϕ40µm micro-glass ball without coating had the best result with roundness of 43nm.

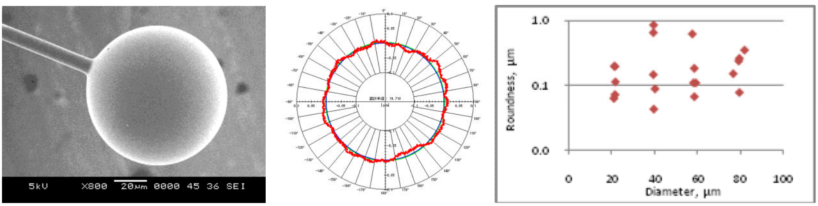

Figure 2: Micro-glass ball ϕ80µm (left), Roundness measurement, 43nm (right)

We have shown that it is possible to form a micro-glass ball using YAG laser but the biggest problem is the need of an absorbent as glass barely absorb the laser. However this rendered the spheres with irregular blotched surfaces. This was probably due to the gold molecule became massed together with the glass. Furthermore, continuous irradiation removes the absorbent layer and forming a sphere with bigger sized fibres will become more difficult.

4 Formation of micro-glass spheres using CO_2 Laser (λ=10.59µm)

4.1 Experimental setup and procedure

To improve the quality and success rate of forming micro-glass balls, CO_2 laser was used since the wavelength is greatly absorbed by silica glass. A stable and efficient processing system consisting of a processing part and an observation part (Figure 3) was constructed. CO_2 Laser was irradiated at the tip of the glass fibre where the beam was focused by f-θ lens where the spot size at focal point was 205µm. The three experiment variables were irradiation times (1~5times), laser power (0.5W~20W) and the galvanometer's scanning speed (5mm/s~500mm/s) which was swept at 6mm in length. A fibre was set onto a base plate and by observing the LCD monitor, the sample was carefully placed onto the XY-axis stage of the observation section. The stage was then moved towards the processing section where CO_2 Laser was scanned using a pair of galvanometer mirrors. Both the stage and galvanometer mirrors were controlled using a computer. After processing the fibre, we evaluated the results using the same method as section 3.

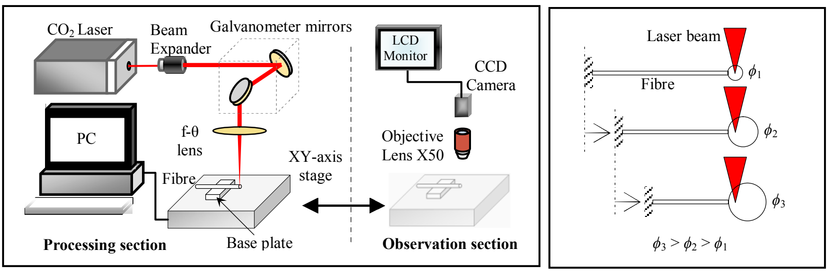

Figure 3: Experiment apparatus (left), number of irradiation increases ball size (right)

4.2 Results

The system we constructed successfully formed micro-glass balls. By setting the laser power at 3.27W~12.36W and scanning speed at 5mm/s~500mm/s, we found that the fibre bent towards the irradiating laser. This was probably due to the CO_2 laser's beam profile which emits Gaussian beam where the output power is higher towards the centre and lower towards the outer circumference. By using a higher output power (19.65W) and a faster scanning speed (500mm/s) an unbent fibre with a sphere was successfully formed. The average size of the spheres was ϕ40µm. A ϕ36µm micro-glass ball had the best result with roundness of 43nm. Considering the excellent properties of optical fibre and its promise for new applications, we also attempted to form a micro-glass ball on the tip of an optical fibre with a diameter of ϕ50µm. We found that the micro-glass ball failed to form with similar experimental conditions. This was probably due to the larger optical fibre requiring more energy to absorb in order to melt and form a sphere. Based on this hypothesis, we then adjusted the scanning speed to 10mm/s to match the properties of the optical fibre and successfully formed micro-glass balls. However, we found that the sphere did not form in the middle of the axis. This was solved by scanning the fibre 3 times and the size of the sphere increases with each irradiation. From the results, the micro-glass balls diameter averaged at ϕ171.7µm with a success rate of 100%. Furthermore a micro-glass ball with ϕ176µm in diameter has the best roundness of 81nm. According to literature [2] the relative precision values of both glass fibres and optical fibres are (1.2×10^{-3}) and (5.0×10^{-4}) which puts it in the ultra-precision and nanotechnology levels respectively.

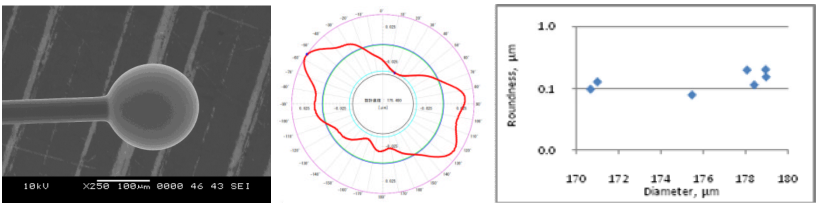

Figure 4: Micro-glass ball ϕ170µm (left), Roundness of ϕ175µm ball, 81nm (right)

5 Conclusion

We have successfully proved that by melting the tip of glass fibres and fibre optics using lasers, micro-glass balls with excellent roundness can be formed by surface tension. Furthermore, by using a CO_2 laser the success rate of forming micro-glass balls increased to 100%. In the future, we plan to use the micro-glass balls to develop real world applications such as fibre optics sensors, micro-probes for use in the field of metrology and in the field of laser processing.

References

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[2] Shibata, J. (2011). *Sphere.* Japan: Gihodo Books. ISBN: 978-4-7655-4467-2