Dynamically Adjustable Annular Laser Trapping for Sperm Chemotaxis Study

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Abstract: A diameter-adjustable annular laser trapping system based on axicons was designed for sperm chemotactaxis and fertilizability characterization. Experiment on microspheres testified the feasibility and performance of the system and was consistent with theoretical expectation.

OCIS codes: (140.7010) Trapping; (170.4520) Optical confinement and manipulation

1. Introduction

Laser trapping has been widely applied for the confinement and physiological study of biological cells [1-2] and organelles [3]. In mammal fertility research, single spot laser tweezers were successfully utilized to trap individual sperm and quantitatively evaluate the motile force generated by a sperm [4, 5]. With the help of laser tweezers, the relationship between sperm motility and swimming behavior were revealed [5] and the effects of medical approaches on sperm activity were investigated [6, 7].

As sperm chemotaxis draws increasing interests in fertility research, the study on sperm-egg communication may help to explain infertility and provide new approaches to contraception [8]. While single spot laser trap can only be used to investigate one target at a time, greatly limiting the experimental efficiency and throughput, a ring-shaped laser trap, if feasible, could not only trap multiple samples at the same time, but also provide an equal-distance (from the center) condition, which is essential and perfect for biological tropism study.

Here we present a novel annular laser trap based on axicons for sperm chemotaxis study. Experiment with 15 micron polystyrene spheres shows the feasibility and performance of the system. With chemoattractant located in the center and sperms approaching from all directions, the annular laser trapping could serve as a sperm sifter for fertility sorting. When an additional pair of axicons is introduced into the optics, the first of which shifts along the optical axis back and forth, the diameter of the annular trap can be dynamically tuned from 130 micron to 428 micron, providing a real time variation on experimental condition for critical power analysis. This new scheme of optical trapping will bring high efficiency and fresh perspective to a vast variety of bio-tropism (phototaxis, geotaxis, galvanotaxis, etc.) research.

2. Design of optical system

2.1 Annular laser trap

According to earlier research [2], the deviation of the trapping spot from the optical axis is proportional to the inclination of the input collimated beam. A uniform annular trapping requires incident light be composed of collimated beam from all directions with the same angle to the optical axis, i.e. the input light be a cone of collimated beam intersecting at the back aperture of objective. The thickness of the cone should be equal to the diameter of the back aperture so that the numerical aperture of the objective is fully used, and the beams are focused tight enough to guarantee high gradient forces. This could be achieved with an axicon.

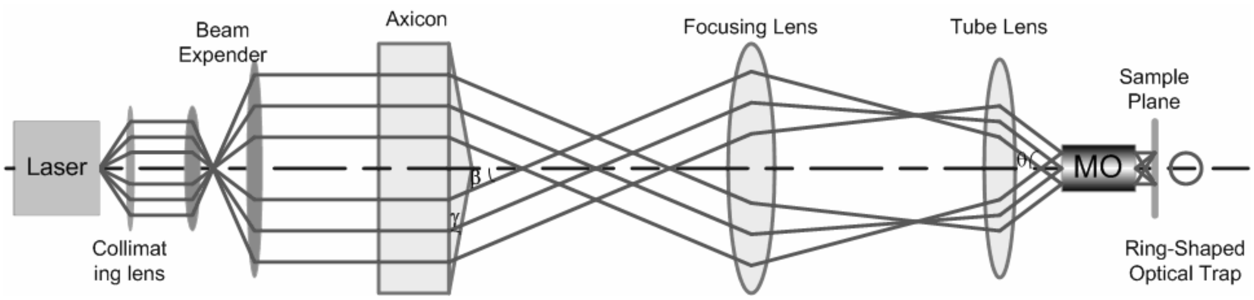

Fig. 1. Experimental scheme for annular laser trapping (not to scale)

As shown in Fig. 1, laser beam at 1064 nm wavelength from a Nd:YAG laser (Spectra-Physics) was collimated, expanded to 6 mm diameter and incident to the front facet of an axicon lens (Del Mar Ventures) (γ =10°, n=1.51). The beams exiting from the axicon was bended toward the optical axis at $\beta = arcsin(n sin\gamma) - \gamma$=5.2°. The cone of collimated beams was focused into a ring by a focusing lens, and then imaged to the conjugate sample plane via the tube lens-objective combination. Experimentally, the side port of the inverted microscope (Zeiss) was used, and the focusing lens was chosen as f_{FL}=50mm, so that together with the embedded tube lens (f_{TL}=164.5mm), the beams incident microscope objective (Zeiss, M=63X, NA1.40, oil immersion) at inclination θ=1.51°, corresponding to a focus ring of diameter $d=2f_{EFL}tan(\theta)$=137 micron at the sample plane, where the effective focal length $f_{EFL}=f_{TL}/M$.

2.2 Diameter-adjustble annular laser trap

With fixed total power, changing the size of the annular trap leads to a change of trapping power per spot. This could be used for quantitative evaluation, sorting sperms with different levels of fertilizability.

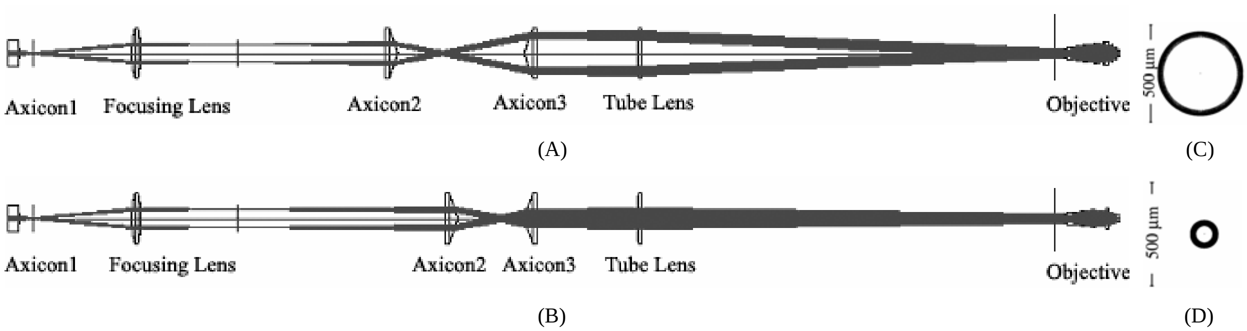

Fig. 2. ZEMAX simulations of adjustable annular laser trap with 40X NA1.30 oil immersion objective. Layout for (A) maximal ring size, (B) minimal ring size, and Sample plane spot diagram for (C) maximal ring, (D) minimal ring.

The size of the focus ring is determined by the inclination of input collimated beams. To change this angle dynamically, two more axicons were added (axicon2 and 3 in Fig. 2). ZEMAX Simulations with 40X NA1.30 oil immersion objective, f_{FL}=100mm, f_{TL}=400mm show that with all other elements fixed, shifting axicon2 along the optical axis ≤30 mm will result in a considerable input angle change (Fig. 2 (A) and (B)) and a trapping ring diameter change from 130 micron (Fig. 2 (D)) to 428 micron (Fig. 2 (C)).

3. Experimental result

To verify the feasibility of the annular laser trap, preliminary experiment was conducted with 15 micron polystyrene spheres (Duke Scientific). With 63X NA1.40 oil immersion objective (Zeiss), the video frame in Fig. 3 shows the trapping of a continuous ring of microspheres on the sample plane at laser output power as low as 1.00 W. The size of the ring determined from the screen is about 140 micron, which agrees with the theoretical expectation.

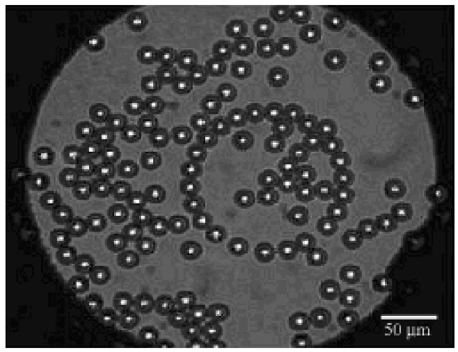

Fig. 3. Video frame of annular laser trapping of 15 micron polystyrene spheres in water with 63X NA1.40 oil immersion objective.

The result promises sperm chemotaxis study in the near future. Further experiment will be conducted with adjustable annular trap and more results will be presented on the conference.

4. Conclusions

An optical system for dynamically adjustable annular laser trap was designed. Simulation results show a diameter adjustment range of 300 micron. By varying the diameter of the trap, critical power required to trap sperms with different fertilizability (chemotaxis and motility) could be characterized for sperm sorting.

5. References

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