Whitepaper

Shaping of light beams along curves in three dimensions

***Abstract**: Researchers at the University Complutense Madrid (UCM) have recently presented a method for generating laser beams whose intensity and phase are prescribed along arbitrary 3 dimensional curves. Using a **ventus 532** 1.5W laser from Laser Quantum, the beams are focussed to the diffraction limit with high intensity and controlled phase gradients that make them attractive in such applications as laser micro-machining and optical trapping.*

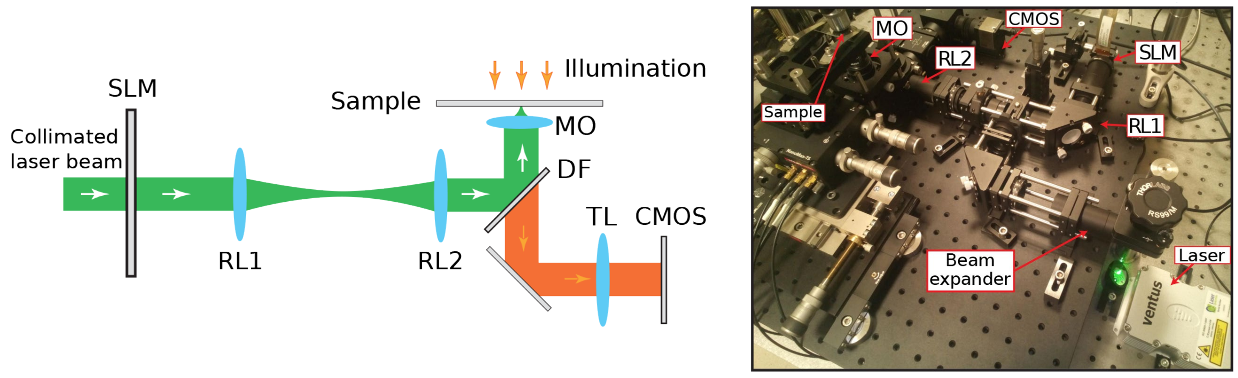

Figure 1: Schematic of the 3D optical trap setup
MO=Microscope objective, RL=Relay lenses, DF=dichroic filter, TL=tube lens, CMOS=camera.
Laser = ventus 532nm 1.5W (Laser Quantum, Stockport UK)

Introduction

Numerous methods have been developed to shape a coherent laser beam, but most are confined to two dimensions and require complex algorithms for solving inversion problems, and tend to only shape the beam's intensity. Designing beams with prescribed intensity and phase in three dimensions is more challenging, but has important applications in fields such as imaging, micro-machining and optical trapping and manipulation. These optical "tweezers" have been used to trap small particles such as viruses, cells, and even DNA and their use is becoming more important in the bio-molecular disciplines due to the fine measurements that can be achieved and the low risk of the trapping mechanism affecting results.

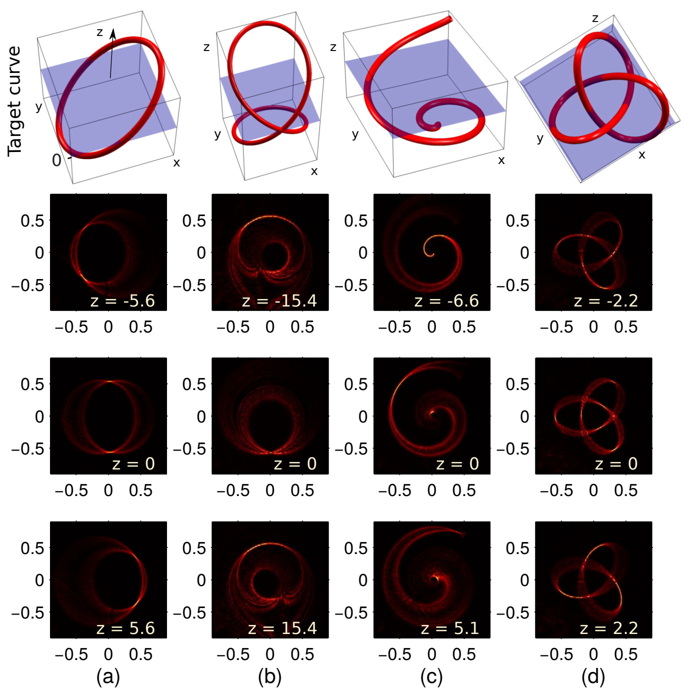

Figure 2: Experimental results. Intensity distributions before, at and after the focal plane

Small particles are held in an optical trap by intensity gradients at the focal point of the beam. Two-dimensional traps only exhibit the required gradient in the plane transverse to the optical axis, with gradients in the axial direction being too weak. Additionally, while the intensity gradient is key to trapping a particle, phase gradients control its position and motion within the trap.

Prof Jose Rodrigo and colleagues at UCM have described a method of creating a 3-dimensional trap whose intensity distribution follows a prescribed 3-dimensional curve. The experimental setup required for the trapping beam generation involves a phase only hologram that encodes the amplitude and phase of the **ventus 532** laser beam. The input collimated beam is modulated by the hologram displayed in a programmable spatial light modulator (SLM) and then is relayed into the back aperture of a microscope objective lens (Fig 1.). This lens highly focuses the beam on the sample into a chamber created on a standard microscope slide. Using this method, researchers from UCM demonstrated complex 3-dimensional traps (Fig. 2) such as (a) tilted ring, (b) a Viviani's curve, (c) and Archimedean spiral and (d) a tre-foil knot. The bottom three rows are slices of a volumetric measurement of these traps that can be viewed in the video log by following this link.

Particles trapped in these curved beams perform stable motion around the trap, even moving against the light scattering forces, thus working as a tractor beam. This motion is due to prescribed phase gradients within the holographic trap. The direction of particle motion around the closed curve traps, for example, can be switched from clockwise to anti-clockwise by changing the direction of the phase gradient. In the Archimedean spiral, the control of the up or down motion of the particles can also be performed as in the case of closed curve traps.

Optical trapping is a demanding application for the laser as many aspects of the laser's performance are critical to the optimal performance of the trap, including power stability, beam pointing stability and beam shape. This is a strong application area for Laser Quantum whose lasers are used in many optical manipulation laboratories around the world, including Prof Rodrigo's research team.

Prof Rodrigo and colleagues have demonstrated a simple and effective technique to create coherent scalar beams whose intensity and phase follow prescribed open or closed 3 dimensional curves using a **ventus 532** laser (Fig 3). The trapping of micron-sized particles has been demonstrated experimentally and their forward and backward motion controlled according to the phase gradient of the focused beam.

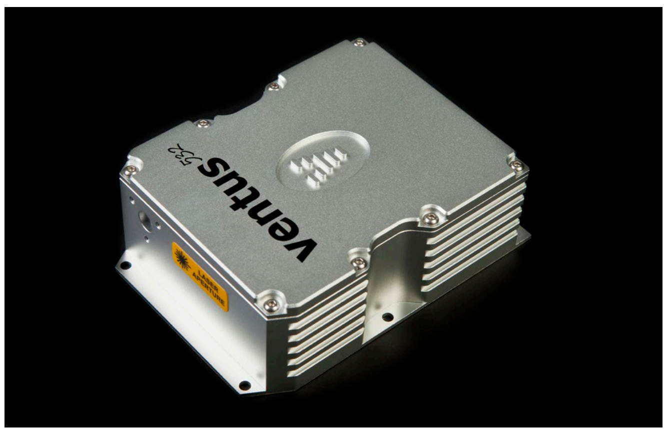

Figure 3: ventus laser

With thanks: Prof Jose Rodrigo et al. Universidad Complutense de Madrid, Facultad de Ciencias Fisicas.
Full paper reference: José A. Rodrigo, Tatiana Alieva, Eugeny Abramochkin, and Izan Castro, "Shaping of light beams along curves in three dimensions," Opt. Express 21, 20544-20555 (2013).

For further information please contact Niccola Seddon, Marketing Coordinator, e: nseddon@laserquantum.com