Femtosecond Laser Nanostructuring for High-Topological Charge Vortex Tweezers with Continuously Tunable Orbital Angular Momentum

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It is well known that the light carries linear and angular momentum that can be transferred to the irradiated objects. Angular momentum of the beam is comprised of spin angular momentum (SAM) and orbital angular momentum (OAM). SAM is associated to the beam's polarization and is always intrinsic. OAM comes from the azimuthal phase variations of the beam and can be both extrinsic and intrinsic. The beam with helical phase $\varphi = l\phi$, where φ is phase, ϕ is polar angle and l is positive or negative integer number, possesses well-defined OAM with $l\hbar$ [1]. Such beams are often refered to as optical vortices and are exploited in optical tweezer experiments enabling the rotation of trapped particles. Changing the wavefront's helicity, also the geometry of the beam is changed. The higher is $|l|$, the larger is the diameter of the beam. In order to change the total angular momentum of the beam, either the shape of the beam or the photon density has to be changed. As a result, the experiments which require fixed beam size and intensity are limited to fixed OAM. Recently, we implemented optical tweezers with tunable angular momentum, there OAM could be changed from -1 to 1 by controlling ellipticity of the incident laser beam. Here we extend this technology and demonstrate the generation of optical vortices of high topological charge up to 100 (Fig. 1(a)–(i)) using femtosecond laser written polarization converters (the S-waveplate) [2].

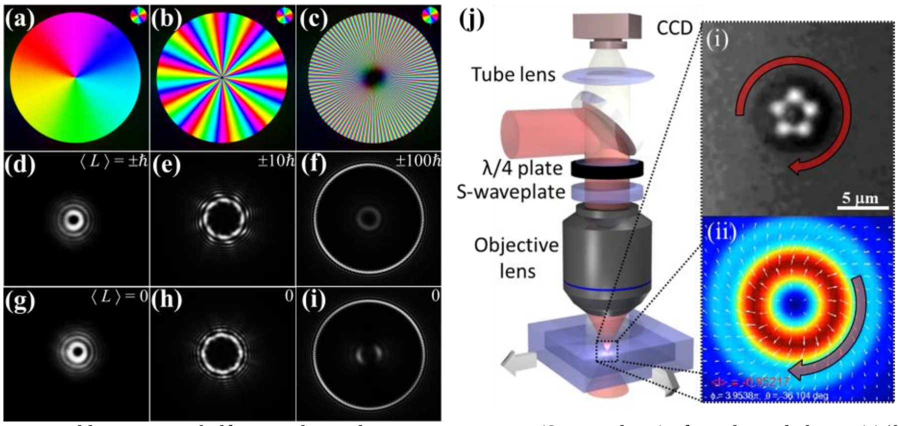

Fig. 1 Femtosecond laser written half-wave plate polarization converters (S-waveplates) of topological charge (a) $|l| = 1$, (b) $|l| = 10$ and (c) $|l| = 100$ used for generation of optical vortices with tunable orbital angular momentum. (d) – (i) Figures show the corresponding laser beam profiles after the S-waveplates, when the incident polarization is (d) – (f) circular ($\langle L \rangle = \pm l\hbar$) and (g) – (i) linear ($\langle L \rangle = 0$). (j) Schematics of the experimental vortex tweezers setup. Inset figures show (i) the rotation of five trapped silica beads and (ii) corresponding calculated vortex intensity profile at particular OAM value. White arrows indicate the vectorial distribution of electric field.

The light transmitted though the S-waveplate undergoes adiabatic change in its polarization state and acquires an additional spatially variant phase term. The phase variation is imprinted by cyclic variation of slow axis orientation of the S-waveplate. This enables continuous optical phase shift without phase resets typically obtained with conventional diffractive optical elements. Combining this advantage with sub-micron resolution of ultrafast laser direct writing we can implement polarization converters for obtaining extremely high optical charges.

If left-handed (right-handed) circularly polarized light is transmitted through the S-waveplate, a right-handed (left-handed) circularly polarized right-handed (left-handed) optical vortex is generated with the topological charge $|l|$. The S-waveplate, depending on the handedness of the input polarization, transfers an OAM of $\pm l\hbar$ to the photons of incident beam (Fig. 1(j)). Within the incident polarization state varying from linear to circular, we control the torque from $\langle L \rangle = 0$ to $\langle L \rangle = \pm l\hbar$ transferred to the trapped silica beads [3]. The gradual transition from maximum OAM (defined by vortices topological charge) to zero is ensured keeping the beam shape and intensity constant.

References

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