P18 – Multiple Traps in a Counter-Propagating Optical Trap Configuration Based on Optical Phase Conjugation

K. Berghoff, M. Woerdemann
and C. Denz

Institut für Angewandte Physik,
Westfälische Wilhelms-Universität Münster
email: konradberghoff@uni-muenster.de

Counter-propagating laser beams that compensate for axial scattering forces resulting from radiation pressure of light are widely used for acceleration and trapping of micro- to nanometer-sized particles [1]. One elegant method to realize such counter-propagating optical traps is based on a photorefractive phase-conjugating mirror which inverts wave vector and phase of incoming light [2, 3]. For counter-propagating optical traps, the laser beam is phase-conjugated after transmission through the intended trapping plane. The resulting phase conjugate beam travels back the optical path and exactly overlaps with the first beam. Hence, a counter-propagating beam trap builds up, which is intrinsically self-aligning and can be generated with low numerical aperture microscope objectives. This is important for application which require long working distances such as generalized phase contrast [4] or when low intensities are needed (trapping of living cells [5]).

We successfully implemented a single beam optical trap configuration based on optical phase conjugation and currently investigate a dual trap geometry which provides trapping of two particles simultaneously. These optical traps are characterized and compared with competing methods by measurement of trap stiffness and trapping potential wells.

The current experimental set-up should be extendable to complex light fields such as beams carrying angular momentum or non-diffracting beams. Coherent superposition of the incoming beam and its counter-propagating phase conjugate in the trapping plane can lead to expanded novel 3D-trapping structures.

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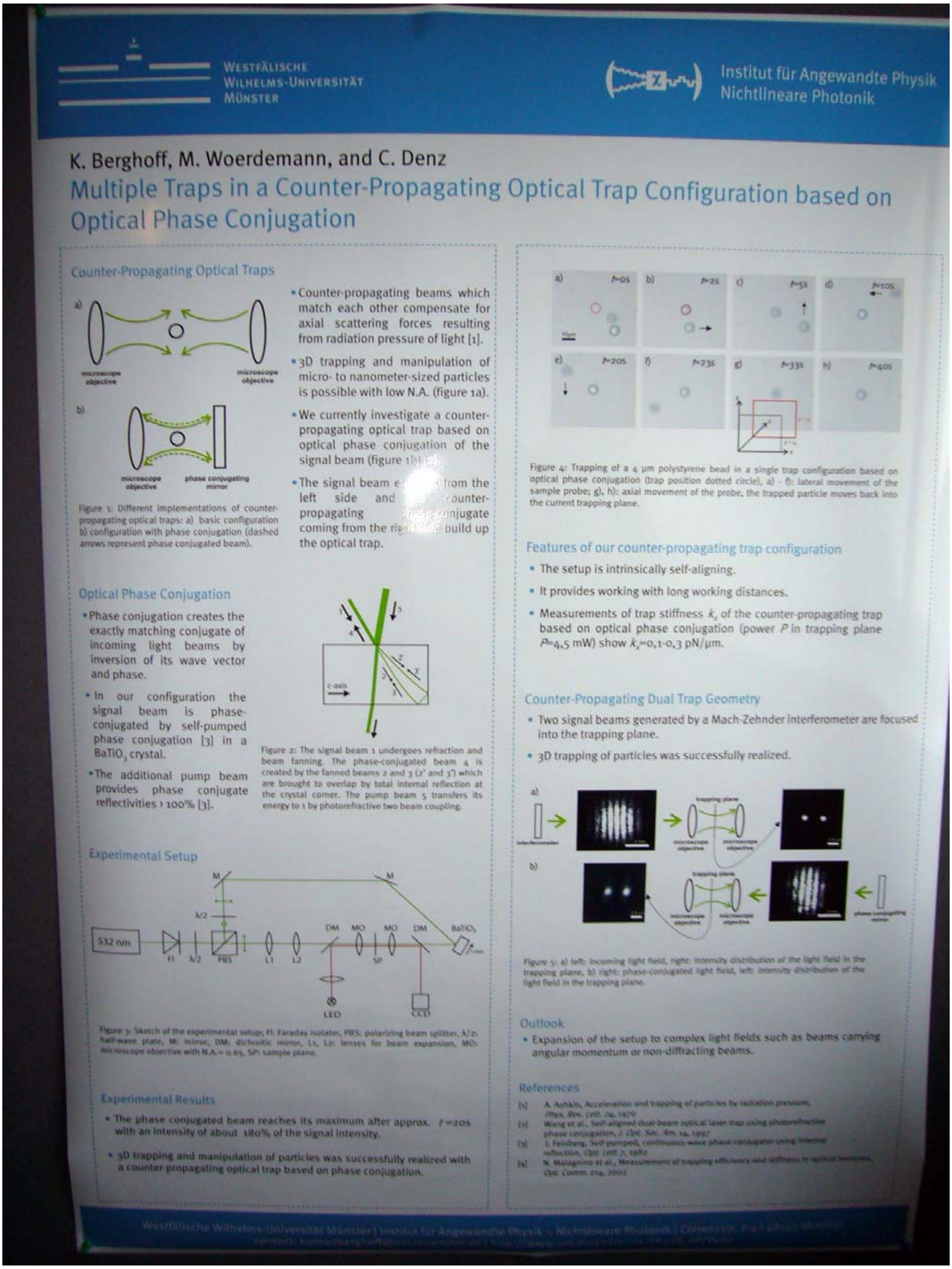
Westfälische Wilhelms-Universität Münster
Institut für Angewandte Physik
Nichtlineare Photonik
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Counter-Propagating Optical Traps
Counter-propagating beams which match each other compensate for axial scattering forces resulting from radiation pressure of light [1].
3D trapping and manipulation of micro- to nanometer-sized particles is possible with low N.A. (figure 1a).
Figure 1: Different implementations of counter-propagating optical traps: a) basic configuration b) configuration with phase conjugation (dashed arrows represent phase conjugated beam).
Optical Phase Conjugation
Phase conjugation creates the exactly matching conjugate of incoming light beams by inversion of its wave vector and phase.
In our configuration the signal beam is phase-conjugated by self-pumped phase conjugation [3] in a BaTiO3 crystal.
The additional pump beam provides phase conjugate reflectivities > 100% [3].
Figure 2: The signal beam 1 undergoes refraction and beam fanning. The phase-conjugated beam 4 is created by the fanned beams 2 and 3 (2' and 3') which are brought to overlap by total internal reflection at the crystal corner. The pump beam 5 transfers its energy to 1 by photorefractive two beam coupling.
Experimental Setup
532 nm
LED
CCD
Figure 3: Sketch of the experimental setup; FI: Faraday isolator, PBS: polarizing beam splitter, λ/2: half-wave plate, M: mirror, DM: dichroitic mirror, L1, L2: lenses for beam expansion, MO: microscope objective with N.A.= 0.65, SP: sample plane.
Experimental Results
The phase conjugated beam reaches its maximum after approx. t=20s with an intensity of about 180% of the signal intensity.
3D trapping and manipulation of particles was successfully realized with a counter-propagating optical trap based on phase conjugation.
Figure 4: Trapping of a 4 µm polystyrene bead in a single trap configuration based on optical phase conjugation (trap position dotted circle). a) - f): lateral movement of the sample probe; g), h): axial movement of the probe, the trapped particle moves back into the current trapping plane.
Features of our counter-propagating trap configuration
The setup is intrinsically self-aligning.
It provides working with long working distances.
Measurements of trap stiffness k of the counter-propagating trap based on optical phase conjugation (power P in trapping plane P=4,5 mW) show k=0,1-0,3 pN/µm.
Counter-Propagating Dual Trap Geometry
Two signal beams generated by a Mach-Zehnder interferometer are focused into the trapping plane.
3D trapping of particles was successfully realized.
Figure 5: a) left: incoming light field, right: intensity distribution of the light field in the trapping plane, b) right: phase-conjugated light field, left: intensity distribution of the light field in the trapping plane.
Outlook
Expansion of the setup to complex light fields such as beams carrying angular momentum or non-diffracting beams.
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