P17 – Self-Pumped Phase Conjugation of Light Beams Carrying Orbital Angular Momentum

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Light beams with screw phase dislocations are known to carry optical orbital angular momentum. A novel field of applications for these beams are optical tweezers where angular momentum is transferred to microscopic samples e.g. to drive micro machines.

A screw phase dislocation (optical vortex) possesses a topological charge, equal to the integer m, where m is defined by the 2m phase change on any closed circuit around the dislocation center. The topological charge also indicates the optical orbital angular momentum, which is given as $m\hbar$ per photon. The sign of m is defined by the handiness of the screw-like surface of fixed phase in space. It is a well known and often used fact, that the sign of the topological charge of a vortex beam is reversed when it is reflected by a mirror. Since the direction of propagation also reverses in normal reflection, orbital momentum is conserved. The situation is different for a phase-conjugating mirror. Due to the time reversal property of the phase-conjugating mirror, the incident and reflected wavefront surfaces match perfectly. As a result, the topological charge does not change sign and the optical orbital angular momentum is reversed. Hence, the difference in angular momentum of $2m\hbar$ per photon needs to be transferred to the phase-conjugating mirror.

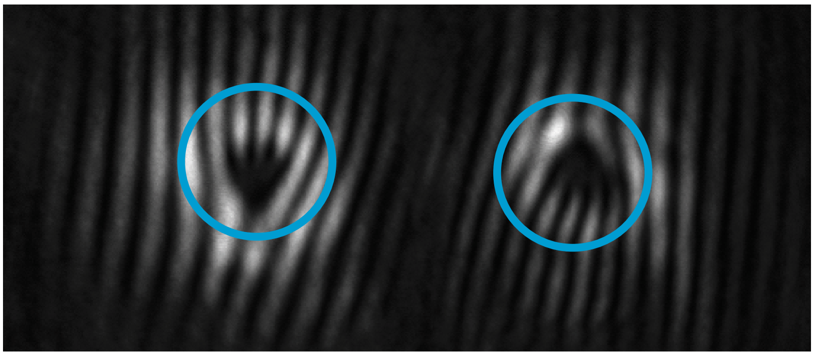
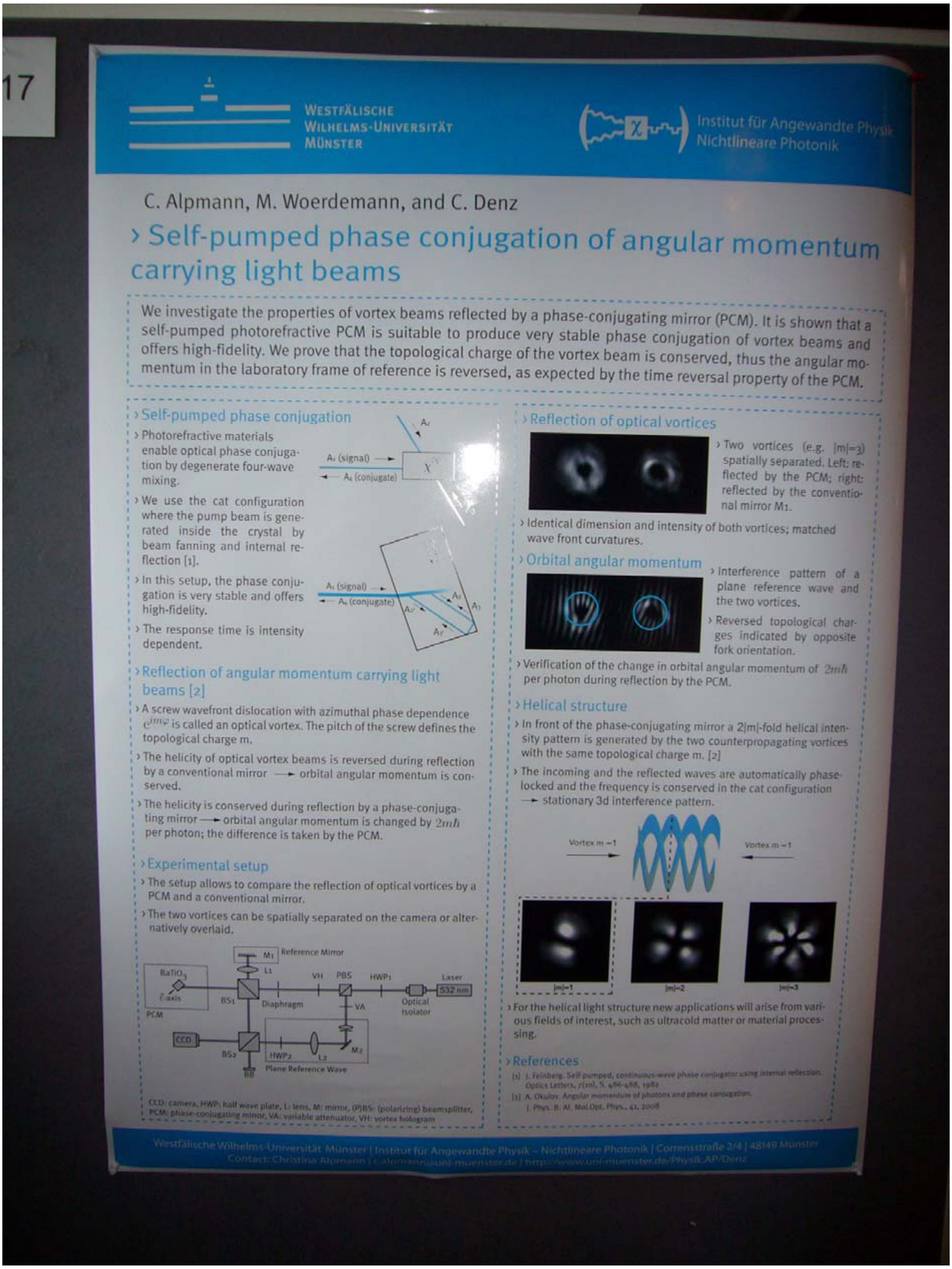


Figure 1 : Interference pattern of a plane wave and a vortex reflected by a phase-conjugating mirror (left) and a conventional mirror (right), respectively. It is clearly seen that the topological charge of the vortex is reversed. The circle indicates the center of the phase dislocation.

In this contribution we demonstrate a self-pumped photorefractive phase-conjugating mirror that is used to investigate these fundamental characteristics. It is shown that this implementation of a phase-conjugating mirror is suitable to produce very stable, high-fidelity phase conjugation of vortex beams. We directly compare the reflection properties of a conventional mirror to that of a phase-conjugating mirror. In front of the phase-conjugating mirror a stationary three dimensional interference pattern is created by two counter propagating vortices of equal charge. This three dimensional interference pattern is studied and applications in optical traps are suggested.



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› Self-pumped phase conjugation of angular momentum carrying light beams

We investigate the properties of vortex beams reflected by a phase-conjugating mirror (PCM). It is shown that a self-pumped photorefractive PCM is suitable to produce very stable phase conjugation of vortex beams and offers high-fidelity. We prove that the topological charge of the vortex beam is conserved, thus the angular momentum in the laboratory frame of reference is reversed, as expected by the time reversal property of the PCM.

› Self-pumped phase conjugation

- › Photorefractive materials enable optical phase conjugation by degenerate four-wave mixing.
- › We use the cat configuration where the pump beam is generated inside the crystal by beam fanning and internal reflection [1].
- › In this setup, the phase conjugation is very stable and offers high-fidelity.
- › The response time is intensity dependent.

› Reflection of angular momentum carrying light beams [2]

- › A screw wavefront dislocation with azimuthal phase dependence $e^{im\varphi}$ is called an optical vortex. The pitch of the screw defines the topological charge m.
- › The helicity of optical vortex beams is reversed during reflection by a conventional mirror → orbital angular momentum is conserved.
- › The helicity is conserved during reflection by a phase-conjugating mirror → orbital angular momentum is changed by $2m\hbar$ per photon; the difference is taken by the PCM.

› Experimental setup

- › The setup allows to compare the reflection of optical vortices by a PCM and a conventional mirror.
- › The two vortices can be spatially separated on the camera or alternatively overlaid.

CCD: camera, HWP: half wave plate, L: lens, M: mirror, (P)BS: (polarizing) beamsplitter, PCM: phase-conjugating mirror, VA: variable attenuator, VH: vortex hologram

› Reflection of optical vortices

- › Two vortices (e.g. |m|=3) spatially separated. Left: reflected by the PCM; right: reflected by the conventional mirror M_1.
- › Identical dimension and intensity of both vortices; matched wave front curvatures.

› Orbital angular momentum

- › Interference pattern of a plane reference wave and the two vortices.
- › Reversed topological charges indicated by opposite fork orientation.
- › Verification of the change in orbital angular momentum of $2m\hbar$ per photon during reflection by the PCM.

› Helical structure

- › In front of the phase-conjugating mirror a 2|m|-fold helical intensity pattern is generated by the two counterpropagating vortices with the same topological charge m. [2]
- › The incoming and the reflected waves are automatically phase-locked and the frequency is conserved in the cat configuration → stationary 3d interference pattern.

- › For the helical light structure new applications will arise from various fields of interest, such as ultracold matter or material processing.

› References

[1] J. Feinberg. Self-pumped, continuous-wave phase conjugator using internal reflection. Optics Letters, 7(10), S. 486-488, 1982
[2] A. Okulov. Angular momentum of photons and phase conjugation. J. Phys. B: At. Mol.Opt. Phys., 41, 2008

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