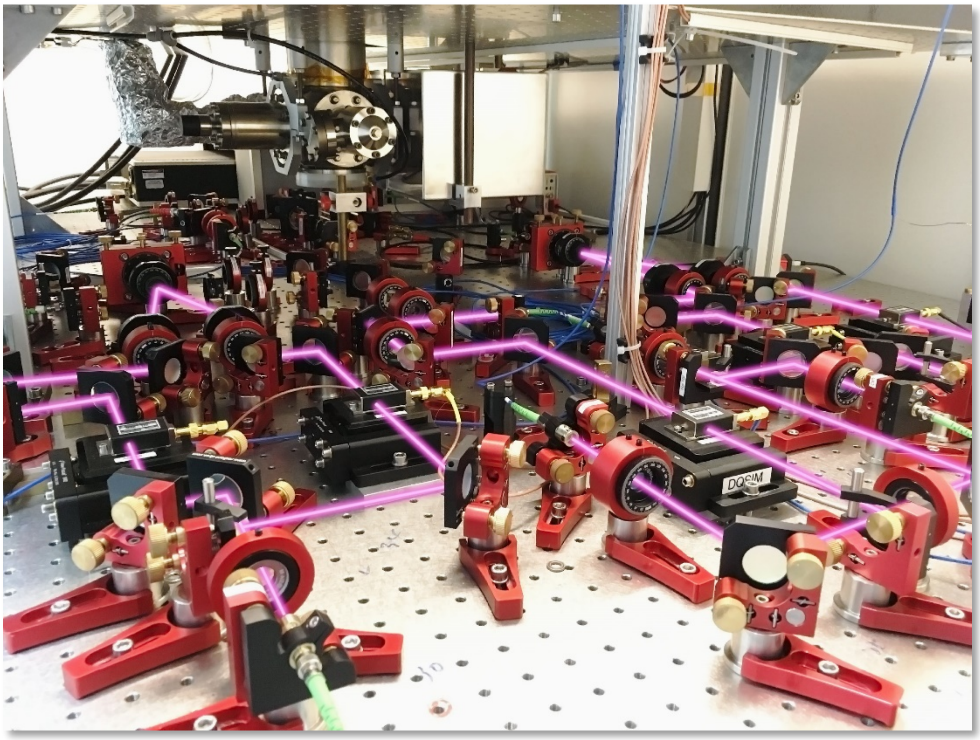
OSCAR[1] Reports–

an SFB/TR 185 quarterly magazine (I/2018)

Author: Prof. Dr. Stefan Linden



[1] stands for **O**pen **S**ystem **C**ontrol of **A**tomic and Photonic Matte**R;** funded by the Deutsche Forschungsgemeinschaft since July 01, 2016

Correlated-photon-pair emission from a cw-pumped Fabry-Perot microcavity (area A)

Emission of time-correlated photon pairs from a high-finesse optical Fabry-Perot microcavity under high-intensity cw pumping

T. F. Langerfeld, H. M. Meyer, M. Köhl

Phys. Rev. A **97**, 023822 (2018)

Correlated photon pairs are an important resource both for fundamental tests of quantum mechanics as well as for future applications of quantum technology. For instance, correlated photons could serve a “flying qubits” that connect the nodes of a distributed quantum network. In this scenario, interfacing of the photons with the “stationary qubits”, i.e., with atomic or solid state emitters, requires a precise control of the bandwidth and frequencies of the photons. An established method for the generation of correlated photon pairs is spontaneous parametric down-conversion (SPDC) in a nonlinear crystal. SPDC-sources with short crystals typically require pulsed laser equitation, leading to a photon bandwidth far exceeding the typical bandwidth of the atomic or solid state systems. In contrast, long crystals can significantly reduce the photon bandwidth but require strict compliance with the phase-matching conditions. The latter aspect often causes restrictions regarding the emission wavelengths and/or efficiencies.

T. F. Langerfeld and coworkers have demonstrated in their work a new source of time-correlated photon pairs. For this purpose, they have studied a high-finesse optical Fabry-Perot microcavity under high-intensity cw pumping. The cavity consists of a micro machined and coated end facet of an optical fiber as one mirror and a conventional planar mirror with identical coating as the second mirror. Spontaneous four-wave mixing in the coating of the mirrors resulted in the creation of time correlated photon pairs, whereby two photons from the pump light field are absorbed and a pair of photons with frequencies shifted by ±1 free spectral range relative to the pump frequency was emitted. The bandwidth of the photons was determined by the bandwidth of the microcavity.

In order to demonstrate the creation of time correlated photon pairs, the output of the Fabry-Perot cavity was monitored using a home-built grating spectrometer, a pair of single photon counting modules (SPCM), and a time-to-digital converter. The observed two-photon coincidence signal comprised a uniform background of spurious coincidences mainly caused by Raman scattering and an excess peak near zero-time delay between the counters resulting from the four-wave mixing process. As expected for a third order nonlinear process, the pair creation rate increased quadratically with the intracavity power.

The setup as presented in the work of T. F. Langerfeld et al. is not yet an efficient source of photon pairs. For an intracavity power of 19 W, about 200 photon pairs per hour were observed. However, the authors are currently working towards a significant increase of the rate. If successful, spontaneous four-wave mixing from a pumped high-finesse Fabry-Perot cavity might become an attractive scheme to build a photon-pair source with application in hybrid quantum systems.

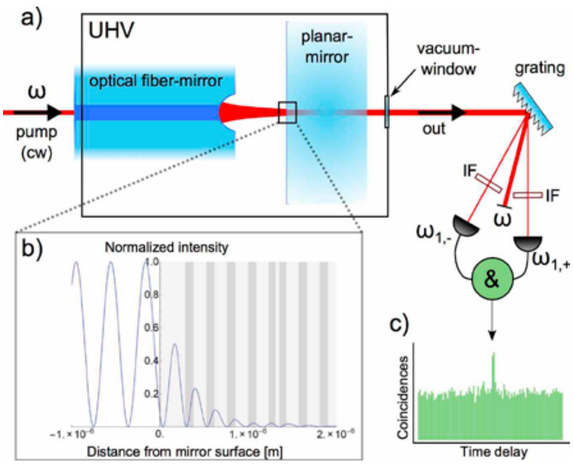


Fig. 1 (a) Scheme of the setup. (b) Calculated intensity distribution in the optical coating of the mirror. (c) Measured pair correlations.

Fast, High-Precision Optical Polarization Synthesizer for Ultracold-Atom Experiments (area A&C)

Technique for the precision synthesis of arbitrary polarization states of light with a high modulation bandwidth

C. Robens, S. Brakhane, W. Alt,
D. Meschede, J. Zopes, A. Alberti

Phys. Rev. Applied **9**, 034016 (2018)

The manipulation of ultracold atoms with light requires not only precise control of the frequency of the light field but also its polarization state. Static polarization control does not constitute a challenge and can be easily achieved with polarizers and wave plates. In contrast, dynamic polarization control is much more demanding. Commercially available dynamical polarization synthesis devices are typically based on some sort of voltage-controlled retarder. For demanding applications in quantum technology, the modulation bandwidth and precision achievable with these devices is however often not sufficient.

C. Robens and coworkers have demonstrated an alternative technique for dynamic polarization synthesis that meets the requirements of ultracold-atom experiments on polarization precision and high modulation bandwidth. The main idea is to directly synthesize the desired polarization state by superimposing two distinct phase-stabilized laser beams with orthogonal circular polarizations. A distinct feature of their setup is that the amplitude and phase of each polarization component can be independently controlled. Careful characterization of the polarization-synthesized beam shows the capability of the setup to modulate the polarization state with a bandwidth of 800 kHz. The measured degree of polarization reaches 99.99 %.

As a first application, C. Robens et al. demonstrated a one-dimensional polarization-synthesized optical lattice. By superimposing the polarization-synthesized beam with a counter propagating linearly polarized beam, they obtained two superimposed yet independently controllable optical-lattice potentials with opposite circular polarizations. Ultracold cesium atoms were trapped in the two lattice potentials depending on their internal state. By continuously increasing the phase of one polarization component, the corresponding optical lattice potential was spatially shifted resulting in a state-dependent adiabatic transport of the cesium atoms. Using motional sideband spectroscopy, virtually no motional excitations were observed at the end of the transport operation.

The technique demonstrated by C. Robens et al. is not only interesting for transport experiments with ultracold atoms but also highly relevant for other applications that require a fast but precise control of the polarization state of light.

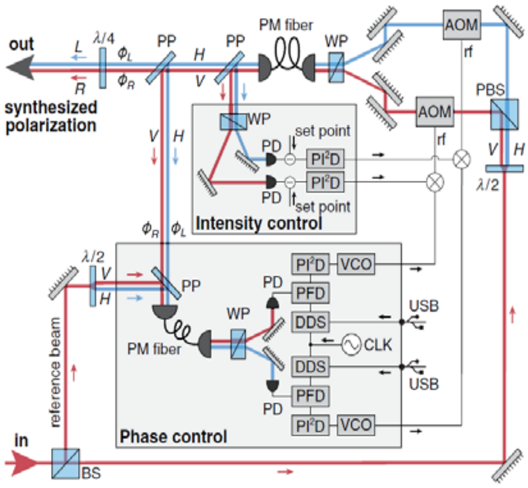


Fig. 2 Scheme of the optical polarization synthesizer

Probing the Topology of Density Matrices (area C)

Generalization of the concept of topology to finite-temperatures and nonequilibrium steady states

Ch.-E. Bardyn, L. Wawer, A. Altland, M. Fleischhauer, S. Diehl

Phys. Rev. X **8**, 011035 (2018)

Topological properties of the ground state of many-particle quantum systems have attracted considerable interest in recent years. They are closely connected with the existence of integer-valued invariants that are robust under perturbations of the system. An unsolved question is to what extend the concept of topology can be also applied to finite-temperature states or non-equilibrium steady-states (NESS) of driven, open systems.

In their work, Ch.-E. Bardyn and coworkers present a theoretical analysis that addresses this question. As nontrivial model systems, they considered periodic one-dimensional (1D) lattices of fermions in Gaussian states. The central quantity of their analysis is the expectation value of the many-body momentum-translation operator, the so-called ensemble geometric phase (EGP):

$$\varphi_E \equiv Im \ln Tr\left(\rho\, e^{i\,\delta k\,\hat{X}}\right),$$

where, ρ is the density matrix describing the system, $\delta k \equiv 2\pi/L$ is the smallest possible momentum in the system with period L, and $\hat{X}$ is the many-particle position operator. They show that the EGP can be considered as a natural generalization of the geometric Zak phase, which characterizes the topological properties of a pure quantum state and its winding is a topological invariant. In particular, they find that the value of the EGP for a finite-temperature state is given by the zero-temperature Zak phase of the ground state of the system up to corrections that vanish in the thermodynamic limit. In the case of a NESS which is not a thermal state, the EGP can be related to the ground-state Zak phase of a fictitious Hamiltonian.

The robustness of the EGP as a geometric phase for mixed states and its relation to ground state topological invariants is a many body effect. This aspect can be understood when writing the EGP as the product of link matrices, which describes the “geometry” underlying the band structure of the mixed state, and a weight factor that determines the statistical weight of a given purity band in the EGP. In gapped systems and in the thermodynamic limit, the weight factors strongly favor the lowest band, thus "filtering" out all but the ground state.

The authors do not only provide a positive answer to the question whether the concept of topology can be also applied to finite-temperature states, they also propose an experiment with an ensemble of ultracold atoms that enables the measurement of the EGP with an interferometric setup.

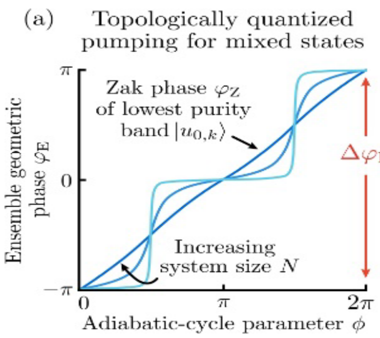


Fig. 3 (a) The EGP of a mixed state reduces to the Zak phase of a pure state in the thermodynamic limit. The state $|u_{0,k}\rangle$ corresponds to the lowest band in the scaled “purity spectrum” of the system.