Non-linear integrated quantum optics

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Classical optical systems harness the coherence of interfering waves. They are used in many applications of today's photonic technologies. Here, integrated optical circuits offer high functionality for establishing larger network structures and compact devices for practical applications. At the quantum level, the quantized nature of light, this means the existence of photons and entangled states, gives rise to genuine quantum effects that can appear completely counter-intuitive. Such phenomena form the basis of a novel quantum technology, which can accomplish classically unfeasible tasks such as secure quantum cryptography or quantum computation.

Recent achievements in the area of integrated quantum optics and quantum information processing have shown impressive progress for the implementation of circuits using waveguide structures. The use of waveguides, which harness a $\chi(2)$ –non-linearity, allows for the realization various devices with different functionalities. These include parametric downconversion sources for photon pair generation with extraordinary brightness, quantum frequency conversion with tailored spectral-temporal properties, and complex circuitries comprising linear elements, and active elements such as polarization rotators or an electro- optically modulators.

For ultrafast-pulsed parametric downconversion processes much effort has been devoted in recent years to engineer sources with uncorrelated spectra, which emit single TM pulsed photon pairs with no intrinsic structure and can achieve very high efficiencies. Contrariwise, we can explore the generation of multi-mode temporal states for multi-dimensional quantum information encoding.

Pulsed quantum states of light are an attractive resource for quantum communication and optical quantum measurements. The temporal-spectral degree of freedom offers distinct advantages for light-based quantum technologies. Temporal modes (TM) of quantum light pulses can be defined as field-orthogonal wave packet states, which are specified by their envelope functions and typically span a high dimensional system. They constitute a fiber- compatible high dimensional basis, because they occupy a single spatial mode.

We have demonstrated the control of the TM structure of quantum light by using non-linear processes for state preparation as well as for state manipulation and detection. We use highly efficient devices based on non-linear waveguide structures for the preparation and manipulation of TMs by means of engineered PDC and our quantum pulse gate (QPG) setups.

We show that we can detect and analyse the TM structure of pulsed light by using dispersion engineered sum frequency generation, this means QPG setups with subsequent single photon detection. Applying QPGs for quantum metrology, we can observe ultimate quantum timing resolution. For quantum communication a multi-output QPG provides the basis for future systems with efficient high-dimensional quantum information encoding.