Nonlinear integrated quantum optics

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High-dimensional photonic quantum systems based on single and multi-photon states offer an attractive platform for quantum information and technology applications. These include advanced quantum communication, quantum metrology as well as quantum simulations. Here we present different approaches for the realization of multi-dimensional quantum states and networks and discuss their potential for applications.

Non-linear integrated quantum circuits with multiple channels enable the implementation of compact and stable photonic systems. The use of structures with 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. In our latest developments we study Lithium niobate on insulator (LNOI) as a new promising material platform for integrated quantum optics. Here we have demonstrated our first two-photon quantum interference as a basis for future quantum techonologies [1].

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. Over the last years we have demonstrated the control of the TM structure of quantum light by using engineered, 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. Recent progress shows that applying the QPGs for quantum metrology can yield ultimate timing resolutions. Moreover, we have developed a multi-output QPG for efficient high dimensional quantum information coding for applications such as quantum key distribution [2].

Finally, time-multiplexed quantum systems are a versatile tool for the implementation of a highly flexible simulation platform with dynamic control of the underlying graph structures and propagation properties as well as for efficient quantum state preparation. By introducing optical modulators in low loss systems, we can precisely control the dynamics of the photonic systems and realize quantum state buffering for source multiplexing in the time domain. We have studied various optical circuits as well as efficient entangled GHZ state generation with feedforward operation in adapted architectures Our work opens a new path for further studies in the area of large scale reconfigurable quantum networks.

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