Many objectives of Quantum Information Processing (QIP) are very suited to optics. These include Quantum Cryptography, Quantum Metrology and some implementations of Quantum Computation (distributed quantum computing). In recent years, research has been focused on integrated, on-chip implementations of quantum optical setups, which have proven superior in terms of stability, achievable complexity and degree of control over the photonic quantum states. Photonic Crystal are very promising for the realization of key components for optical QIP as waveguides, cavities and interferometers. Coupled with quantum dots, they've also demonstrated interesting potential as single-photon sources. We focus on quasi-3D structures (Photonic Crystal slabs) and single-photon states to achieve reliable, scalable and robust manipulation of polarization- and path-encoded qubits. We pursue the design of basic building blocks for a scalable architecture for handling Linear Optical Quantum Computing and Universal Photonic State Manipulation via optical multiports.

Optical QIP

Optical QIP relies on interference effects between wave-packets whose intensity is so low they can be modeled as “single photons”. One needs to generate state with at most one photon for each measurement time-slot to observe quantum interference effects and perform any meaningful quantum computational task. Control over the route and phase of the single photons is also critical and requires ultra-stable interferometers and spatial paths (in free space or guides).

Generation of Pure States

Using non-linear processes in crystalline materials. We have to guarantee:
1) True single-photons emission
2) Ability to create superposition states
3) Ability to create entangled states

Control of Quantum States

4) Beam Splitting
5) Relative Phase
6) Interferometers

Experimental Setup

Single-Photon states from Spontaneous Parametric Down-Conversion are separated by a beam splitter cube (or fiber splitter) sent over to polarization control stages built from quarter- and half-wave plates. In the simplest setup, one photon is used as trigger for the measurement and sent directly to APD 1, while the second is injected in the PhC circuits under test. A second source can be connected to the splitter cube to obtain polarization entangled states (Bell states).

Photonic Circuits

Photonic Crystal Slabs have photonic bandgap in two dimensions and use index guiding to confine light in the vertical direction. They can accommodate virtually any structure needed to steer and control light. Also, fine tuning of the spectral and spatial properties of light inside guides and cavities is possible.

Generation of Pure States

We focus on low-symmetry unit cells (a) which exhibit full 2D bandgap for both TM and TE modes. Simulation based on plane-wave expansion and Finite Difference Time Domain (FDTD) method are used to optimized the band structure (b), the modes overlap (c) and to design circuits with minimum propagation losses and desirable dispersion relations.

On-chip building blocks for polarization qubits

Handling polarization encoded qubits requires a “polarization diversity” scheme. A polarization splitter (1) is needed to separated TE and TM modes. Subsequent interferometers (2) can be optimized separately for different modes (a polarization rotator is also possible). Quantum Dots can moreover be embedded on the chip to act as optical memories, single photon source or frequency converters.

Outlooks

We're in the process of designing and a series of components for optical based on photonic crystal with non standard unit cell. Also, we're preparing a SPDC single-photon source based on a periodically poled MgO:SLT crystal. This source will be used to test our devices before a quantum dot source can be developed. In the close future, we plan to demonstrate single-photon interference for polarization-encoded qubits in a photonic crystal slab. Also, transmission of path-encoded qubits through an integrated interferometer with tolerable losses and high fidelity will be a major goal. The ideal conclusion of this project includes the demonstration of on-chip teleportation of a quantum state or entanglement swapping between two qubits pairs.