Design and Direct Laser Inscription of Integrated Optical Circuits for Quantum Computing

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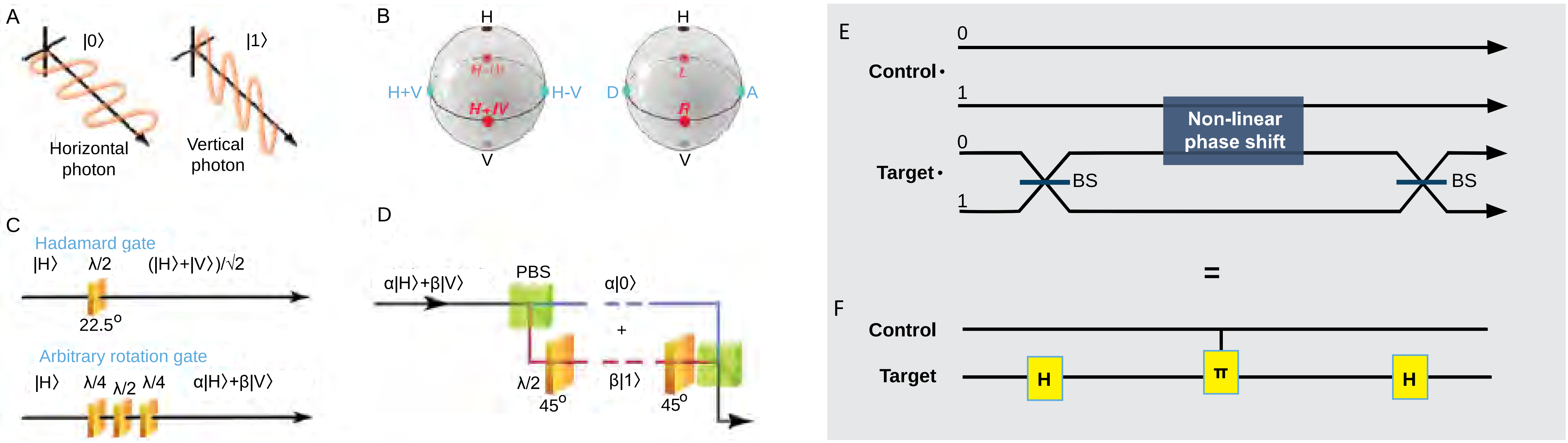
Linear Optics Quantum Computers

Current computers manipulate individual bits: 0 and 1 states.

Quantum computers use superposition and entanglement to manipulate the state of a Quantum Bit (Qubit).

Linear Optics Quantum Computers (LOQCs) can be implemented by linear optical gates and optical components like: **beam splitters, phase shifters, single photon sources and photo-detectors**.

Implementation can be possible by various optical architectures like free space components or integrated



A. Shows how a qubit can be encoded in the polarization of a single photon. B. An arbitrary state of a single qubit can be represented on the Bloch sphere (Diagonal, Anti-diagonal, Right circular and Left circular). C. Single qubit gates using waveplates that retard polarization, causing a rotation of the state on the Bloch sphere. D. Converting between polarization and path encoding using a polarizing beam splitter (PBS). E. Schematic of a possible realization of an optical CNOT gate. F. In the notation of quantum circuits the BSs implement a Hadamard (H) gate.

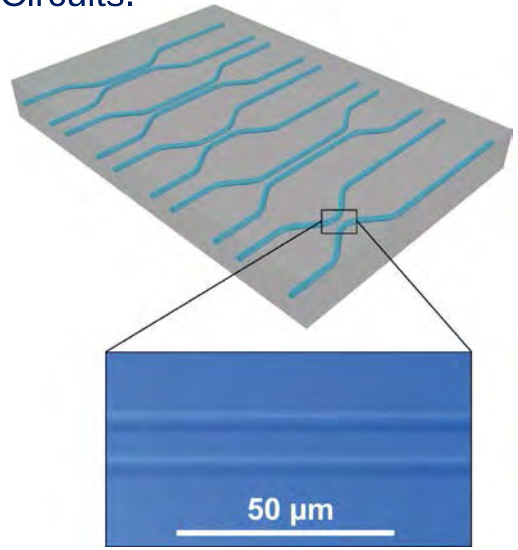
Integrated Optical Circuits Enabling LOQCs

Implementation by flexible Femtosecond Laser Writing

Development of scalable Quantum Computers based on integrated optical circuits in Silica on Silicon Platform

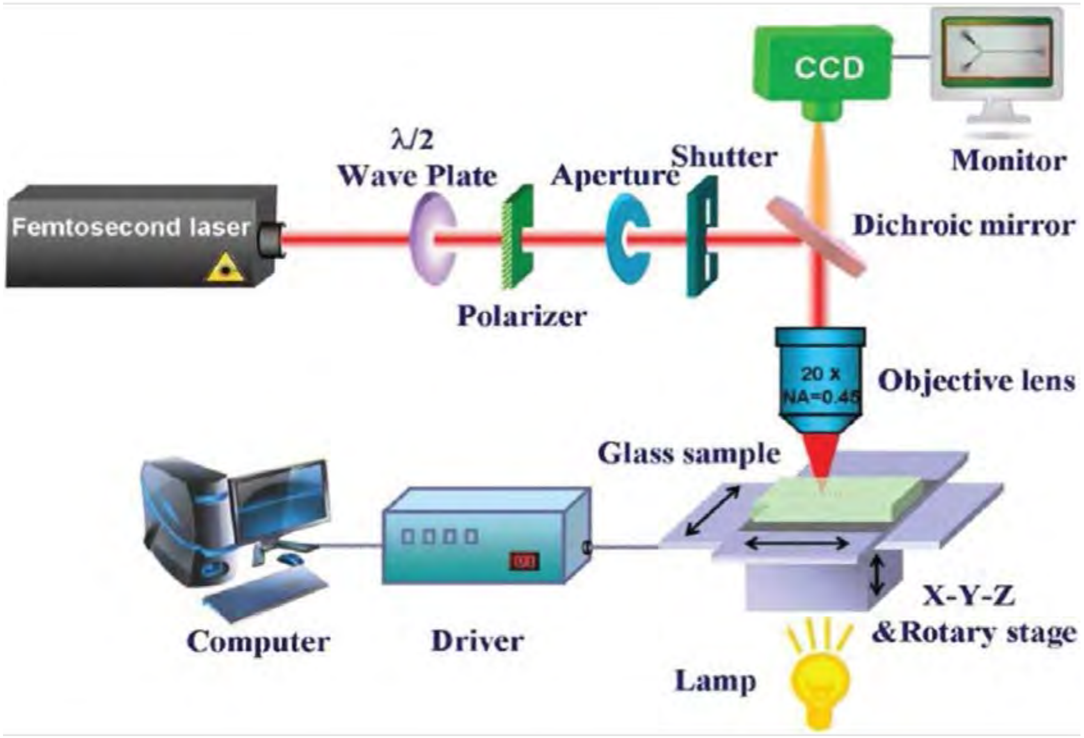
The Direct FLW technique is a promising technology for creating integrated circuits in optical platforms.
Enables: 1) Adiabatic 3D waveguide inscription 2) Accurate micromachining selectively positioned

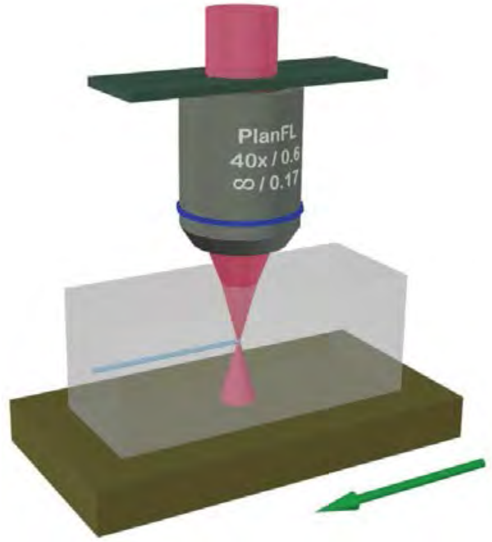
Implementation of waveguide based optical gates in Optical Integrated Circuits.



An optical micrograph showing the central coupling region where the waveguides are separated by 10 µm.

Schematic of femtosecond-based laser direct writing fabrication system.



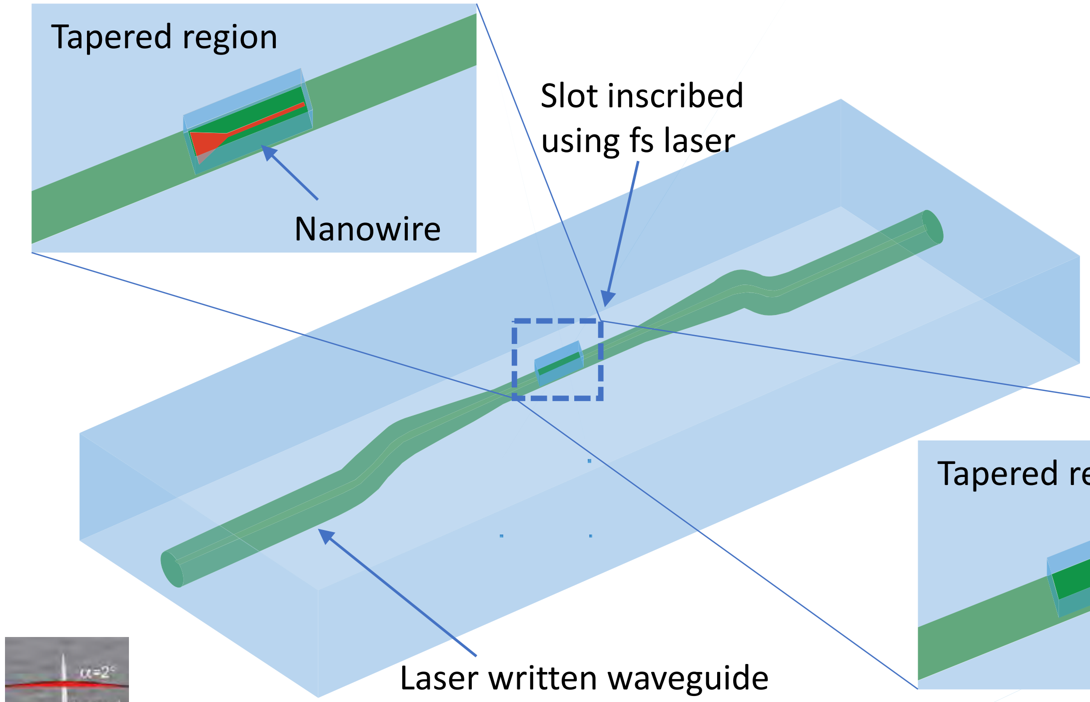


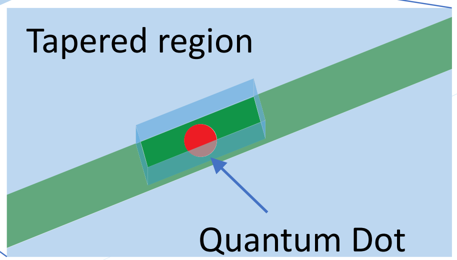
Operating principle of material's refractive index modification by fs pulses.

Integration of Quantum Emitter in Optical Waveguides

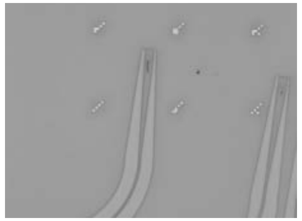
Critical step for enabling scalability in Quantum Circuits

Direct FLW enables to accurately define micromachined slots at specific locations for the <u>deterministic</u> placement of Nanowires Quantum Dots.
Designed by 3D Finite Difference Time Domain (FDTD) and Beam Propagation Methods (BPM).

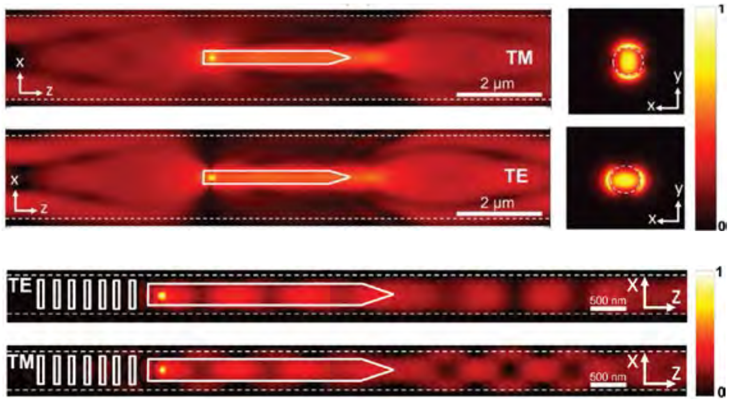


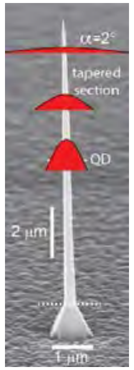


Micro-manipulator for deterministic handling and placement of NQD



3D- FDTD simulation of the emission of a QD embedded in a waveguide as incorporated in a nanowire.





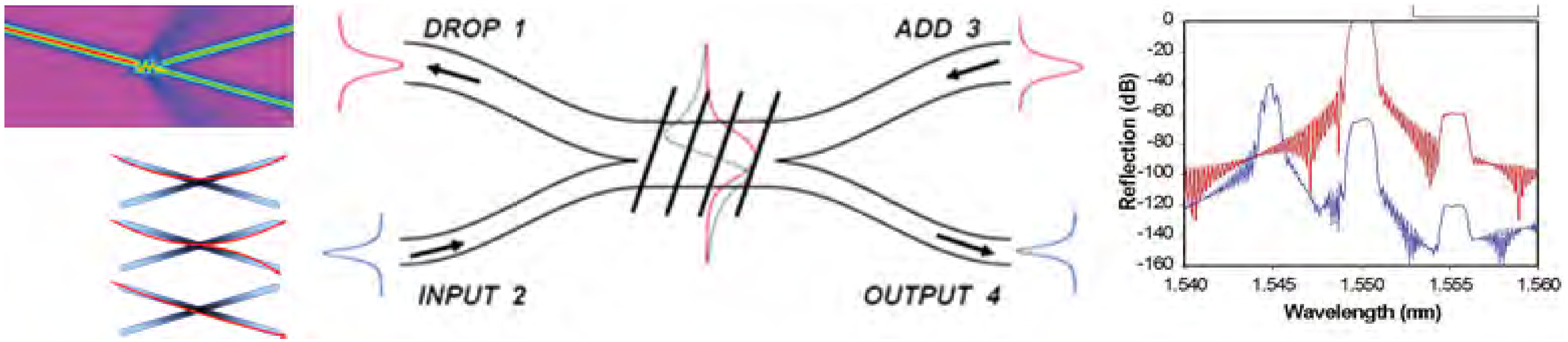
Single Quantum emitters- InP NQDs:

- 1.5−3 µm, length
- 250−300 nm, diameter
- 3−4 nm, of InAsP QD, 200 nm, from the base
- emit at 880nm

- ➢ The electric index intensity profile illustrates the bidirectional emission of the QD in the waveguide resulting thus in significant losses in the desired forward coupling direction.
- ➢ The incorporation of suitably designed BG reflector significantly can reduce the backward coupling of light by maximizing its forward propagation in the waveguide.

Enabling Scalable Quantum Circuits with Multicolor Qubits

Wavelength Division Multiplexing (WDM) techniques as well as wavelength selective filters and channel dropping filters will enable the processing on-chip of different colored photons leading to an increased multiplexed qubit data rate.
Transfer of well known design techniques and architectures from Telecommunications Industry to Quantum Circuits



From left to right: Simulated response and operation of a customizable cross-coupler with minimal footprint. Illustrated an Optical Add Drop Multiplexers (OADM) based on a BG loaded null coupler with the spectrum of a drop action. Optimized response of an OADM with high extinction suppression.

Perspectives

- Photon Processing Components On-Chip will enable Efficient and robust QCs for powerful computing power.
- Emerging applications: cryptography, security, large scale prediction models, machine learning, biomedical modeling, drugs design, financial modeling