Changling Zou, Liang Jiang, Hong Tang

Department of Electrical Engineering and Applied Physics

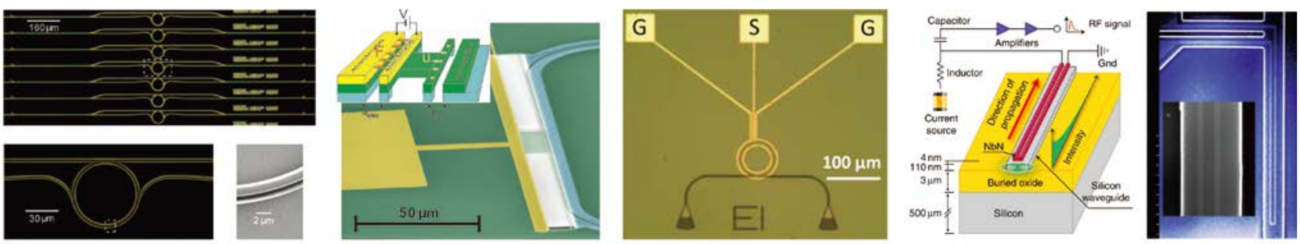
Yale University

Areas of interests: hybrid quantum photonic circuits; solid state quantum information processing;

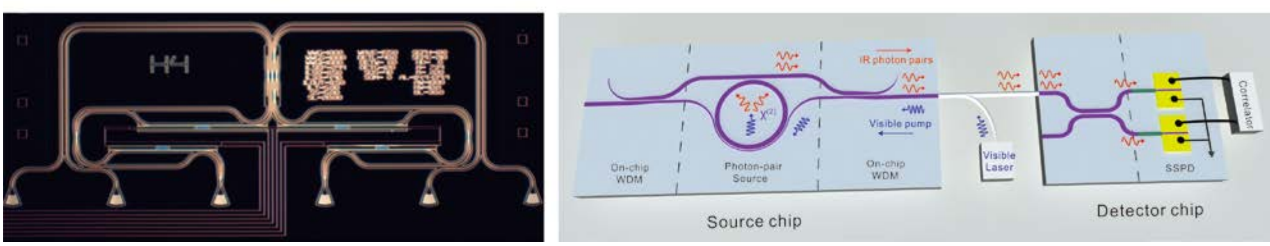
Our group has unique capability for integrating quantum light source, optical circuits, modulators and detector on a monolithic silicon chip:

- **Quantum light source** [Fig. 1(a)]. The Aluminum Nitride (AlN)-on-silicon photonic chip is COMS compatible, and it is unique with second-order optical nonlinearity. In addition, AlN has transparency window spanning visible and IR photons. Therefore, the infrared entangled photon pair and heralded single photon sources can be realized by spontaneous parametric down conversion in high-Q microring resonators.
- Electromechanical phase shifter for reconfigurable circuit [Fig. 1(b)]. Comparing with thermo-optical phase shifters in silicon chip, our electromechanical device does not consume power in static operation and also it can operate over large frequency, wavelength, and power ranges. Operation in the MHz range and sub-us pulses has been demonstrated in our group.
- Lossless electro-optic phase modulation [Fig. 1(c)]. The AlN device allows ultrafast electro-optic modulation up to 20Gb, which is crucial for feedforward control of photonic qubits.
- Waveguide Integrated superconducting **single photon detector** [Fig. 1(d)], with efficiency above 90%, 10^{-3}Hz dark counts and 18 ps jitter time.

Our AlN chip provides a promising platform for photonic quantum computation. We may use a single photon occupying two different modes to encode a physical qubit, with basis $|\mathbf{0}\rangle = |1\rangle_0|0\rangle_1$ and $|\mathbf{1}\rangle = |0\rangle_0|1\rangle_1$, where $|n\rangle_j$ (n,j=1,2) corresponds n photons in j-th waveguide mode. Arbitrary single qubit operation can be realized by directional couplers (for example, X and Hadamard gates) and controllable phase shifter (Z gate) with very high accuracy. Fig. 1(e) is the illustrates the design of heralded Control-NOT gate based on directional couplers and electromechanical phase shifters. In Fig. 1(f), the entangled photon generation and on-chip photon correlation measurement are demonstrated on-chip without any free-space components.



(a) Photon-pair source array **(b)** Phase Shifter **(c)** Electro-optical modulator **(d)** Waveguide integrated detectors



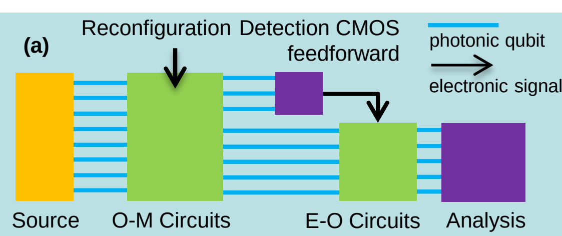
(e) Circuit for CNOT gate **(f)** Integrated photon pair source and correlation measurement

Figure 1 Basic optical components and circuits.

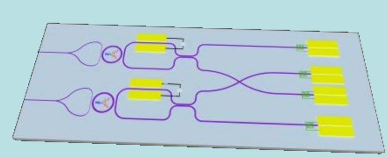
Plan for future works:

- Combining **monolithic quantum photonic chip with electronic circuits clocked at 10GHz.** As schematically shown in Fig. 2(a), the integrated electronic circuit will enable ultrafast feedforward control of photonic qubits, with delay smaller than 1ns. In addition, the photonic circuit is also reconfigurable by open loop controlling phase shifters in real-time.
- **Bell state preparation and Bell measurement**. This is one key component of the linear optics quantum computation. As shown in Fig. 2(b), by using the clockwise and counter-clockwise travelling wave modes in the microring, we can simultaneously generate photon pair in both travelling wave directions. The output state in the dual-rail is $(|0\rangle_0|2\rangle_1 + |2\rangle_0|0\rangle_1)/\sqrt{2}$. After a X-gate, the state becomes $|1\rangle_0|1\rangle_1$. Then, by two microrings, we can generate the Bell state as $(|\mathbf{0}\rangle|\mathbf{1}\rangle + |\mathbf{1}\rangle|\mathbf{0}\rangle)/\sqrt{2}$.
- **Logic qubit encoding and quantum error correction.** The physical qubits can be encoded by quantum parity code, which will enable quantum error correction to protect qubits from photon loss errors

(a)



(b)



Bell state generation

Figure 2 Plan for future works.

hong.tang@yale.edu

203-605-6850

http://www.eng.yale.edu/tanglab/