Topological Quantum Error Correction in Silicon Photonics

The University of British Columbia

November 20, 2018

Overview

Origins and Applications of Quantum Computing

- Feynman's idea: Simulate quantum systems using other quantum systems

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Quantum algorithms:

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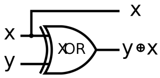
Quantum algorithms:

- Prime Factorization: Exponential speedup
- Discrete Logarithm: Exponential speedup
- Unstructured Database Search: Square root speedup
- Solutions to Linear Systems: Exponential speedup

Classical and Quantum Computation

- Classical: bits can be either 0 or 1, invertible and non-invertible gates applied to bit strings like 1011



input		output	
x	y	x	y+x
0	0	0	0
0	1	0	1
1	0	1	1
1	1	1	0

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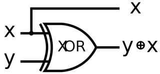

input		output	
x	y	x	y+x
0	0	0	0
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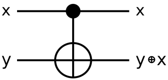
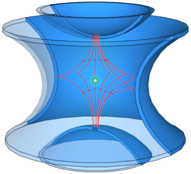
1	0	1	1
1	1	1	0

- Quantum: bits are $|0\rangle$ or $|1\rangle$, unitary operations applied to bit strings $|1011\rangle$



input		output	
x	y	x	y+x
$\vert 0\rangle$	$\vert 0\rangle$	$\vert 0\rangle$	$\vert 0\rangle$
$\vert 0\rangle$	$\vert 1\rangle$	$\vert 0\rangle$	$\vert 1\rangle$
$\vert 1\rangle$	$\vert 0\rangle$	$\vert 1\rangle$	$\vert 1\rangle$
$\vert 1\rangle$	$\vert 1\rangle$	$\vert 1\rangle$	$\vert 0\rangle$

Experimental Realizations



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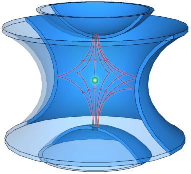

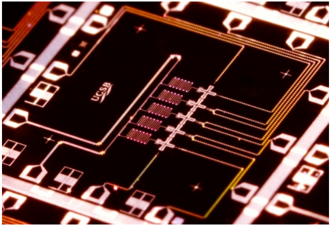

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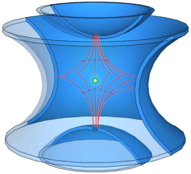
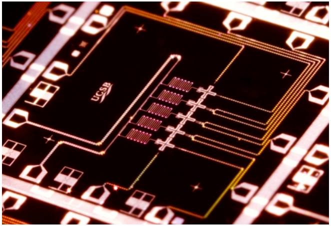
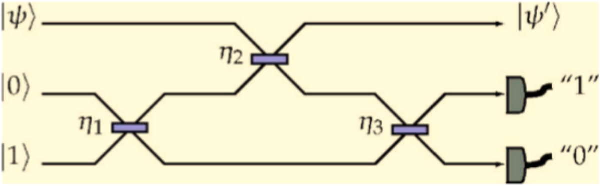
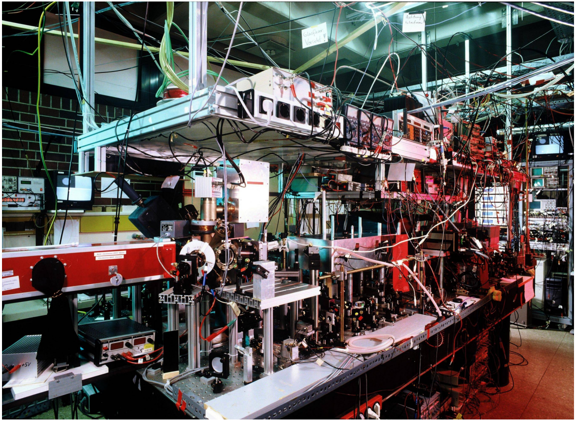




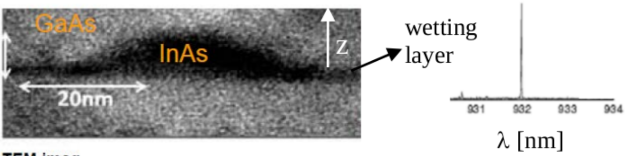


Experimental Difficulties



Pure quantum states are extremely fragile

Quantum Dots

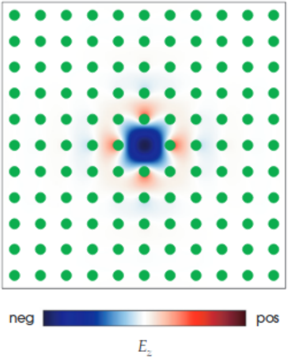


TEM imag

$$V(x,y,z) = \begin{cases} \frac{1}{2}m^*\omega_0^2(x^2+y^2), & |z| < \frac{L}{2} \\ \infty, & |z| > \frac{L}{2} \end{cases}$$

Photonic Crystal Cavities

- Permitivity of material varies periodically: $\mathbf{D}(\mathbf{r}) = \varepsilon(\mathbf{r})\mathbf{E}(\mathbf{r})$, $\varepsilon(\mathbf{r}) = \varepsilon(\mathbf{r} + \mathbf{R})$.



Quantum Error Correction

- Encode information using redundancy

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- If 1 qubit gets flipped, we can measure and flip it back:

$$|000\rangle \xrightarrow[\text{Error}]{} |100\rangle \xrightarrow[\text{Error}]{\text{Measure}} \sigma_x \otimes \mathbb{I}_2 \otimes \mathbb{I}_2 |100\rangle \rightarrow |000\rangle$$

Stabilizers

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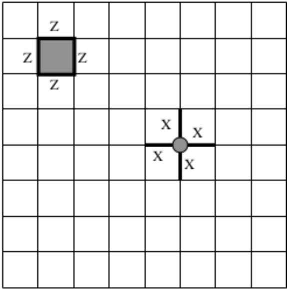
- Example: $\sigma_z \otimes \sigma_z \otimes \sigma_z|000\rangle = |000\rangle \rightarrow |000\rangle$ is stabilized by $\sigma_z \otimes \sigma_z \otimes \sigma_z$. Same for $|110\rangle, |101\rangle, |011\rangle$.

Topological Quantum Error Correction



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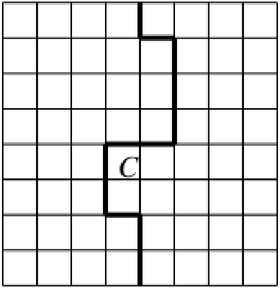

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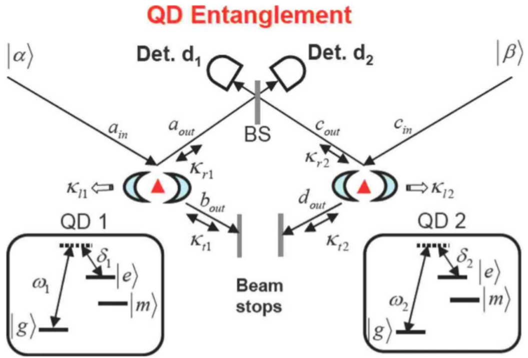
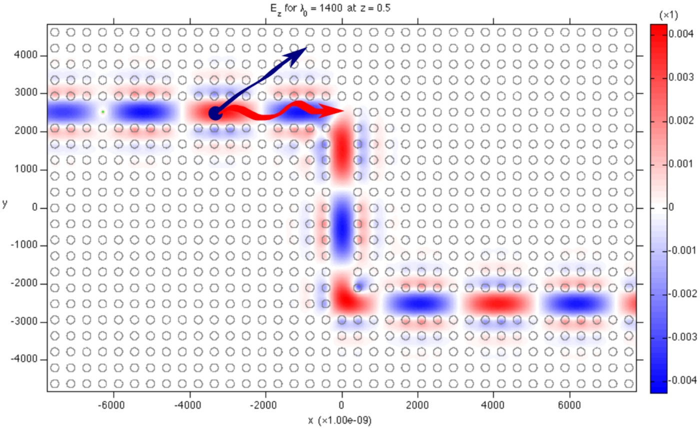
Entangling Gate



Entangling gate proposed by Deepak Sridharan and Edo Waks from the University of Maryland.

Losses in Photonic Circuits



Resources and Schedule

- Photon loss and QEC calculations are being done analytically and using Mathematica.
- Simulations of toric code will be done in Python.

Task	Date
Literature Review	May-Aug
Study effects of photon loss	Sept-Nov
Implement toric code with entangling gate	Dec
Analyze fault tolerance of code	Jan-Feb
Repeat analysis with Colour Code.	Mar
Submit thesis	Apr

Acknowledgements

Summary

- Quantum error correction will be fundamental in any implementation of quantum information processing.
- Quantum dots in silicon photonic circuits is a promising scalable platform. I will investigate this area further.
- I will develop a scalable architecture using the 2-qubit entangling gate and toric codes as building blocks.