Efficient fiber-to-chip coupling enabling on-chip quantum optics

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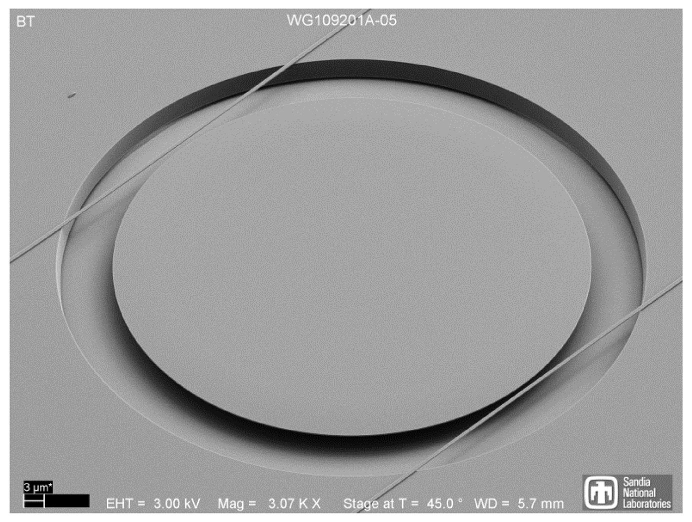
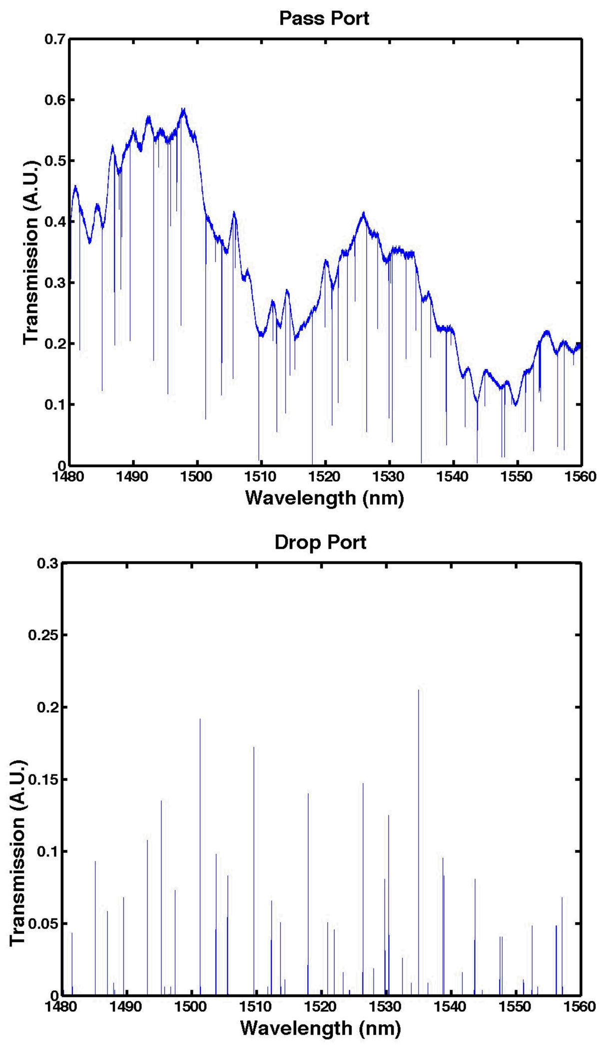
High Q Resonators in Si_3N_4

Sandia has developed a process for depositing and annealing Si_3N_4 that achieves extremely high quality films. We are able to observe loaded quality factors in excess of a million which corresponds to intrinsic quality factors on the order of 10 million.

As pictured, these devices have had a localized sacrificial etch allowing us interact with the mode all around the disks. We have previously leveraged this for non-linear interactions with gasses such as Rb and Xe. However, these would also be excellent devices for chemical and biological sensing applications.





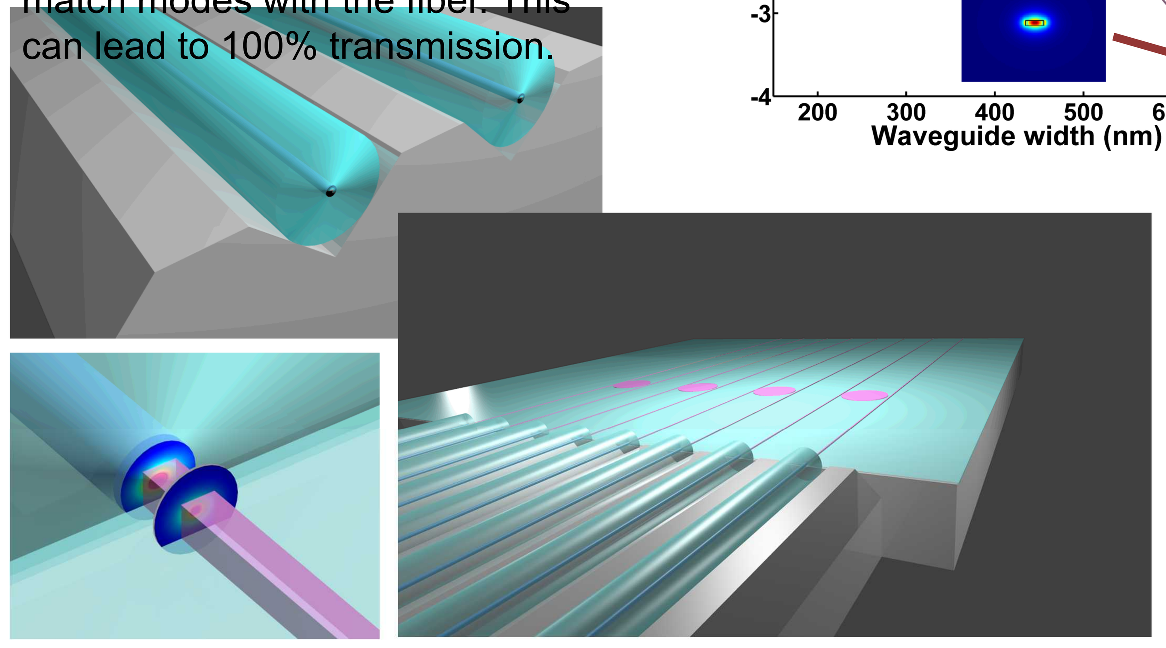
SEM micrograph of a sample Si_3N_4 micro-disk. The coupling waveguides and disk have been undercut through a sacrificial etch. The four port structure used allows us to monitor bot the dropped and passed signal. Example spectra are displayed on the right. Loaded Qs in excess of a million are observed.

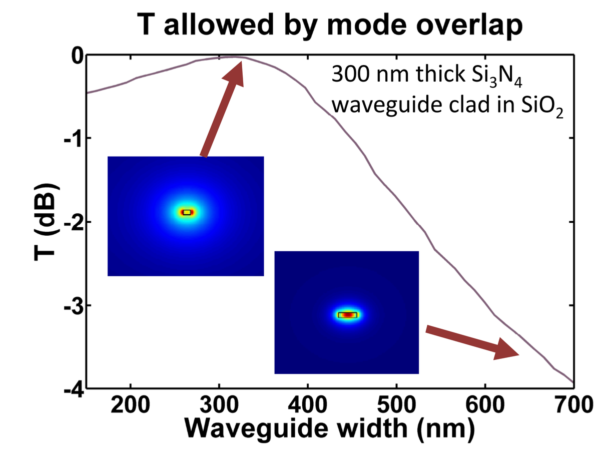
Why high efficiency is required?

In the world of classical optics the loss of individual photons is viewed more as a nuisance than a major hindrance. Signals are carried by huge numbers of photons that can be amplified to counter high levels of loss. In the quantum paradigm we are much more limited. A carefully prepared qunatum state can be completely destroyed by the loss of a single photon.

Our approach is to use end-fire coupling to perfectly match the mode in an integrated waveguide to the mode in a high-index fiber. If we can increase the coupling efficiency to above 90% per facet a slew of new experiments will be enabled.

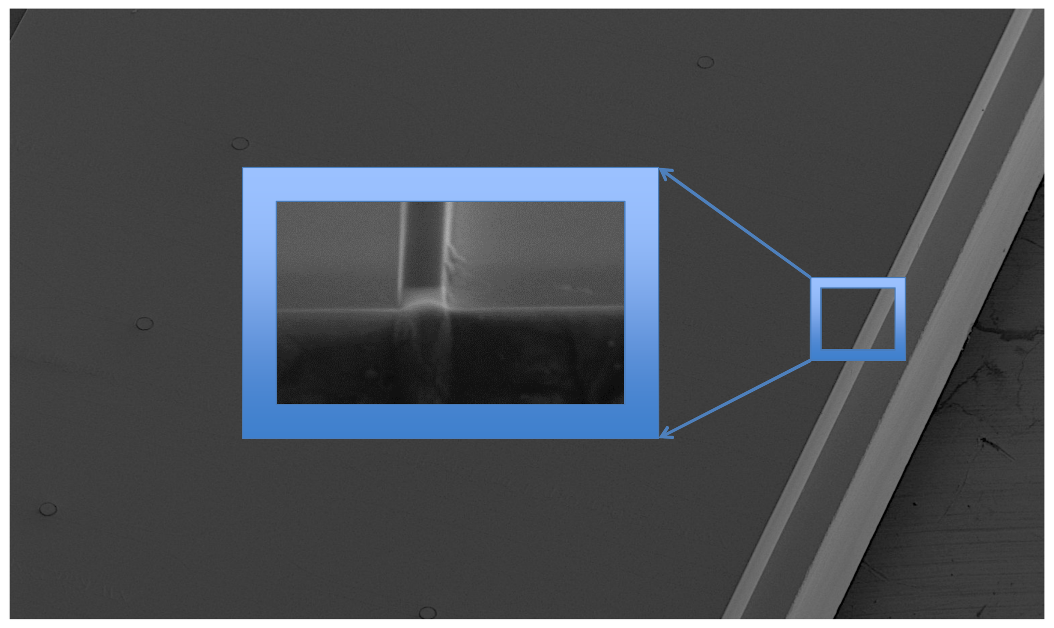
Fibers polished and placed in precise silicon v-grooves. A polished edge of a chip is then matched to the fiber array. We adjust the on-chip waveguides to match modes with the fiber. This can lead to 100% transmission.



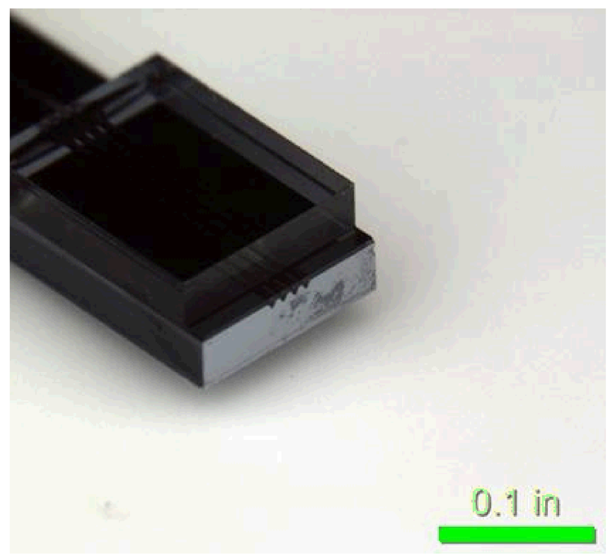


Scalable Facet Definition

End-fire coupling requires a clean facet on the edge of the chip to allow a polished fiber be brought flush to coupling region. Traditionally this has been accomplished by manually polishing the edges of the chip. We have developed a deep reactive ion etch (DRIE) which allows us to define pristine facets on a wafer scale. The dicing is then done away from the facet and specially machined fiber arrays are used to accomplish the mating.

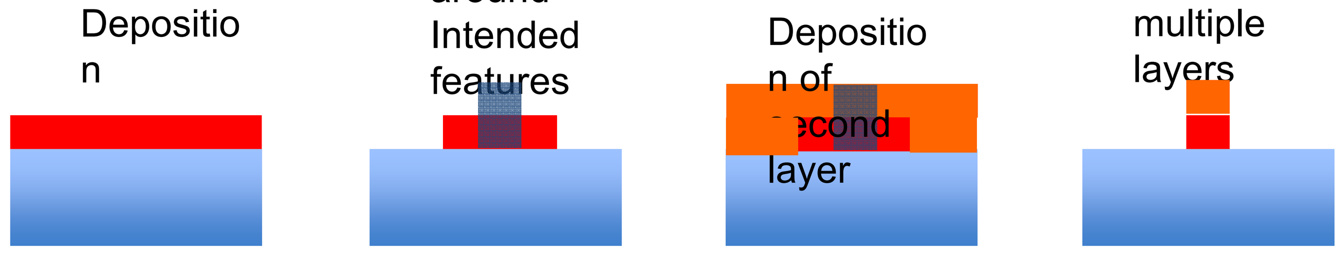


A view of a chip that has a facet defined by a DRIE step and then diced away from the facet. To the right is an image of a fiber array that have been machined so that the fiber facet can be brought up to the recessed waveguide facet.



Thick Si_3N_4 for Anomalous Dispersion

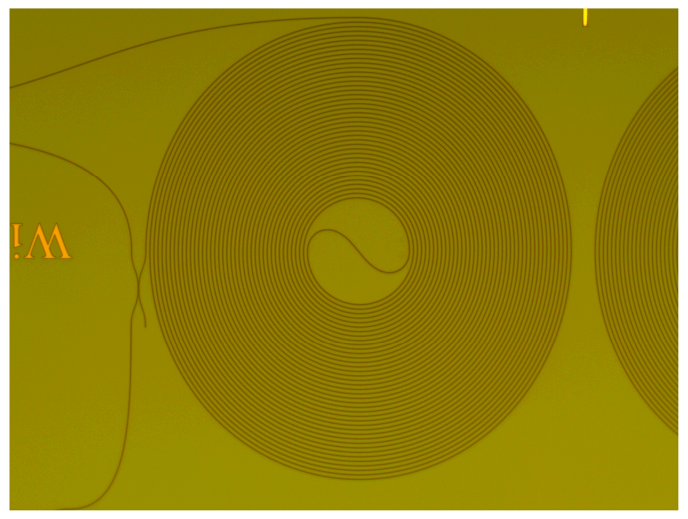
The biggest drawback to depositing Si_3N_4 on SiO_2 is the extreme stress that develops in the film, limiting a single deposition to 300 – 400 nm of thickness. Around this thickness Si_3N_4 waveguides have high normal dispersion. Many experiments require either low dispersion or even anomalous dispersion, which can be found in films of 600 nm or more. We are in the process of developing a multistep process that allows features such as waveguides to traverse large areas of a chip while minimizing the stress in the film by etching away unused nitride away from the final features after each deposition step.



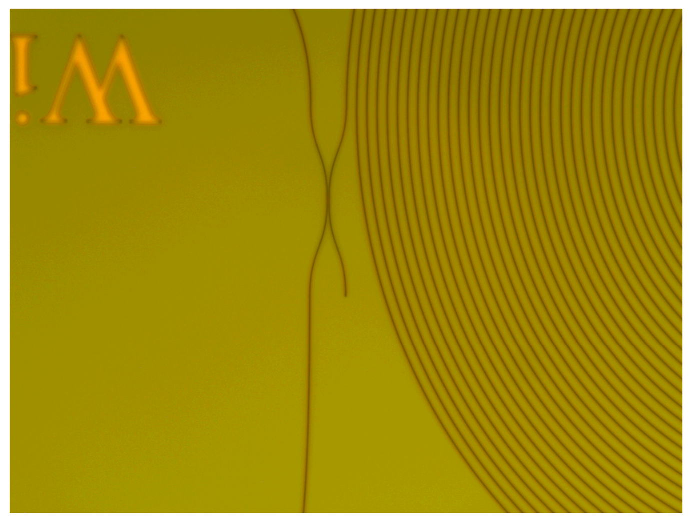
Franson Interferometry – a technique simplified by integrated optics.

Franson interferometry is a method of violating a Bell inequality for energy-time entanglement. For photons that have been entangled by spontaneous creation methods and have no polarization entanglement it is the preferred way of demonstrating entanglement and has applications in quantum information and quantum security protocols. The key to the technique is to have two spatially separated specialized interferometers that are perfectly identical. A feat that is extremely difficult outside of integrated optics where the temperature and spatial stability becomes simple to control.

An overview of sets of devices that will yield a complete Franson-type experiments.



A 660 ps delay line. Optical delay lines are one of the more the difficult things to accomplish on-chip.



The integrated optics version of a beam splitter. Here it is used to construct a Mach-Zender interferometer.

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