National Aeronautics and Space Administration

Developing atomic layer etching techniques for ultra-low loss photonic components

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Objectives

The objective of this proposal was to identify how to pattern SiN films with ultrasmooth sidewalls to reduce lossusing a novel technique called Atomic Layer Etching. This material system is considered the workhorse of integrated photonics and lasers. Reducing loss in the fabricated micro and nanostructures can enable new technologies, while providing guidelines as how to etch a broader class of material systems. Our aim was to fabricate silicon nitride ring resonators with quality factors on the order of 200M (limited by the material absorption loss). This would be a 5x enhancement over the state of the art, which would enable the new classes of devices we seek to fabricate

Background

Loss is the primary effect compromising the performance of photonic integrated circuits. There is an ever increasing need to reduce the waveguide/resonator loss in applications pertaining to lasers (in order to increase the coherence and reduce threshold), sensors (to improve the detection limit), and nonlinear photonics. Specifically, one of the key sources of loss in photonic components is the surface roughness of the fabricated structures. We have shown that ALE can dramatically reduce surface roughness on a variety of metal, semiconductor, and insulator structures to the sub-nm scale. This process could be a breakthrough for the creation of ultra-low loss photonic waveguides, resonators, and other components. The PIs from USC are working on new types of photonic sensors and lasers where the performance of the devices highly depends on the level of scattering loss from sidewalls in silicon nitride and III-V structures. The team extended the use of ALE to such material systems, where it is expected to have a significant impact on related technologies. In particular, such low scattering loss structures when bonded with III-epitaxial films can be used to realize highly coherent lasers with Hz-level linewidths that can be used in fast coherent imaging and sensing applications.

Approach and Results

The approach used here was to take silicon/oxide/silicon nitride substrates as the starting substrate. Next, we lithographically pattern optoelectronic structures in the silicon nitride layer for visible wavelength integrated photonics. Finally, we ran a SiN atomic layer etch processes on the resulting SiN. For this project, two different deposition techniques were used to create the SIN layer. First, a low-stress SiN was deposited using LPCVD. When this was etched, it was found that the loss in this layer was relatively high. This intrinsic loss was deemed high enough to wash out any signal that would be observable from the ALE smoothing process. Next, a stoichiometric SiN layer was deposited also using LPCVD. However, when smoothing this layer, it was found that the etch rates were not controlled, as would be expected from an atomic layer etch process. While modifications to the process window were explored, this anomalous etch rate persisted. We finally identified hydrogen as the culprit. Due to the mechanism of etching during ALE, it was found that the hydrogen incorporated into the film dramatically increased the etch rate, to a point that the general mechanism was no longer behaving as expected. This is an extremely important finding, and is one that can be further explored as the need for ALE smoothing expands to various deposited and grown materials.

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Significance/Benefits to JPL and NASA

Direct integration of III-V actives on a silicon photonics platform, is of great interest for communication and integrated spectroscopic tools. However, present day silicon photonics platforms cannot support direct growth of lasers, and thus primarily utilize bonded dies or lasers. This approach has been successful but the true strength of the photonics approach lies in the ability to use wavelength division multiplexing (WDM), which requires different lasers for each wavelength, but enable bandwidth scaling in proportion to the number of wavelengths used. While the presently used approaches limit the number of lasers that can be integrated to <10, the approach we propose here could allow 100's or even 1000's of lasers to be fabricated directly on a silicon integrated photonics platform. This increase in component density would linearly correspond to bandwidth increases with a WDM scheme. Furthermore, while germanium detectors and silicon modulators are presently used, there are also significant potential performance advantages for moving to III-V based integrated detectors and modulators. Low loss SiN waveguides will only enhance this benefit.

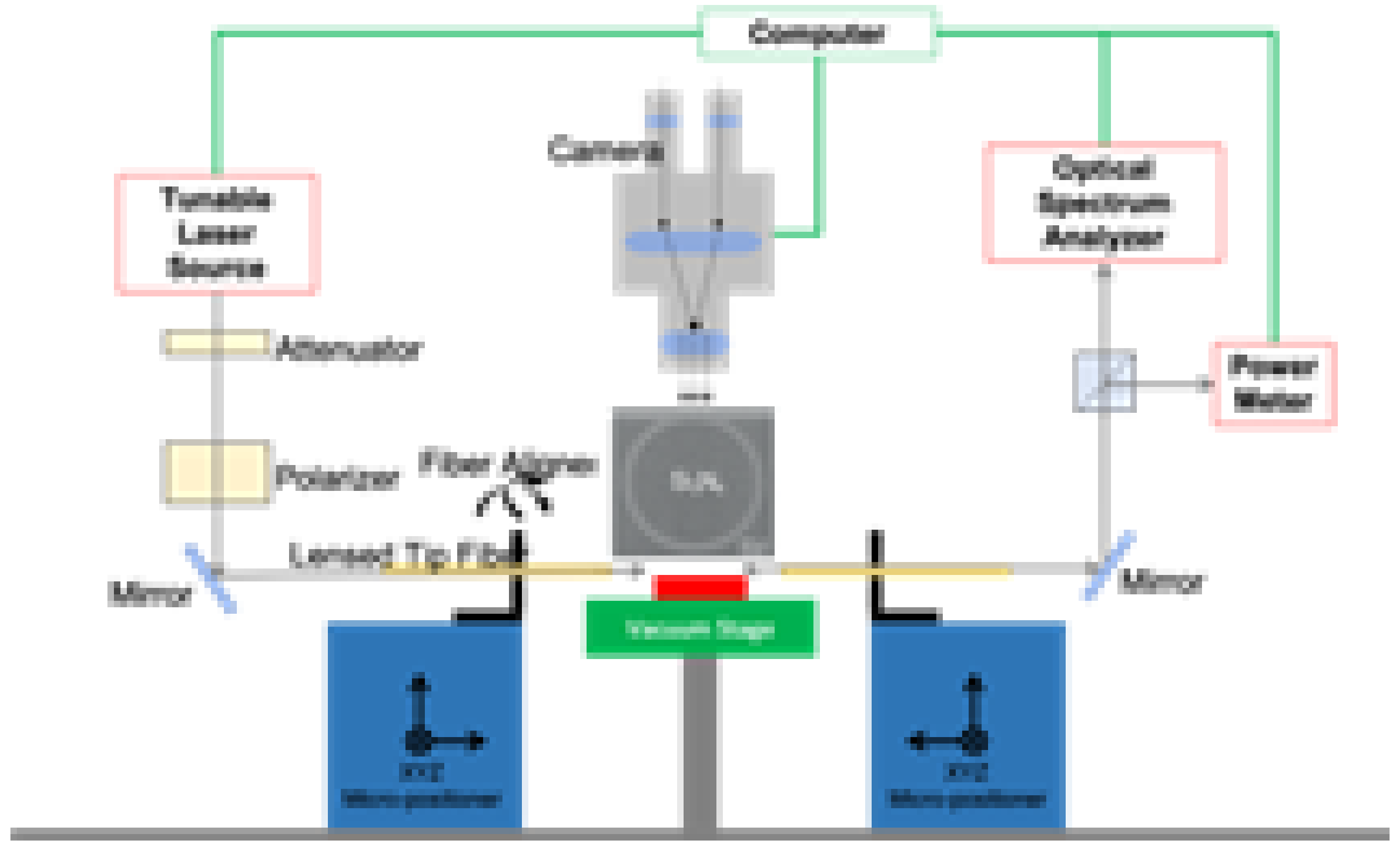

Figure 1. Setup for characterizing the Q-factor of the fabricated ring resonators

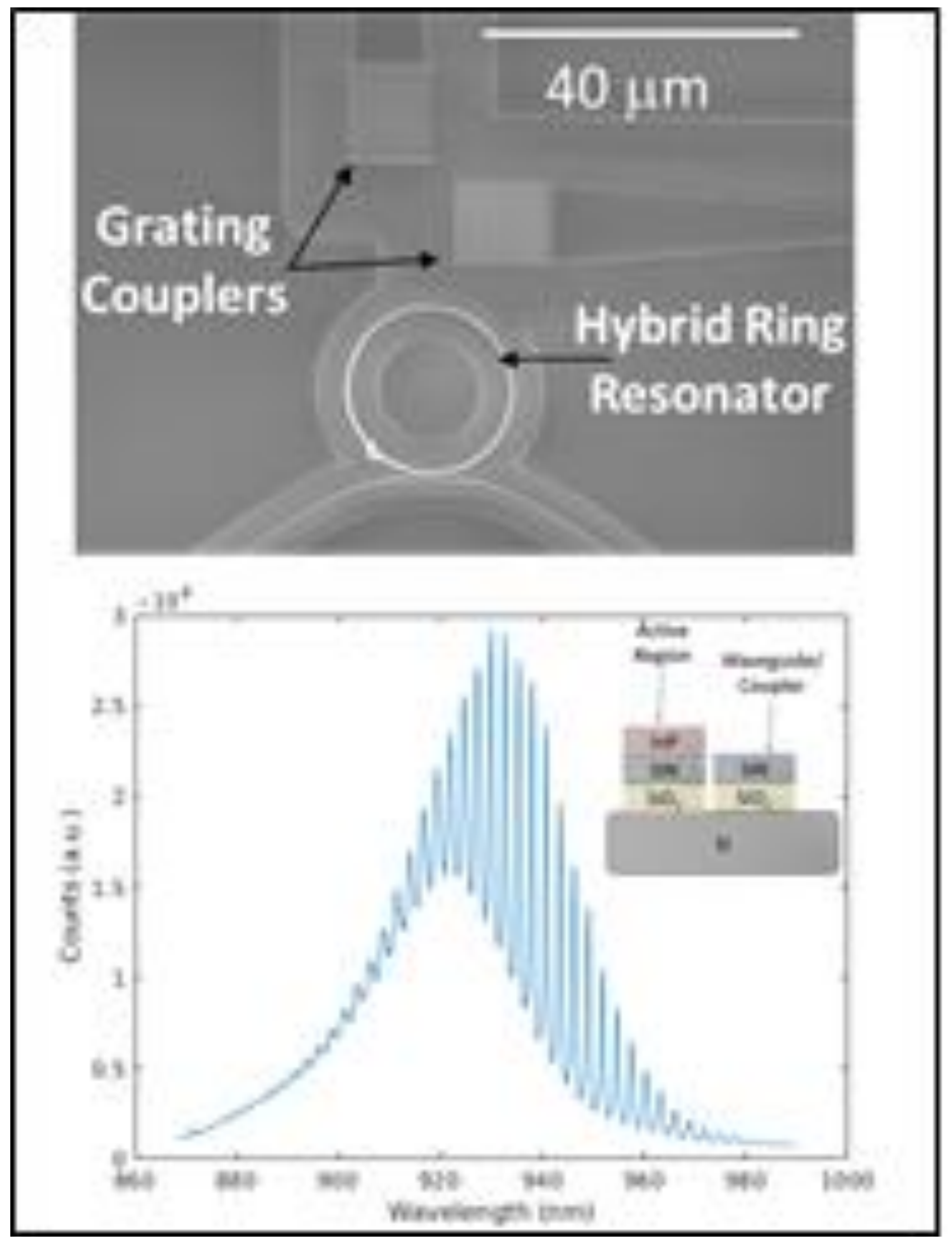

Figure 2. Ring resonator device

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