Ultra-Low Loss Si₃N₄ Planar Waveguide Platform and Applications

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Abstract The ultra low-loss Si₃N₄/Oxide on silicon waveguide platform has yielded a wide range of passive and active components that open up new PIC applications. Delay lines, 3D stacking, gratings, filters, gain, lasers, resonators and switches open new designs for applications including lasers, tunable filters, adaptive dispersion compensators and optical gyroscopes.

Introduction
We describe an integrated ultra low loss (ULLW) Si₃N₄/Oxide on silicon platform that represents a key primary addition to silicon photonics and InP photonic platforms, with characteristics and design points that augment and overcome certain limitations of these other platforms, enabling a broader range of applications and performance. On-chip optical waveguide losses of 0.045dB/m and the realization of long waveguide delays and other PIC elements that enable complex PIC circuits have been reported. This platform opens up a wide array of applications that require integrated optical circuits with very low loss, high level of multi-component integration and functions that perform at lower power consumption than equivalent electronics. In this talk the ULLW platform, passive and active devices, and PIC circuits and applications will be described.

Ultra-Low Loss (ULLW) Integration Platform
The ULLW consists of a silica-based planar waveguide with high aspect ratio thin (40-120nm) Si₃N₄ core, surrounded by a low H absorption oxide cladding. The optical mode is dilute and confined mostly in the SiO₂ cladding. The lower cladding is thermally grown SiO₂ on silicon, with an etched Si₃N₄ core. The very low loss 0.045±0.04dB/m waveguides utilized a wafer-bonded thermal grown SiO₂ upper cladding [1]. More recently in order to provide more complex integration, higher-level functions and greater design flexibility, non-bonded approaches using PECVD deposited upper cladding as shown in Fig. 1. These newer designs have been developed with losses in the range 0.1 to 1.0dB/m.

To accommodate a wide range of design requirements, the waveguide core thickness is designed between 40nm to 175nm in order to balance device size and bend radius and other device characteristics with propagation loss. For example, designing systems on a chip with various core thicknesses each allocated to a dedicated layer in a 3D integration platform [3][6] as illustrated in Fig. 2 with an equalizer on the bottom layer and wavelength demultiplexer on the upper layer. An important feature of this platform is the waveguides support very dilute optical modes that enable high optical power handling capabilities critical for resonant structures without nonlinear loss limitations like two photon absorption, lower Kerr effect when desired, high mode volume, small FSR, very high Q-factors and high photon densities for applications like SBS lasers, optical gyros, and filtering and laser linewidth narrowing.

Fig. 1: Active and passive waveguide structures

Fig. 2: Example 3D structure with optimized layers

This platform has extremely high polarization selectivity (>75dB) waveguides [5] that enable applications that benefit from single polarization operation like high-Q, high mode volume resonators and optical sensors and coupling of many devices on a single chip. Passive structures can be integrated with rare earth
doped gain media like Er3+ to provide on-chip robust temperature independent gain blocks for lasers, amplifiers and pumps.

**ULLW Passive and Active Devices and PICS**

The basic passive Si3N4/Oxide on silicon waveguide structure and modified Er3+/Al2O3 active waveguides are shown in Fig. 1. Table 1 summarizes a subset of ULLW devices demonstrated to date. Ultra low-loss optical delay-lines have been fabricated including single-layer delay lines and coils [1][2] with 90 degrees low-loss crossings and large area coils fabricated across 4 DUV stitched stepper exposures with low loss stitching losses [2] as shown in Figure 3.

**Tab. 1: SiN, ULLW Devices**

|------------------------------------------|----------------------|

True time delay (TTD) circuits have been fabricated by combining ULLW delays with thermally controlled 2x2 MMI switches [6]. 10-stage programmable matched optical filters can be used to replace power hungry DSPs for optical dispersion compensation, without a large optical power penalty, by using ULLW optical switches and long delay lines to realize tunable lattice filters [7]. A last example is chip-scale integration of interferometric optical gyro (iWog) where the optical delays are integrated on-chip instead of using a fiber coil and integrating the iWog optoelectronic front-end is achieved using a silicon photonics PIC [12][13].

**Tab. 2: SiN, ULLW Applications**

<table>
<thead>
<tr>
<th>WDM Erbium Lasers [9][10][11]</th>
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<tr>
<td>True Time Delays [6]</td>
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<tr>
<td>Programmable Optical Equalizers [7]</td>
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<tr>
<td>Integrated Optical Gyros [12][13]</td>
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**ULLW PIC Applications**

ULLW PICs enable a wide range of new applications at the chip-level and offer solutions to handle functions normally done with electronics into the optical domain in order to save power and space. Examples are listed in Table 2. WDM DFB and DBR lasers have been demonstrated with record low threshold powers and slope efficiency by combining active waveguides and sidewall gratings [9]. Due to the extreme temperature stability of erbium as a gain medium and well behaved thermal characteristics of glass these lasers have been operated up to 400C with little change in threshold or slope efficiency [11]. An illustration of sidewall grating etched nitride and erbium doped gain section DBR is shown in Figure 5.

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**References**


Fig. 3: Large area gyro coil

Fig. 4: 3D Multi-Layer ULLW Design

Fig. 5: Erbium doped DBR laser