Hybrid Low Loss Photonic Integrated Circuits: From Chipscale Frequency Combs, Travelling Wave Parametric Amplifiers to Cryogenic Quantum Interconnects

Tobias J. Kippenberg
EPFL, Lausanne, Switzerland

Abstract— Silicon photonics has transitioned from academic research to industrial use in datacenters and optical communications. Yet despite its relevance for microelectronics, silicon is far from an ideal material for integrated photonics. Triggered by the developments in nonlinear integrated photonics for Kerr frequency comb generation, silicon nitride integrated photonic circuits have emerged as an excellently suited material for nonlinear integrated photonics. Owing to advances that allow to manufacture tightly confining low loss waveguides, silicon nitride integrated photonics has significantly matured, and has become today an integrated photonics platform in itself, that benefits from a visible to mid IR transparency window, high power handling, large Kerr nonlinearity — offering the potential to explore applications that are beyond those accessible with silicon.

Over the past decade we have introduced the the photonic damascene process [1], that now allows to achieve tightly confining waveguides with losses below 1.4 dB/m, that are wafer scale and high yield — enabling novel applications such chipscale frequency combs [2] ("microcombs) that are compatible with both heterogeneously and hybrid integrated lasers. Such chipscale microcombs have numerous applications from terabit per second optical communications, neuromorphic computing to parallel LiDAR. We have also shown that the ability to create meter long spiral waveguides enables novel amplification paradigms on chip: allowing net gain continuous pumped traveling wave parametric amplifiers [3], that have remained elusive for the past two decades. In addition using ion implantation it is possible to achieve for the first time Erbium amplifiers [4], that have a performance on par with EDFA, enabling > 140 mW output power. By heterogenous integrated with MEMS actuators, notably AlN and PZT, it is possible, to achieve or narrow linewidth frequency agile lasers [5, 6] that exhibit phase noise below state of the art fiber lasers, and unprecedentedly fast tuning with Petahertz-per second. We also have demonstrated the ability to endow such low loss silicon nitride with electro-optical functionality, via bonding of Lithium Niobate, enabling frequency agile ultrafast tunable lasers [7]. This platform also allows to create modulators for classical readout of superconducting qubits, replacing classical HEMT amplifiers, and quantum coherent transducers from the microwave to the optical domain.

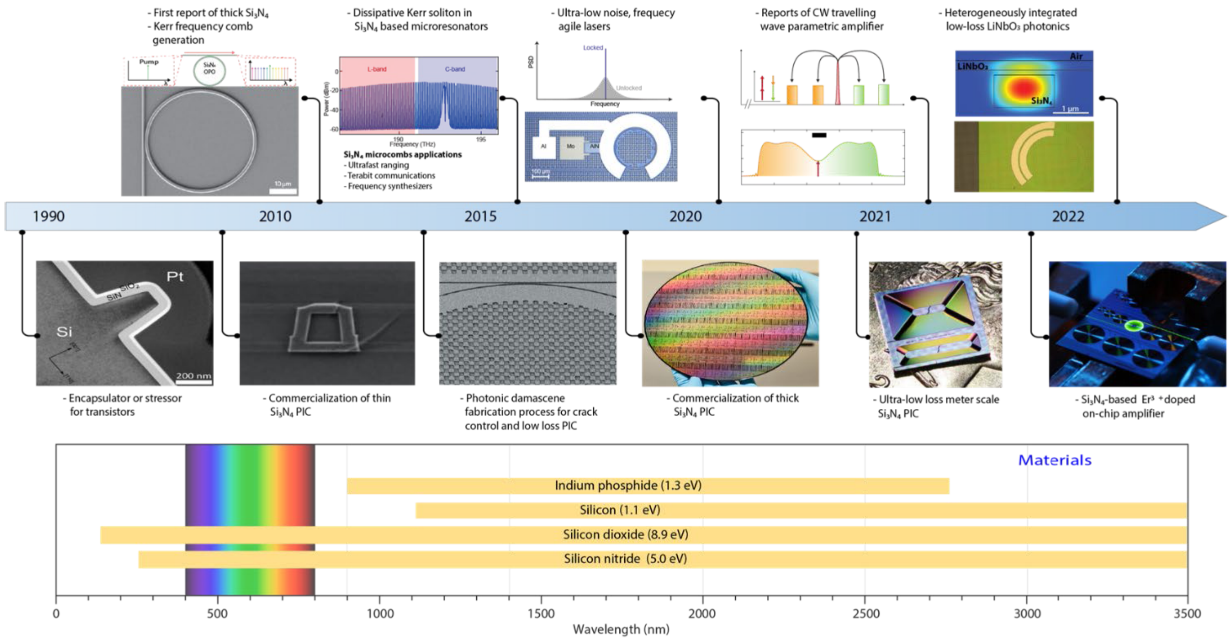

Figure 1: Applications of ultra-low loss silicon nitride based photonic integrated circuits.

Tobias J. Kippenberg is Full Professor in the Institute of Physics and Electrical Engineering at EPFL in Switzerland since 2013 and joined EPFL in 2008 as Tenure Track Assistant Professor. Prior to EPFL, he was Independent Max Planck Junior Research group leader at the Max Planck Institute of Quantum Optics in Garching, Germany. While at the MPQ he demonstrated radiation pressure cooling of optical micro-resonators, and developed techniques with which mechanical oscillators can be cooled, measured and manipulated in the quantum regime that are now part of the research field of Cavity Quantum Optomechanics. Moreover, his group discovered the generation of optical frequency combs using high Q micro-resonators, a principle known now as micro-combs or Kerr combs. This discovery unlocked record data transmission rate which led to the development of new concepts in telecommunications in collaborations with industry. He was recipient of the EFTF Award for Young Scientists (2011), The Helmholtz Prize in Metrology (2009), the EPS Fresnel Prize (2009), ICO Award (2014), Swiss Latsis Prize (2015), the Wilhelmy Klung Research Prize in Physics (2015), the 2018 ZEISS Research Award, and the R. Wood Award (2021). He is co-founder of the startup LIGENTEC SA, an integrated photonics foundry, DEEPLIGHT SA, a supplier of advanced laser sources, and LUXTELLIGENCE SA, a thin-film lithium niobate foundry.

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