Xanadu Tackles Quantum Scaling with Low-loss Photonics

CASE STUDY

/ Business Need

Xanadu is an innovative startup setting out to build quantum computers that are useful and available to people everywhere, pursuing an approach based on programmable integrated quantum photonics. Leveraging the technological advances of the last decades in integrated photonics fabrication and measurement-driven by the telecom industry, Xanadu's solution promises to avoid much of the cumbersome and expensive cryogenics required for superconducting-based solutions in favor of a compact form factor operating at room temperature. An additional benefit to the approach taken by Xanadu is the scalability of the solution, which is enabled by their architectural choices and the use of integrated photonics. Based on these premises, the company recently published its blueprint for a fault-tolerant universal quantum computer.[1]

The primary challenge to building quantum computers is achieving fault tolerance, and the error mitigation strategies used to correct even a single logical qubit can require thousands of physical qubits. For Xanadu, this means that photonic components must be designed with low loss while maintaining performance and stability with respect to manufacturing imperfections. This can only be achieved with savvy component design techniques coupled with the right simulation tools. Minimal loss is crucial, and success is tied to efficient optimization workflows centered around simulation tools that are accurate, flexible, and highly parallel. These flows must have the ability to be seamlessly migrated to on-site and cloud-based high-performance computing (HPC) platforms and with high scalability.

/ Results

Example results for the multiple free design-parameter optimizations of a multimode interferometer (MMI) 1x2 combiner is shown in Figure 2. An outline of the final optimized device is shown in Figure 3, paired with its field intensity distribution. This class of optical components is particularly relevant as it represents a fundamental building block used for both classical and quantum-light routing and mixing on-chip. Several MMIs are required in a single GBS device, and therefore minimizing their insertion loss is of primary importance.

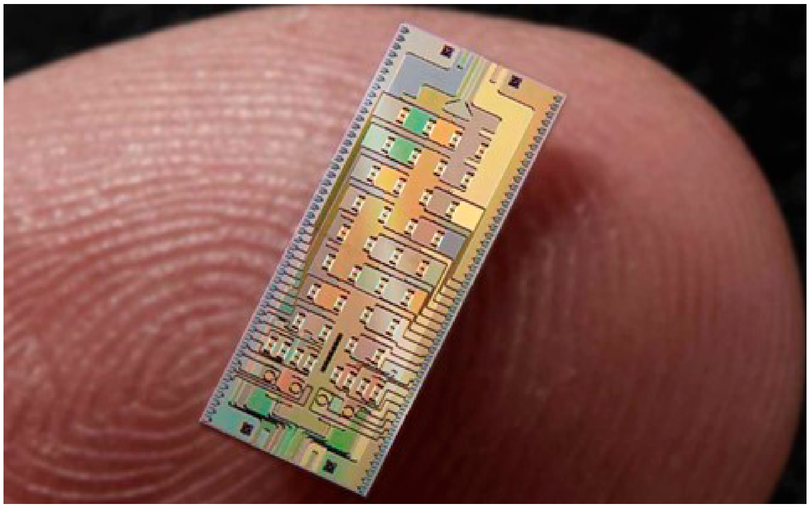

Figure 1. Xanadu's X8 photonic quantum computing chip

/ Xanadu's X8 Quantum Computing Chip

Xanadu's X8 chip was recently launched in fall 2020 and is the first of its kind.[2,3] X8 is a 4 mm x 10 mm 8-qubit Gaussian boson sampling (GBS) device based on photonics and fabricated using a silicon nitride process. When developing X8, Xanadu considered several simulation solutions, but in the end, they decided to use an Ansys multiphysics workflow based on the Ansys Lumerical FDTD, MODE, FEEM, and HEAT solvers.

The decision to use Lumerical tools for simulation was driven by their accuracy, flexible scripting support, advanced optimization functions, and highly interoperable multiphysics solvers. Lumerical provided an ideal platform for Xanadu to achieve its aggressive design goals with a custom flow that combines their internally developed tools with best-in-class photonics simulation.

With an aggressive development timeline, Xanadu leveraged high-performance cloud computing and Lumerical FDTD Accelerators. This was made possible because Ansys Lumerical tools are highly parallelizable and can be seamlessly deployed to both on-site and cloud-based HPC platforms.

With the accuracy, flexibility, and cloud-readiness of Lumerical tools, Xanadu was able to efficiently meet its goals. Xanadu's lead of integration Blair Morrison said, "With the help of Ansys Lumerical with their optimization, scripting, and cloud support, we were able to optimize each and every component of our X8 circuit for unprecedented low-loss performance, compactness, and high manufacturing tolerance."

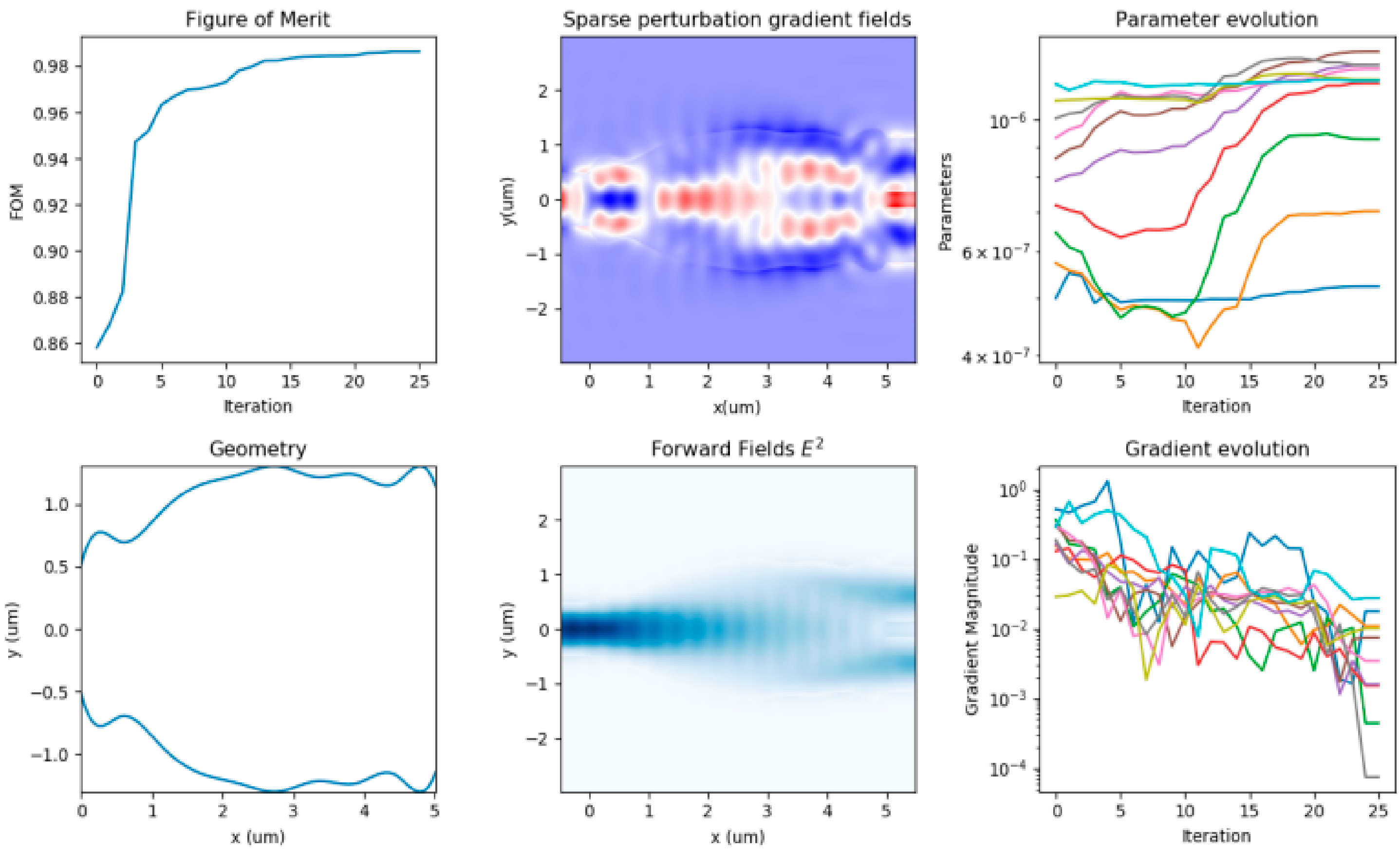

Figure 2. Results for a 1x2 MMI combiner optimization, including: (a) the evolution of the figure of merit (FOM) over time; (b) the sparse perturbation gradient field; (c) the evolution of the parameter values over time; (d) the final geometry; (e) the final forward electric field; and (f) the evolution of the gradient over time

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Ansys Lumerical provided the accuracy, run-time scalability, and flexibility needed to meet Xanadu's design goals on time and on spec. Xanadu's quantum photonics engineer Matteo Menotti said, "Lumerical's FDTD solutions paired with its cloud Accelerators allowed us to reduce insertion loss by more than 15% while significantly accelerating our design schedule".

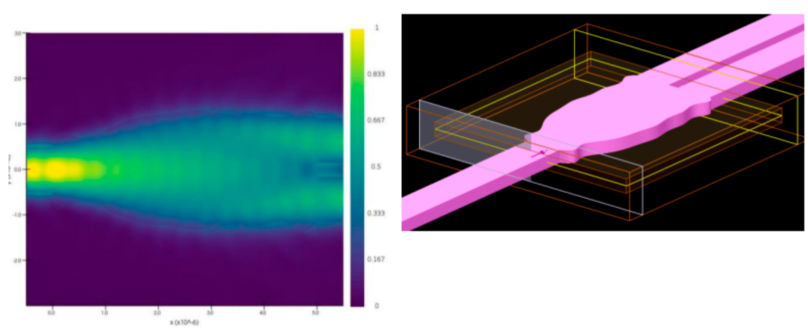

Figure 3. The field intensity distribution (left) and final optimized MMI combiner (right)

/ References

1. Bourassa, J. Eli, et al. "Blueprint for a scalable photonic fault-tolerant quantum computer." Quantum 5 (2021): 392.
2. Arrazola, J. M., et al. "Quantum circuits with many photons on a programmable nanophotonic chip." Nature 591 (2021): 54-60.
3. Vaidya, Varun D., et al. "Broadband quadrature-squeezed vacuum and nonclassical photon number correlations from a nanophotonic device." Science advances 6 (2020): eaba9186.

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