

# Integrated photonic technologies for manipulation and detection of quantum states of light

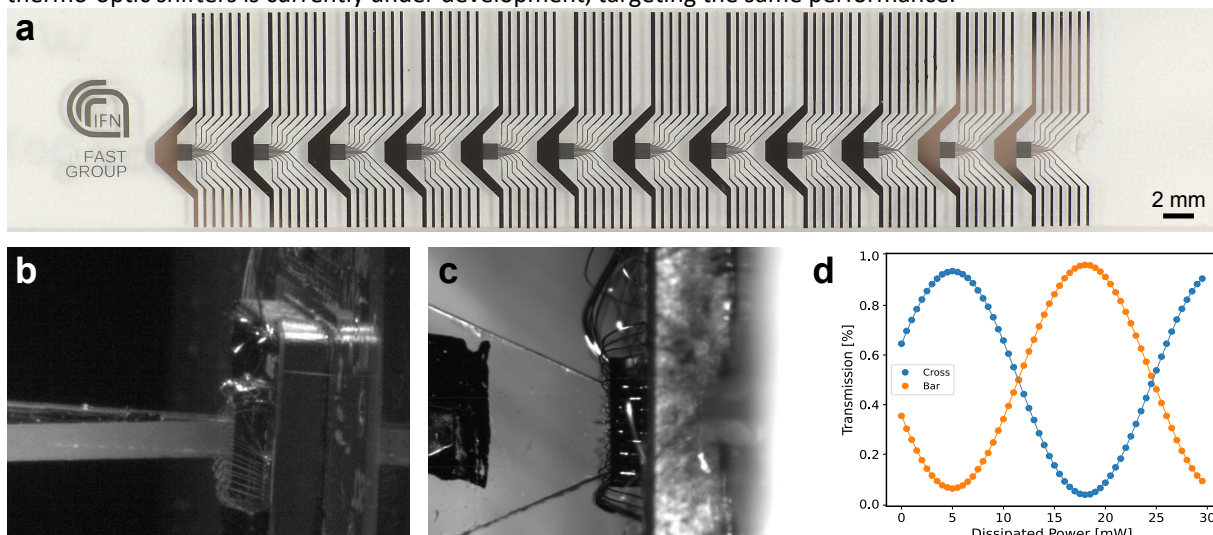
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**Abstract:** We present the fabrication of increasingly complex universal photonic processors via femtosecond laser writing. The hybrid integration of these circuits with single-photon avalanche diode arrays enables practical quantum optics experiments, including photon statistics reconstruction.

Integrated photonics is a highly scalable, room-temperature platform for advancing quantum technologies. Within this field, integrating photonic circuits (PICs), along with single-photon detectors (SPDs), represent essential tools for building practical quantum information processing systems.

On the circuit side, femtosecond laser writing (FLW) has established itself as a prominent platform for the fabrication of PICs [1]. By directly inscribing waveguides into glass substrates with ultrashort laser pulses, FLW enables the realization of 3D architectures with low propagation losses ( $\sim 0.1$  dB/cm), efficient fiber-to-chip coupling ( $< 0.2$  dB), and polarization-insensitive operation. In this platform, recent work has focused on the realization of increasingly complex universal photonic processors. A notable achievement has been the demonstration of a 12-mode processor controlled via 132 thermo-optic phase shifters (Fig. 1a), with total insertion losses below 3 dB and achieving fidelities exceeding 99% [2]. A 20-mode processor employing 380 thermo-optic shifters is currently under development, targeting the same performance.



**Fig. 1** (a) Photograph of the 12-mode universal photonic processor before packaging. (b, c) The PIC-SPAD assembly (side and top view, respectively). (c) Single-photon operation of a reconfigurable FLW MZI directly coupled to the SPAD array.

On the detector side, we rely on single-photon avalanche diodes (SPADs), which are array-compatible and amenable to semiconductor processing [3]. In a recent experiment, we directly coupled a FLW-PIC to a thin silicon SPAD array by orthogonal assembly (Fig. 1b,c), achieving a system efficiency of 41.0% at 561 nm and showing strong tolerance to misalignment. In addition, we used the SPAD array to characterize a reconfigurable MZI (Fig. 1d), validating the viability of such compact PIC-SPAD systems for quantum applications [4]. Building on these results, we are currently leveraging this photonic platform to scale up quantum optics experiments, such as the reconstruction of photon statistics for a large number of simultaneously detected photons.

## References

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- [4] Gualandi, G., et al. "Laser-written reconfigurable photonic integrated circuit directly coupled to a single-photon avalanche diode array." *Light-Sci. Appl.* 14.1 (2025): 199.