
Quantum Chaos in Silicon Photonic Waveguide Graphs

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Résumé

Wave graphs describe wave propagation in networks of one-dimensional bonds-optical waveguides, microwave cables, or quantum wires-connected at vertices, where waves propagate along the links and scatter at junctions (1). Despite their simple 1D structure, they capture key features of transport and resonances in complex wave networks, while remaining unusually tractable: eigenmodes, wavefunctions, and scattering properties can be computed explicitly. This makes them a powerful playground for **quantum chaos**, which seeks universal quantum signatures of underlying classical dynamics. In the classical picture, a particle hops from bond to bond; if the motion is **mixing** (**chaotic**), it explores the network uniformly. For sufficiently large mixing graphs, the spectrum follows GOE random-matrix fluctuations, and rigorous versions of the Bohigas–Giannoni–Schmit scenario can be established (2).

Experimental realizations have mostly relied on microwave networks, giving access to spectra and wave intensities (3,4). Here, we introduce a scalable **silicon-photonic** platform: **integrated optical waveguide networks** at telecom wavelengths and room temperature. In our chips, bonds are single-mode silicon waveguides and vertices are implemented with 2×2 directional couplers.

We probe the graphs by injecting a tunable laser through lensed fibers and recording transmission at the opposite facet. Thanks to high-Q resonances (up to about 2*10ˆ5), we resolve roughly 850 modes in a single device and perform unfolded spectral statistics. We compare two topologies: an ergodic but non-mixing network and a fully mixing one. Consistent with theory, only the mixing graph exhibits GOE-like fluctuations, while the non-mixing graph shows clear deviations.

Beyond spectral data, we exploit silicon's optical nonlinearity: near-field imaging based

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on third-harmonic generation maps the optical wavefunction with subwavelength resolution. Repeating this over many resonances quantifies mode delocalization and links eigenfunction structure to the presence (or absence) of mixing.

This silicon platform validates key predictions of quantum chaos in an integrated, telecom-compatible setting and provides a scalable testbed for wave transport and eigenmode statistics in complex photonic networks.

References

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