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Engineering Thin-Film Lithium Niobate Cavities for On-Chip Frequency-Space Lattices

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The synthetic dimension approach offers a powerful means of probing high-dimensional physical models in comparatively simple devices, by treating non-spatial degrees of freedom as additional independent coordinates. In photonics, the discrete equidistantly spaced frequency modes of a ring resonator are a natural synthetic lattice, straightforwardly coupled and partitioned by dynamic modulation. While early demonstrations of this concept relied on macroscopic fiber loop setups, miniaturization and on-chip integration have been identified as essential steps toward scalable and environmentally stable implementations.

Thin-film lithium niobate on insulator (LNOI) is particularly well suited to this task. Its combination of efficient broadband electro-optic response, low propagation loss, high optical power handling, and strong optical nonlinearity makes it useful for demanding electro-optic applications. Realizing synthetic frequency dimension devices in this setting compresses the optical path length by three orders of magnitude relative to fiber predecessors, shifting the relevant operating frequencies from the megahertz into the gigahertz range.

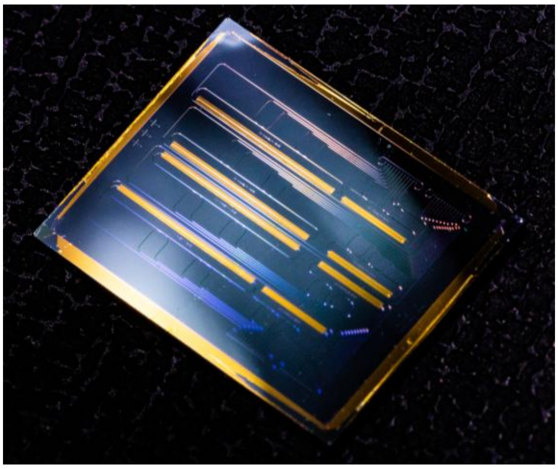

Fig. 1 LNOI photonic chip (14 mm × 11 mm) for synthetic frequency dimension lattice realization.

Within this platform we explore how lattice properties - connectivity, geometry, gauge potential, and boundary conditions - can be controlled through drive signal design and cavity architecture rather than fixed at fabrication. Electro-optic modulation and inter-cavity coupling emerge as complementary tools, together enabling a range of reconfigurable tight-binding lattice configurations of increasing complexity to be realized on the same device.

We present a series of experiments spanning single and coupled LNOI ring cavity configurations. Band structure spectroscopy is used throughout as a direct probe of tight-binding lattice dynamics, connecting experimental observables to the underlying physical models.

REFERENCES

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