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RESEARCH HIGHLIGHT

$\chi^{(2)}$-nonlinearity enables topological soliton frequency comb on a chip

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Topological solitons from a quadratic optical parametric oscillator yield robust frequency combs on a nanophotonic lithium niobate chip.

Optical frequency combs—light sources that generate equally-spaced discrete frequency lines—have revolutionized precision metrology, high-speed communications, spectral sensing and other fields. Integrated Kerr and electro-optic combs have been realized on chips, but they typically require high-Q resonators, specific dispersion conditions, or complex stabilization, which restrict their wavelength coverage and scalability. Degenerate optical parametric oscillators (DOPOs) based on quadratic ($\chi^{(2)}$) nonlinearity offer an alternative pathway to overcome these limitations through topological solitons. However, temporal topological solitons have never been experimentally demonstrated on a nanophotonic platform due to challenges in phase matching and temporal characterization.

Recently, researchers from California Institute of Technology, PINC Technologies and University of Almeria report the first on-chip topological soliton frequency comb [1]. They hybrid-integrate a semiconductor laser with a DOPO on a nanophotonic lithium niobate chip. The DOPO consists of a ring resonator with a coupled poled section for phase-matched parametric process, where pump photons at $2\omega_1$ are converted into pairs of signal photons at ω_1. The coexistence of two opposite-sign solutions creates domain walls at the signal wavelength, corresponding to the formation of dark temporal topological solitons. Bright pulses are formed simultaneously at the pump wavelength, yielding a two-color frequency comb.

On-chip cross-correlation using a degenerate optical parametric amplifier enables direct temporal characterization of the solitons. Above the oscillation threshold, temporal topological solitons as short as 60–70 fs spontaneously form at the signal wavelength (~2 μm). These solitons exist in both normal and anomalous dispersion regimes and require neither a high-Q cavity nor fast modulators.

This demonstration provides a scalable, dispersion-agnostic platform for chip-scale frequency combs, opening access to hard-to-reach spectral regions such as the mid-infrared, and promises applications in Lidar and coherent communications.

Reference

1. Englebert, N., Gray, R.M., Ledezma, L., Sekine, R., Zacharias, T., Ramesh, R., Gutierrez, B.K., Parra-Rivas, P., Marandi, A.: Topological soliton frequency comb in nanophotonic lithium niobate. Nature **652**(8108), 76–81 (2026)

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