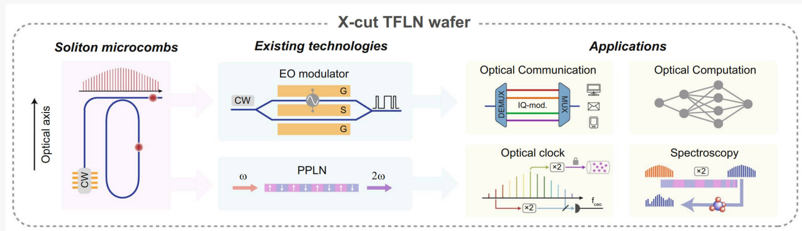
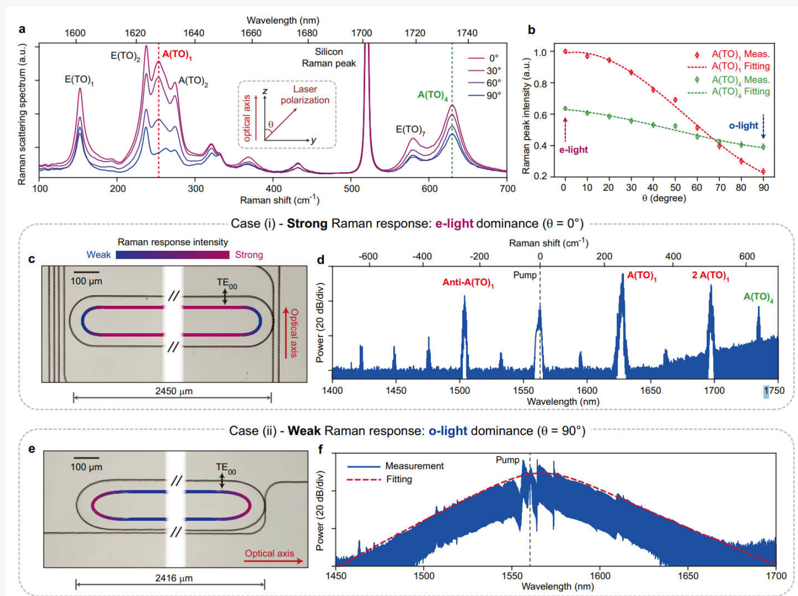
Soliton microcombs in X-cut LiNbO3 microresonators

GA, UNITED STATES, July 28, 2025 /EINPresswire.com/ -- Chip-scale integration of optical frequency combs provides miniaturized instrumentation that bridges optical and microwave signals. Recently, Chinese scientists have demonstrated soliton microcombs in high-Q microresonators on X-cut thin-film lithium niobate (TFLN), a platform that enables monolithic integration of modulators and frequency doublers—essential for realizing complete comb functionality on photonic chips. This advance overcomes a key limitation of TFLN photonics and supports fully integrated, fast-tunable, self-referenced microcombs for chip-scale applications in timekeeping, ranging, and spectroscopy.



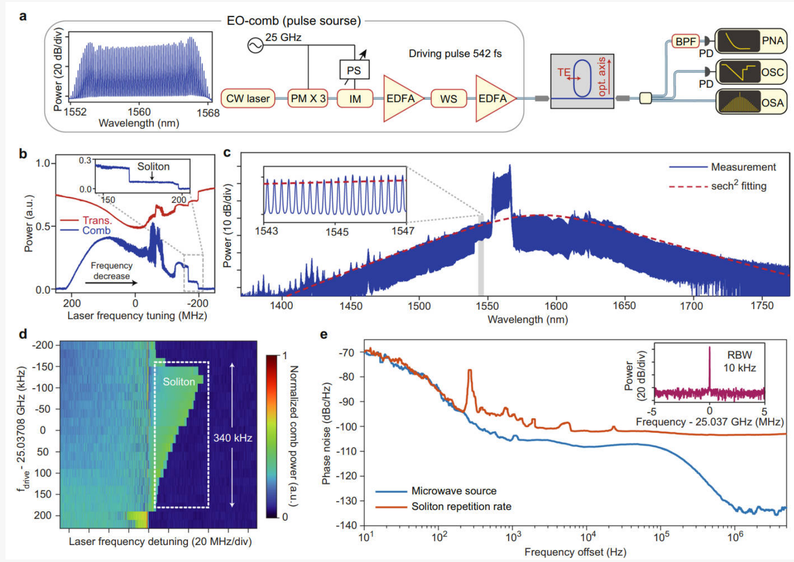
Technologies and applications based-on X-cut TFLN.



Raman response of X-cut TFLN and soliton microcomb generation.

The rapid evolution of integrated photonics is driving the demand for multifunctional material platforms that support diverse on-chip optical operations. Among these platforms, thin-film lithium niobate (TFLN) has emerged as a prime candidate owing to its ultralow optical losses, robust second-order nonlinear response, and high electro-optic efficiency. These advances have enabled state-of-the-art high-speed modulators and efficient frequency doublers (Fig. 1).

Chip-based optical frequency combs, or microcombs, have concurrently transformed the architecture of integrated photonics. These microcombs are indispensable for the co-integration of microwave and atomic systems in applications such as optical frequency synthesis, timekeeping, and advanced computational tasks. Realizing complete comb functionalities on photonic chips requires the co-integration of high-speed modulators and efficient frequency doublers—features that are available in a monolithic form on X-cut thin-film lithium niobate (TFLN). Unfortunately, in this configuration, the strong Raman response associated with extraordinary-polarized light has so far precluded soliton formation, instead favoring Raman lasing.



Pulse-pumped soliton microcombs.

In a new paper published in eLight, a team of scientists, led by Professor Fang Bo from Nankai University and Professor Qi-Fan Yang from Peking University, have demonstrated soliton microcombs in high-Q microresonators on X-cut TFLN chips. By precisely orienting the racetrack microresonator relative to the optical axis, Raman nonlinearity can be mitigated, thus enabling soliton formation under continuous-wave laser pumping. Moreover, the soliton microcomb spectra are extended to 350 nm with pulsed laser pumping. This work expands the capabilities of TFLN photonics and paves the way for the monolithic integration of fast-tunable, self-referenced microcombs, promising applications in optical communication, computation, timing, and spectroscopy (Fig. 1).

Firstly, the research group characterizes the polarization-dependence of the Raman response of an X-cut TFLN chip using Raman spectroscopy (Fig. 2a-b). The Raman intensities decreasing as the pump polarization transitions from parallel (extraordinary light) to perpendicular (ordinary light) to the optical axis. Two racetrack microresonators with different orientations on X-cut TFLN-on-insulator chips are tested.

·In device (i), the straight waveguides are perpendicular to the optical axis, such that the fundamental TE mode is polarized along the optical axis, thereby exhibiting a relatively strong overall Raman response (Fig. 2c). The resulting Raman-Kerr comb spectrum is shown in Fig. 2d.

·In device (ii), the straight waveguides are parallel to the optical axis, such that the fundamental TE mode is polarized perpendicular to the optical axis, thereby exhibiting a relatively weak overall Raman response (Fig. 2e). Soliton microcombs are generated in this microresonator (Fig. 2f). The electrical spectrum and single-sideband phase noise of the soliton repetition frequency is shown in Fig. g-h.

Soliton microcombs can also be generated using synchronized pulsed lasers, offering higher optical-to-optical conversion efficiencies and a broader spectral range. The experimental setup is shown in Fig. 3a. The characteristic step-like comb power is observed during frequency scanning (Fig. 3b). Soliton formation is observed across a wide tuning range of approximately 340 kHz for

the EO comb repetition frequency (Fig. 3d). The optical spectrum of the single soliton state spans from 1400 nm to 1750 nm, following a sech2-shaped spectral envelope (Fig. 3c). The phase noise spectra of the soliton microcomb and the driven microwave are presented in Fig. 3e.
The demonstration of soliton microcombs on X-cut TFLN provides a clear path toward fully integrated on-chip comb functionality. Unlike Si_3N_4 microcombs, the X-cut $LiNbO_3$ platform enables monolithic integration with electrodes for high-speed modulation, thereby affording an additional degree of freedom for fast feedback control of both repetition frequency and carrier-envelope offset frequency of soliton microcombs. Furthermore, integration with PPLN waveguide facilitates on-chip self-reference. Collectively, these advances lay the groundwork for the realization of chip- based optical clocks, building on recent progress in visible laser technologies and photonic-integrated atomic systems.

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