Scientists demonstrate octave-spanning soliton frequency combs on thin-film lithium niobate

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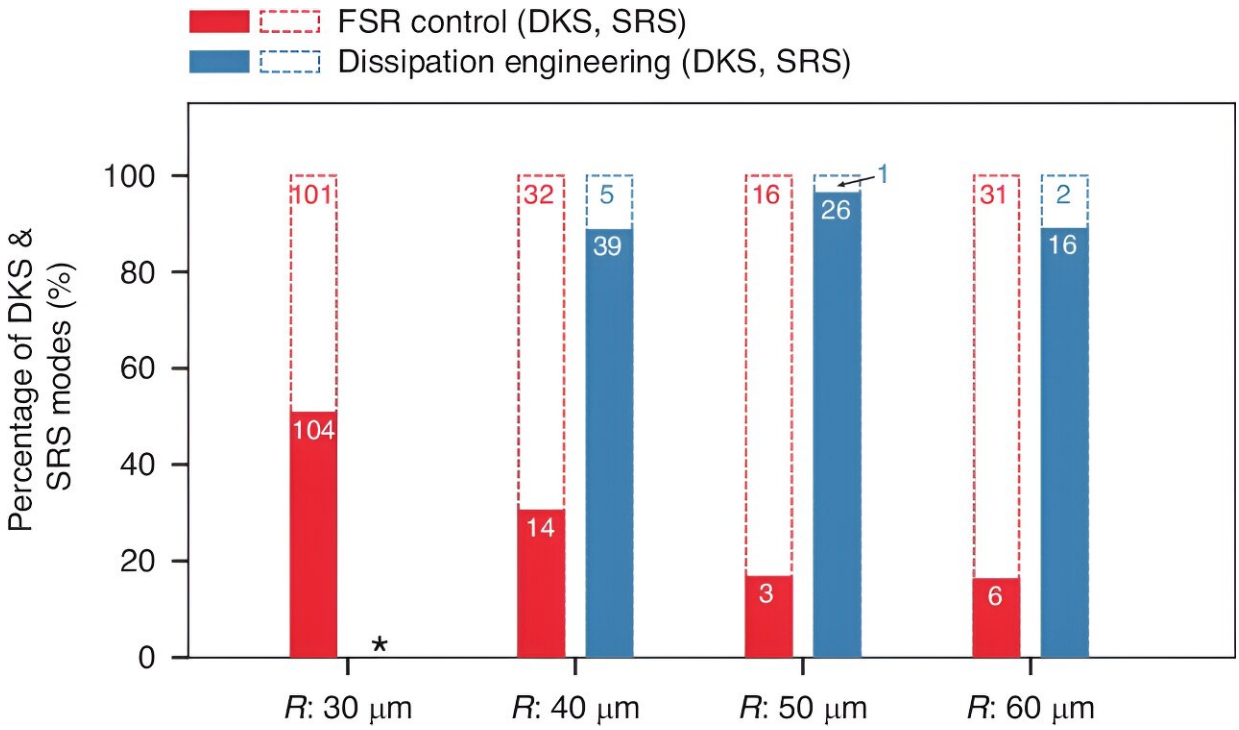

Percentage of microring modes that yield DKS states (solid) or SRS (dashed), utilizing the FSR control method (red) and dissipation engineering method (blue). Dissipation-engineered microrings with radius 30 μm were not attempted (star). A total of 396 modes across 94 microrings have been tested, where all microrings selected approximately satisfied design guidelines. Credit: *Light: Science & Applications* (2024). DOI: 10.1038/s41377-024-01546-7

The invention of optical frequency combs revolutionized frequency metrology and time-keeping. Miniaturization of such combs onto photonic chips, primarily leveraging the microresonator Kerr soliton frequency comb, expands on these functionalities by providing portable solutions to ultrafast spectroscopy, laser frequency synchronization, as well as stable optical, millimeter wave, and microwave frequency generation.

For many such applications, low-noise soliton frequency combs are required, yet stabilization of the soliton repetition rate and carrier-envelope offset typically requires complicated off-chip machinery such as frequency doubling and electro-optic division.

The ultralow-loss thin-film lithium niobate photonic platform, with its strong electro-optic effect and efficient second-harmonic generation, holds promise in hosting integrated frequency combs fully-stabilized by on-chip components. However, octave-spanning solitons with entirely connected spectrum, suitable for stabilization by integrated electro-optic modulators and periodically-poled waveguides, have not been demonstrated.

This is in part due to lithium niobate microresonators exhibiting low-threshold Raman lasing, a nonlinear process in competition with the Kerr effect that initiates parametric oscillation and mode-locks soliton states. Therefore, precise guidelines are needed to suppress Raman lasing in lithium niobate microresonators, which would not only enable octave-spanning soliton sources, but also facilitate their chip-scale stabilization and reliable integration into large-scale photonic systems.

"Thin-film lithium niobate has proven to be a very powerful material for photonics" said Yunxiang Song, a Ph.D. student in Quantum Science and Engineering at Harvard University. "So, our goal was to develop a comprehensive understanding for soliton microcomb generation on this

platform, so they could be used in conjunction with its well-established active modulation and frequency conversion capabilities, ultimately for building better integrated comb sources."

In a new paper published in *Light: Science & Applications*, a team of scientists, led by Professors Marko Lončar and Kiyoul Yang from the John A. Paulson School of Engineering and Applied Sciences at Harvard University, have made progress towards this goal. They demonstrated octave-spanning Kerr soliton frequency combs on the thin-film lithium niobate photonic platform.

They also established design rules, based on engineering the microresonator mode spacing and dissipation profile, that consistently suppresses Raman lasing in favor of soliton frequency comb generation. Specifically, when the microresonator mode spacing is made larger than the Raman gain bandwidth, they showed an octave-spanning soliton spanning 131 to 263 THz.

Even better, when dissipation near Raman lasing modes was increased using a pulley-type coupling, they achieved over 88% success rate in fabricating soliton-supporting microresonators across different designs, including various dispersions and resonator sizes, and also showed an octave-spanning soliton spanning 126 to 252 THz with no spectral gaps.

The reported Raman suppression method may accelerate future development of soliton frequency combs on thin-film lithium niobate, as well as enable straightforward nonlinear frequency comb generation in other emerging electro-optic, crystalline materials such as thin-film lithium tantalate, where interfering Raman lasing is expected to play a role. Additionally, the entirely connected, octave-spanning soliton states may unlock system-level demonstrations, such as optical frequency synthesis and comb-referenced laser spectroscopy.

The team believes that "although still in its early stages, the reliable fabrication of octave-spanning soliton frequency combs shows potential for developing monolithic and compact comb-driven photonic systems based on thin-film lithium niobate."

More information: Yunxiang Song et al, Octave-spanning Kerr soliton frequency combs in dispersion- and dissipation-engineered lithium niobate microresonators, *Light: Science & Applications* (2024). DOI: 10.1038/s41377-024-01546-7

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