Single 'solitons' promising for optical technologies

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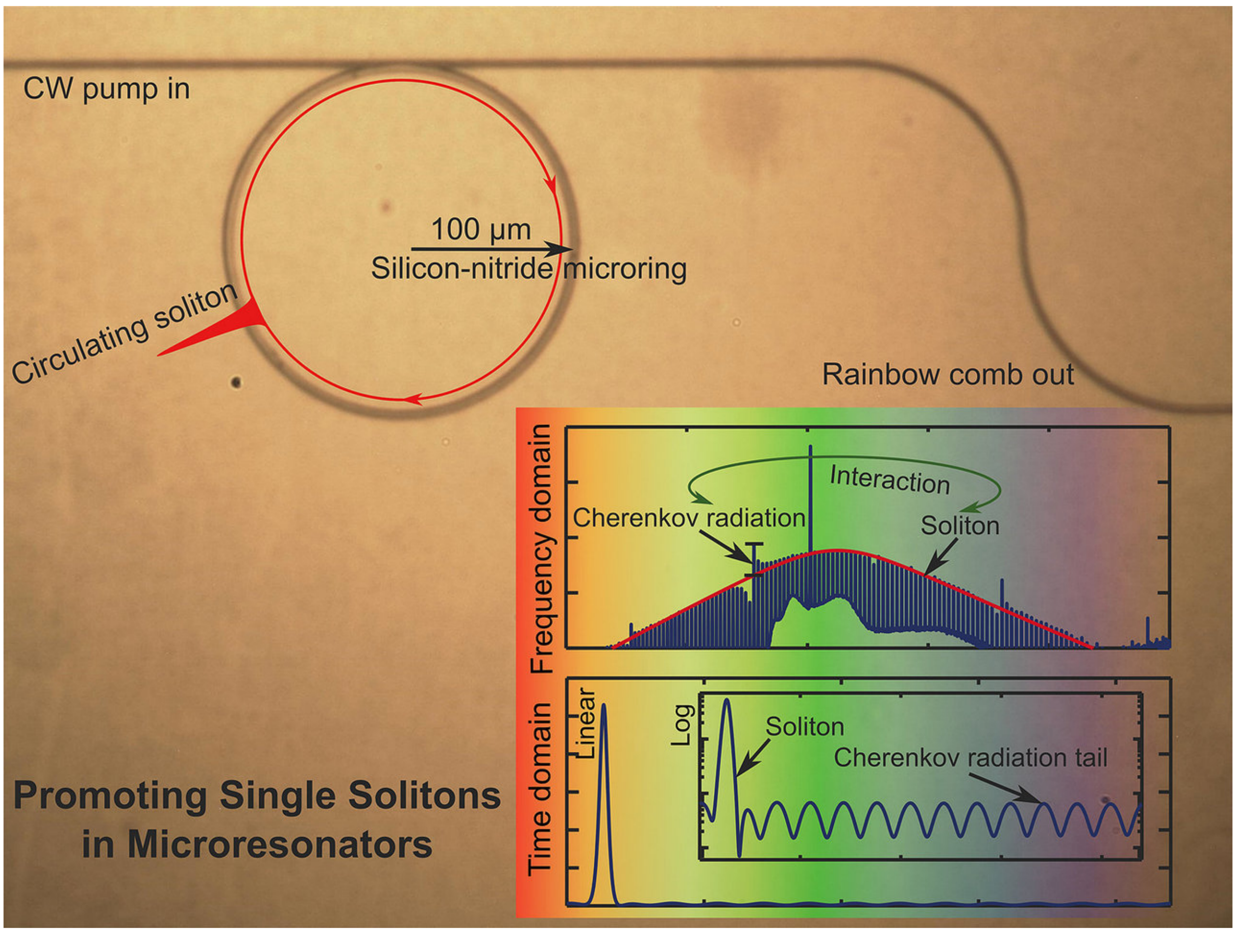

Purdue researchers have used tiny microrings (top left) to generate single pulses of light called solitons, an advance that could aid efforts to develop advanced optical technologies. Two graphs show the relationship between a phenomenon called Cherenkov radiation and production of single solitons. Credit: Purdue University photo/Chengying Bao

Researchers are a step closer to harnessing single pulses of light called solitons, using tiny ring-shaped microresonators, in findings that could aid efforts to develop advanced sensors, high-speed optical communications and research tools.

Being able to harness the solitons using devices small enough to fit on an electronic chip could bring a host of applications, from miniature optical sensors that detect chemicals and biological compounds, to high-precision spectroscopy and optical communications systems that transmit greater volumes of information with better quality.

Researchers have been successful in consistently creating several solitons at a time and single solitons; however, relatively complicated "active tuning" or control is needed. Now, new findings describe a passive method that sidesteps the need of active control for single soliton generation.

"Our work has identified a new way of guiding this system into a single stable soliton," said Andrew M. Weiner, Purdue University's Scifres Family Distinguished Professor of Electrical and Computer Engineering.

The approach has shown how to harness a phenomenon called Cherenkov radiation, which is normally a hindrance to developing practical microresonator devices based on solitons.

"The important novelty of this work is that this Cherenkov interaction isn't just harmful, as it is usually regarded, but actually can in some cases be harnessed to guide you to this nice clean single soliton," Weiner said. "So, we can use Cherenkov radiation to our advantage."

The researchers learned that having a moderately weak source of Cherenkov radiation promotes the generation of single solitons.

"We discovered that if the strength is just right it can guide you to getting a single soliton, which is really useful," Weiner said.

Findings are detailed in research paper published on Aug. 22 in the journal *Optica*. The paper's lead author was Purdue postdoctoral research associate Chengying Bao.

Solitons are short and highly stable pulses of light that form within the microring resonator and propagate stably around the ring in a circular fashion.

"Once each time around, a small portion of the soliton's power couples out of the ring where it is available for use in measurements and applications," Weiner said.

This happens periodically hundreds of billions of times per second because one trip around the tiny structure takes only a few picoseconds, or trillionths of a second.

Such periodic sequences of optical pulses form a "frequency comb" containing a large number of equally spaced optical frequencies. Frequency combs were demonstrated from "mode-locked" lasers more than 15 years ago, with revolutionary impacts on a wide range of precision measurement technologies and leading to the Nobel Prize in Physics in 2005. However, mode-locked lasers are relatively large and costly, which hinders deployment outside of specialized laboratories, Weiner said.

The microrings used in the Purdue study have a radius of about 100 micrometers (about the thickness of a sheet of paper) and are fabricated with a thin film of silicon nitride, a material compatible with silicon material used for electronics. Consequently, microresonators offer potential for smaller, lower cost optical frequency combs that may be compatible with widespread applications.

When there is more than one soliton within the microring, different spectral lines, or colors of light in the comb, may vary in strength.

"Some will be higher power, but some will be much weaker and not useful for applications," Weiner said.

However, generating just a single soliton within the microring promotes a smooth comb.

"Being able to guarantee having a smooth envelope by generating single solitons, so that you don't have some missing most of their power, would be very useful," he said.

Producing solitons generally requires a precise control and tuning of a "continuous wave pump laser." Generating only a single soliton requires even more complex tuning, making this feat difficult. However, the new findings suggest it is possible to produce single solitons passively, significantly simplifying the control process by taking advantage of the optical Cherenkov radiation.

"To obtain single soliton operation, the loss of energy to the Cherenkov radiation should be neither too weak nor too strong," Weiner said. "At present the manufacturing process does not allow sufficient control over the strength of the Cherenkov radiation."

However, future work may explore ways to more actively control the effect with more sophisticated designs based on coupling between two closely spaced microrings, which can be tuned thermally by heating them.

The single soliton combs could enable transmission of hundreds of independent communications channels in optical fibers, precise multi-frequency optical sensors that detect airborne pollutants for environmental monitoring, and ultra-precise "optical clocks" for time keeping or navigation.

"Environmental monitoring is really starting to happen with larger frequency combs based on lasers, but can we do that with chip-scale sources at lower cost for widespread use?" Weiner said. "We're not there yet, but the potential is promising."

The paper was authored by Bao; Yi Xuan, a research assistant professor at Purdue's Birck Nanotechnology Center; senior research scientist Daniel E. Leaird; Stefan Wabnitz, a researcher from Università di Brescia in Italy; Minghao Qi, a Purdue professor of electrical and computer engineering; and Weiner.

More information: Chengying Bao et al. Spatial mode-interaction induced single soliton generation in microresonators, *Optica* (2017). DOI: 10.1364/OPTICA.4.001011

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