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Electrically tunable “super-lasers”

Researchers demonstrate a new way to make spatially separated lasers synchronize and act as a single coherent light source – without extreme conditions or complex materials.

A team of physicists from the University of Southampton (UK), University of Warsaw (PL), Military University of Technology (PL), Institut Pascal, Université Clermont Auvergne, CNRS (FR), and CNR (IT) has developed a new class of tunable photonic devices in which multiple tiny laser beams spontaneously synchronize and behave as a unified, spatially extended, and coherent light source. Remarkably, this effect is achieved at room temperature using a simple system based on liquid crystals and organic dye molecules, opening new possibilities for low-cost and reconfigurable optical technologies.

The study demonstrates that spatially separated laser spots inside an optical microcavity can spontaneously phase-lock – that is, align (or synchronize) their oscillations – and form a collective state known as a “supermode”. Traditionally, such behavior has only been observed in highly specialized semiconductor systems operating at cryogenic temperatures and in the so-called strong light-matter coupling regime.

“Our results show that you don’t need complex quantum materials or low temperatures to achieve this kind of collective behavior of light,” says Dmitriy Dovzhenko from the University of Southampton, the first author of the article, who conceived the experiment. – “We can obtain similar effects in a much simpler and more practical platform, which offers all-optical reconfigurability, electrical tuneability and robust operation under ambient conditions with the benefit of unconventional operation regimes, unattainable in the previously reported platforms”.

“The device consists of a microscopic optical cavity filled with a liquid crystal mixed with a standard laser dye – a technological masterpiece fabricated in Warsaw”, says Wiktor Piecek from the Military University of Technology. When excited by the spatially structured light, corresponding small regions of the cavity begin to lase – emitting coherent light like tiny lasers. Instead of acting independently, these regions can interact through light propagating inside the cavity plane. This interaction leads to the emergence of a macroscopic coherent state extending across multiple laser spots. In this regime, the system behaves like a network of coupled oscillators that spontaneously synchronize. “Surprisingly, this occurs in the weak light-matter coupling regime, where light and matter interact only weakly, and do not form hybridized light-matter state – contrary to previous studies where such hybrid nature of excited state was considered essential” says Dmitry Solnyshkov, theorist form CNRS France.

A key advantage of the new platform is its electrical tunability. By applying a small voltage, researchers can reorient the liquid crystal molecules inside the cavity. This changes how light propagates and allows them to switch the interaction between laser spots on and off and control the strength of coupling between them. It also modifies the direction and polarization of the emitted light by inducing effects analogous to spin-orbit coupling of photons. This level of control enables dynamic reconfiguration of the lasing “supermode” in real time.

“The mechanism behind the effect relies on a subtle physical process” adds Dmitriy Dovzhenko – “When the laser is excited, the optical properties of the material shift slightly (a so-called blueshift), creating a localized effective potential within the excited area of the sample that causes photons to propagate away from the lasing spot within the cavity plane. These propagating coherent photons mediate the interaction between the distant laser spots, allowing them to synchronize – even when separated by tens of micrometers.” Luciano Ricco, currently the post-doc at the University of Warsaw, comments – “We show that such behavior, previously only observed in strongly-coupled light-matter systems, can be theoretically explained and numerically verified with semi-classical approach of Maxwell-Bloch equations, which are commonly used in laser physics to describe the dynamics of a two-state quantum system interacting with the electromagnetic mode of an optical resonator”.

“This is a fundamentally different way of coupling lasers” explains Jacek Szczytko from the Faculty of Physics at the University of Warsaw – “Instead of relying on strong interactions between light and matter, we use the propagation of light itself. The findings open a new route toward scalable and re-programmable photonic systems, with potential applications in optical computing and neural networks allowing photonic simulators of complex systems. Additional control can be crucial in beam shaping and advanced laser technologies. It also opens new possibilities in integrated optical circuits. Because the system operates at room temperature and uses well-established materials, it offers a promising path toward practical devices.”

The work challenges a long-standing assumption in photonics – that complex collective states of light require strong light-matter coupling and cryogenic environments. Instead, it shows that similar physics can emerge in simpler, semiclassical systems, provided the right conditions for light excitation and propagation are met.

Faculty of Physics at the University of Warsaw

Physics and astronomy at the University of Warsaw appeared in 1816 as part of the then Faculty of Philosophy. In 1825, the Astronomical Observatory was established. Currently, the Faculty of Physics at the University of Warsaw consists of the following institutes: Experimental Physics, Theoretical Physics, Geophysics and the Department of Mathematical Methods in Physics. The research covers almost all areas of modern physics on scales from quantum to cosmological. The Faculty's research and teaching staff consists of over 250 academic teachers. About 1300 students and over 150 doctoral students study at the Faculty of Physics UW. The University of Warsaw is among the 200 best universities in the world, educating in the field of physics according to Shanghai’s Global Ranking of Academic Subjects.

SCIENTIFIC PUBLICATION:

Marcin Muszyński, Daniil Bobylev, Piotr Kapuściński, Przemysław Oliwa, Joanna Mędrzycka, Eva Oton, Rafał Mazur, Przemysław Morawiak, Wiktor Piecek, Przemysław Kula, Dmitry Solnyshkov, Gillaume Malpuech, Jacek Szczytko ''Ground Electrically reconfigurable extended lasing state in an organic liquid-crystal'', *Nature Communications* **17**, 5335 (2026). https://doi.org/10.1038/s41467-026-71733-0

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GRAPHIC MATERIALS:

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https://www.fuw.edu.pl/tl_files/press/images/2026/FUW260619b_fot01.jpg
Several spatially separated laser spots spontaneously synchronize and emit as a single coherent supermode in a liquid-crystal microcavity. *(Visualisation: Marcin Muszyński, Faculty of Physics University of Warsaw)*.

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