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Physicists from the University of Warsaw co-created a microlaser emitting two circular beams.

Scientists from the University of Warsaw, the Military University of Technology and the University of Southampton presented a new type of tunable microlaser emitting two beams. – These beams are polarized circularly and directed at different angles – says Prof. Jacek Szczytko from the Faculty of Physics of the University of Warsaw. This achievement was obtained by creating the so-called a persistent-spin helix on the surface of the microcavity. The results have been published in "Physical Review Applied".

To achieve this effect, scientists filled the optical microcavity with a liquid crystal doped with an organic laser dye. The microcavity consists of two perfect mirrors placed close to each other - at a distance of 2-3 microns, so that a standing electromagnetic wave is formed inside. The space between the mirrors was filled with a special optical medium - liquid crystal, which was additionally organized using a special mirror coating. – The characteristic feature of liquid crystals are their elongated molecules and, figuratively speaking, they were "combed" on the surface of the mirrors and could stand up under the influence of an external electric field, turning also other molecules filling the cavity – comments first author, Marcin Muszyński, PhD candidate from the Faculty of Physics of the University of Warsaw.

The light in the cavity interacts with the molecules differently when the electric field of the propagating wave oscillates along the molecules and differently, when oscillation are perpendicular to them. The liquid crystal is a birefringent medium - it can be characterized by two refractive indexes, which depend on the direction of the electric field oscillations, i.e. the so-called electromagnetic wave polarization. The precise arrangement of molecules inside the laser microcavity, obtained at the Military University of Technology resulted in the appearance of two linearly polarized light modes in the cavity - i.e. two standing waves of light with opposite linear polarizations. The electric field changed the orientation of the

molecules inside the optical cavity, which changed the effective refractive index of the liquid crystal layers. Thus it controlled the length of the so-called the optical path of light - the product of the width of the cavity and the refractive index on which the energy (color) of the emitted light depends. One of the modes did not change its energy as the molecules rotated, while the energy of the other increased as the orientation of the molecules changed.

By stimulating optically the organic dye placed between the molecules of the liquid crystal, lasing effect was obtained - coherent light radiation with a strictly defined energy. The gradual rotation of the liquid crystal molecules led to unexpected properties of this lasing. The lasing was achieved for this tunable mode: the laser emitted one linearly polarized beam perpendicular to the surface of the mirrors. The use of liquid crystals allowed for a smooth tuning of the light wavelength with the electric field by as much as 40 nm. – However, when we rotated the liquid crystal molecules so that both energy of modes - the one sensitive to the orientation of the molecules and the one that did not change its energy - overlapped (that is, they were in resonance), the light emitted from the cavity suddenly changed its polarization from linear to two circular: right - and left-handed, with both circular polarities propagating in different directions, at an angle of several degrees – describes Prof. Jacek Szczytko, from the Faculty of Physics of the University of Warsaw.

The phase coherence of the laser has been confirmed in an interesting way. – The so-called persistent-spin helix - pattern of stripes with different polarization of light, spaced 3 microns apart - appeared on the surface of the sample. Theoretical calculations show that such a pattern can be formed when two oppositely polarized beams are phase coherent and both modes of light are inseparable - this phenomenon is compared to quantum entanglement – explains Marcin Muszyński.

So far, the laser works in pulses, because the organic dye that was used slowly photodegrades under the influence of intensive light. Scientists hope that replacing the organic emitter with more durable polymers or inorganic materials (e.g. perovskites) will allow for longer lifetime. –The obtained precisely tunable laser can be used in many fields of physics, chemistry, medicine and communication. We use nonlinear phenomena to create a fully optical neuromorphic network. This new photonic architecture can provide a powerful machine learning tool for solving complex classification and inference problems, and for processing large amounts of information with increasing speed and energy efficiency – adds Prof. Barbara Piętka, from The Faculty of Physics UW.

The research is carried out in the Polariton group at the Faculty of Physics, University of Warsaw, led jointly by Prof. Jacek Szczytko and Prof. Barbara Piętka in collaboration with the Military University of Technology and the University of Southampton. The first author is Marcin Muszyński from the Faculty of Physics, University of Warsaw. This work was co-financed under the grants IDUB UW, NCN and UE H2020 FET Open TopoLight (964770) project.

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, the Department of Mathematical Methods and the Astronomical Observatory. The research covers almost all areas of modern physics, on scales from quantum to cosmological.

The Faculty's research and teaching staff consist of over 200 academic teachers, 81 of whom are professors. About 1,000 students and over 170 doctoral students study at the Faculty of Physics at the University of Warsaw.

SCIENTIFIC PUBLICATION:

Marcin Muszyński, Mateusz Król, Katarzyna Rechcińska, Przemysław Oliwa, Mateusz Kędziora, Karolina Łempicka-Mirek, Rafał Mazur, Przemysław Morawiak, Wiktor Piecek, Przemysław Kula, Pavlos G. Lagoudakis, Barbara Piętka, and Jacek Szczytko *Realizing Persistent-Spin-Helix Lasing in the Regime of Rashba-Dresselhaus Spin-Orbit Coupling in a Dye-Filled Liquid-Crystal Optical Microcavity*
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CONTACT:

Jacek Szczytko
Faculty of Physics University of Warsaw
email: jacek.szczytko@fuw.edu.pl
Tel. +48 22 55 32 764

RELATED WEBSITES WWW:

<http://polariton.fuw.edu.pl/>
Website of the Polariton Group

<https://www.fuw.edu.pl/~szczytko/>
Jacek Szczytko's website

<https://www.fuw.edu.pl/faculty-of-physics-home.html>
Website of the Faculty of Physics University of Warsaw

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GRAPHIC MATERIALS:

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https://www.fuw.edu.pl/tl_files/press/images/FUW220323b_fot01.png

Obtained tunable microlaser emitting two beams. The beams are circularly polarized and directed at different angles. (*visualization: Mateusz Król, source: Faculty of Physics, University of Warsaw*)