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'Liquid' light shows social behaviour

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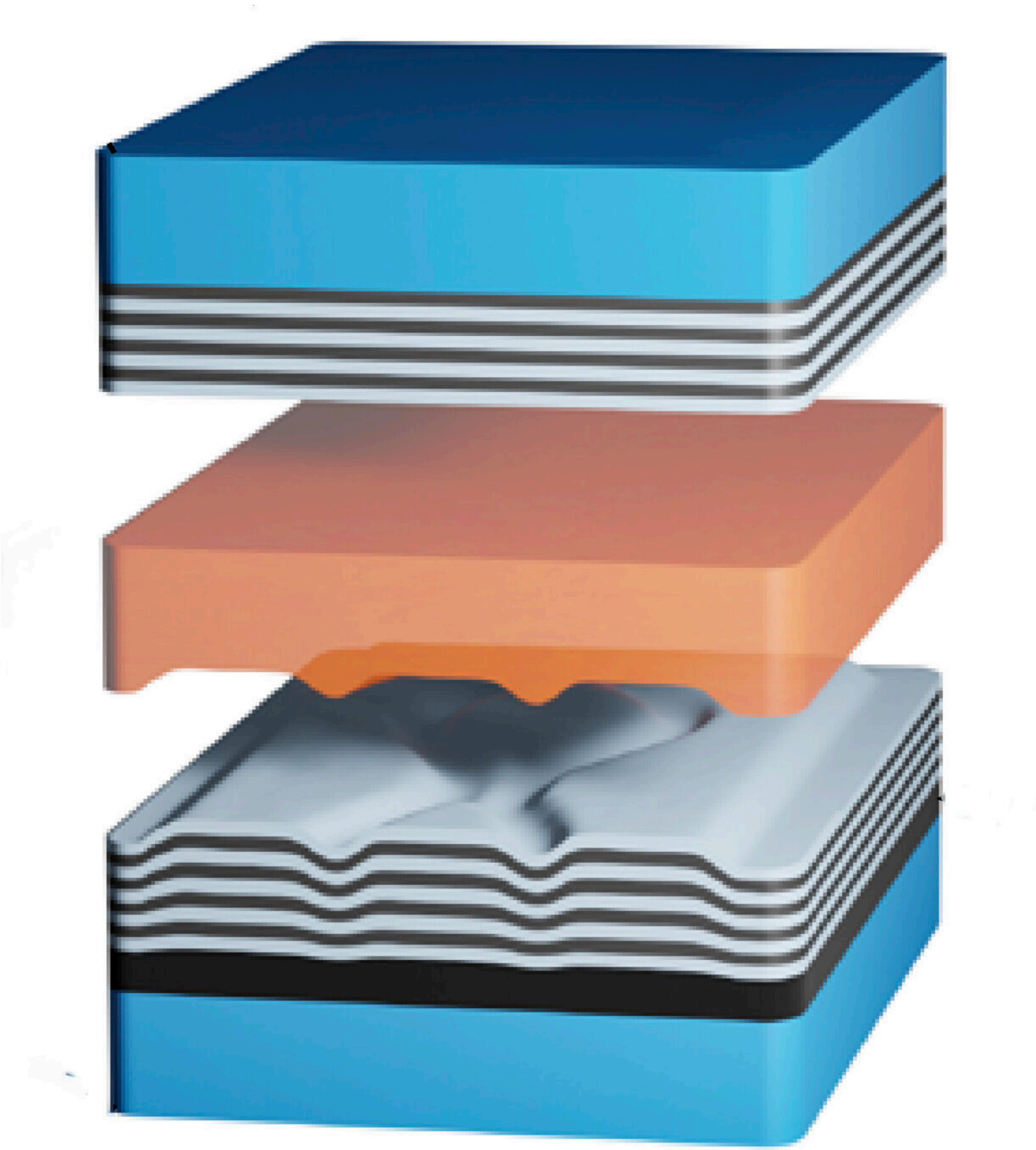

Mirror structures with channels. Credit: University of Twente

Could photons, light particles, really condense? And how will this "liquid light" behave? Condensed light is an example of a Bose-Einstein condensate: The theory has been there for 100 years, but University of Twente researchers have now demonstrated the effect even at room temperature. For this, they created a micro-size mirror with channels in which photons actually flow like a liquid. In these channels, the photons try to stay together as group by choosing the path that leads to the lowest losses, and thus, in a way, demonstrate "social behavior." The results are published in *Nature Communications*.

A Bose-Einstein condensate (BEC) is typically a sort of wave in which the separate particles can not be seen anymore: There is a wave of matter, a superfluid that typically is formed at temperatures close to absolute zero. Helium, for example, becomes a superfluid at those temperatures, with remarkable properties. The phenomenon was predicted by Albert Einstein almost 100 years ago, based on the work of Satyendra Nath Bose; this state of matter was named for the researchers. One type of elementary particle that can form a Bose-Einstein condensate is the photon, the light particle. UT researcher Jan Klärs and his team developed a mirror structure with channels. Light traveling through the channels behaves like a superfluid and also moves in a preferred direction. Extremely low temperatures are not required in this case, and it works at room temperature.

The structure is the well-known Mach-Zehnder interferometer, in which a channel splits into two channels, and then rejoins again. In such interferometers, the wave nature of photons manifests, in which a photon can be in both channels at the same time. At the reunification point, there are now two options: The light can either take a channel with a closed end, or a channel with an open end. Jan Klärs and his team found that the liquid decides for itself which path to take by adjusting its frequency of oscillation. In this case, the photons try to stay together by choosing the path that leads to the lowest losses—the channel with the closed end. You could call it "social behavior," according to researcher Klärs. Other types of bosons, like fermions, prefer staying separate.

The mirror structure somewhat resembles that of a laser, in which light is reflected back and forth between two mirrors. The major difference is in the extremely high reflection of the mirrors: 99.9985 percent. This value is so high that photons don't get the chance to escape; they will be absorbed again. It is in this stadium that the photon gas starts taking the same temperature as room temperature via thermalization. Technically speaking, it then resembles the radiation of a black body: Radiation is in equilibrium with matter. This thermalization is the crucial difference between a normal laser and a Bose-Einstein condensate of photons.

In superconductive devices at which the electrical resistance becomes zero, Bose-Einstein condensates play a major role. The photonic microstructures now presented could be used as basic units in a system that solves mathematical problems like the Traveling Salesman problem. But primarily, the paper shows insight into yet another remarkable property of light.

More information: Mario Vretenar et al, Modified Bose-Einstein condensation in an optical quantum gas, *Nature Communications* (2021). DOI: 10.1038/s41467-021-26087-0

Provided by University of Twente

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