Research achieves photo-induced superconductivity on a chip

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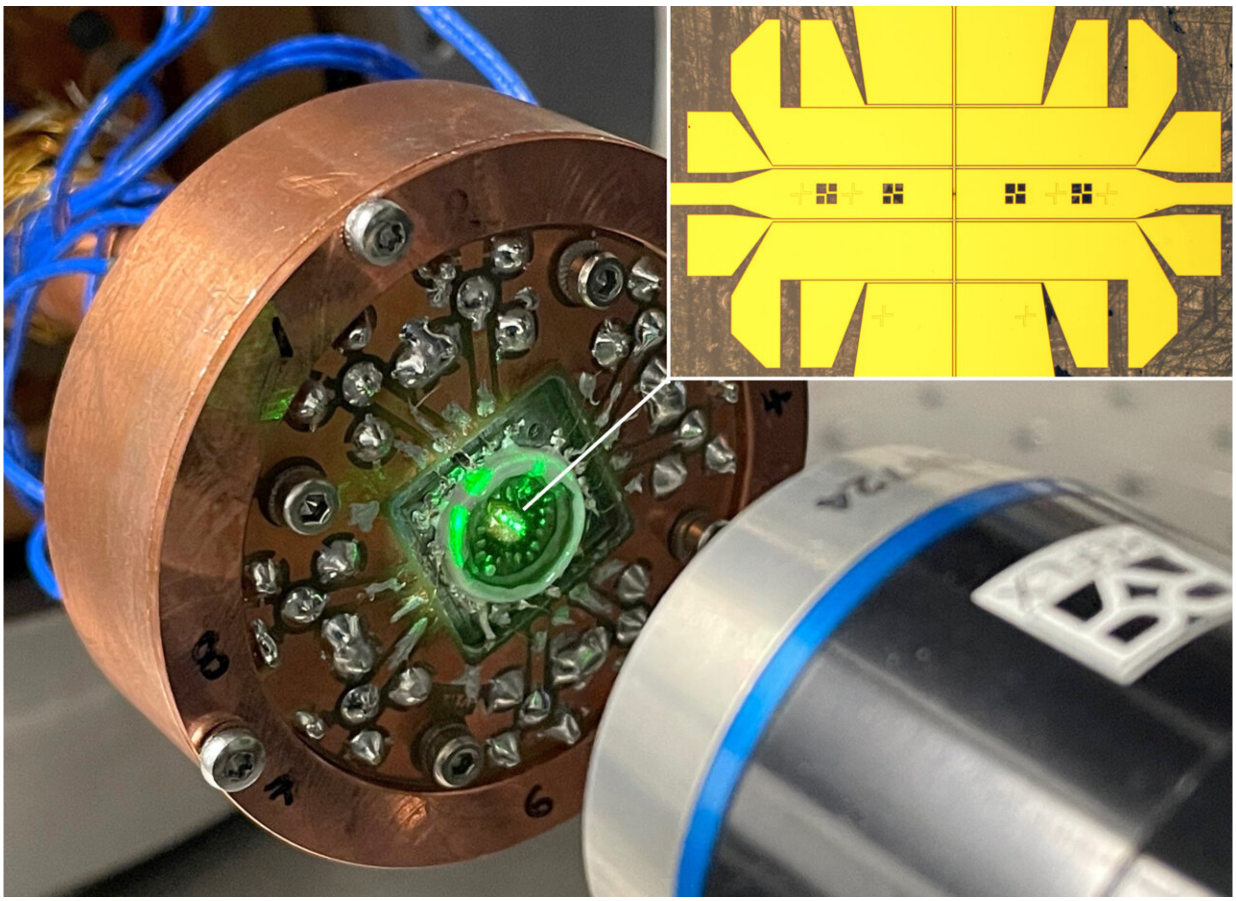

Measurement setup, in which mid-infrared and visible beams are focused onto the optoelectronic device. Insert: Image of the device on which picosecond current pulses are launched, transported and detected. Credit: Eryin Wang, MPSD

Researchers at the Max Planck Institute for the Structure and Dynamics of Matter (MPSD) in Hamburg, Germany, have shown that a previously demonstrated ability to turn on superconductivity with a laser beam can be integrated on a chip, opening up a route toward opto-electronic applications.

Their work, now published in *Nature Communications*, also shows that the electrical response of photo-excited K_3C_{60} is not linear, that is, the resistance of the sample depends on the applied current. This is a key feature of superconductivity, validates some of the previous observations and provides new information and perspectives on the physics of K_3C_{60} thin films.

The optical manipulation of materials to produce superconductivity at high temperatures is a key research focus of the MPSD. So far, this strategy has proven successful in several quantum materials, including cuprates, k-$(ET)_2$-X and K_3C_{60}. Enhanced electrical coherence and vanishing resistance have been observed in previous studies on the optically driven states in these materials.

In this study, researchers from the Cavalleri group deployed on-chip non-linear THz spectroscopy to open up the realm of picosecond transport measurements (a picosecond is a trillionth of a second). They connected thin films of K_3C_{60} to photo-conductive switches with co-planar waveguides.

Using a visible laser pulse to trigger the switch, they sent a strong electrical current pulse lasting just one picosecond through the material. After traveling through the solid at around half the speed of light, the current pulse reached another switch which served as a detector to reveal important information, such as the characteristic electrical signatures of superconductivity.

By simultaneously exposing the K_3C_{60} films to mid-infrared light, the researchers were able to observe non-linear current changes in the optically excited material. This so-called critical current behavior and the Meissner effect are the two key features of superconductors. However, neither has been measured so far—making this demonstration of critical current behavior in the excited solid particularly significant. Moreover, the team discovered that the optically driven state of K_3C_{60} resembled that of a so-called granular superconductor, consisting of weakly connected superconducting islands.

The MPSD is uniquely placed to carry out such measurements on the picosecond scale, with the on-chip set-up having been designed and built in-house. "We developed a technique platform which is perfect for probing non-linear transport phenomena away from equilibrium, like the non-linear and anomalous Hall effects, the Andreev reflection and others," says lead author Eryin Wang, a staff scientist in the Cavalleri group. In addition, the integration of non-equilibrium superconductivity into optoelectronic platforms may lead to new devices based on this effect.

Andrea Cavalleri, who has founded and is currently leading the research group, adds, "This work underscores the scientific and technological developments within the MPSD in Hamburg, where new experimental methods are constantly being developed to achieve new scientific understanding. We have been working on ultrafast electrical transport methods for nearly a decade and are now in a position to study so many new phenomena in non-equilibrium materials, and potentially to introduce lasting changes in technology."

More information: E. Wang et al, Superconducting nonlinear transport in optically driven high-temperature K3C60, *Nature Communications* (2023). DOI: 10.1038/s41467-023-42989-7

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