New quasiparticle unveiled in room temperature semiconductors

February 12 2020

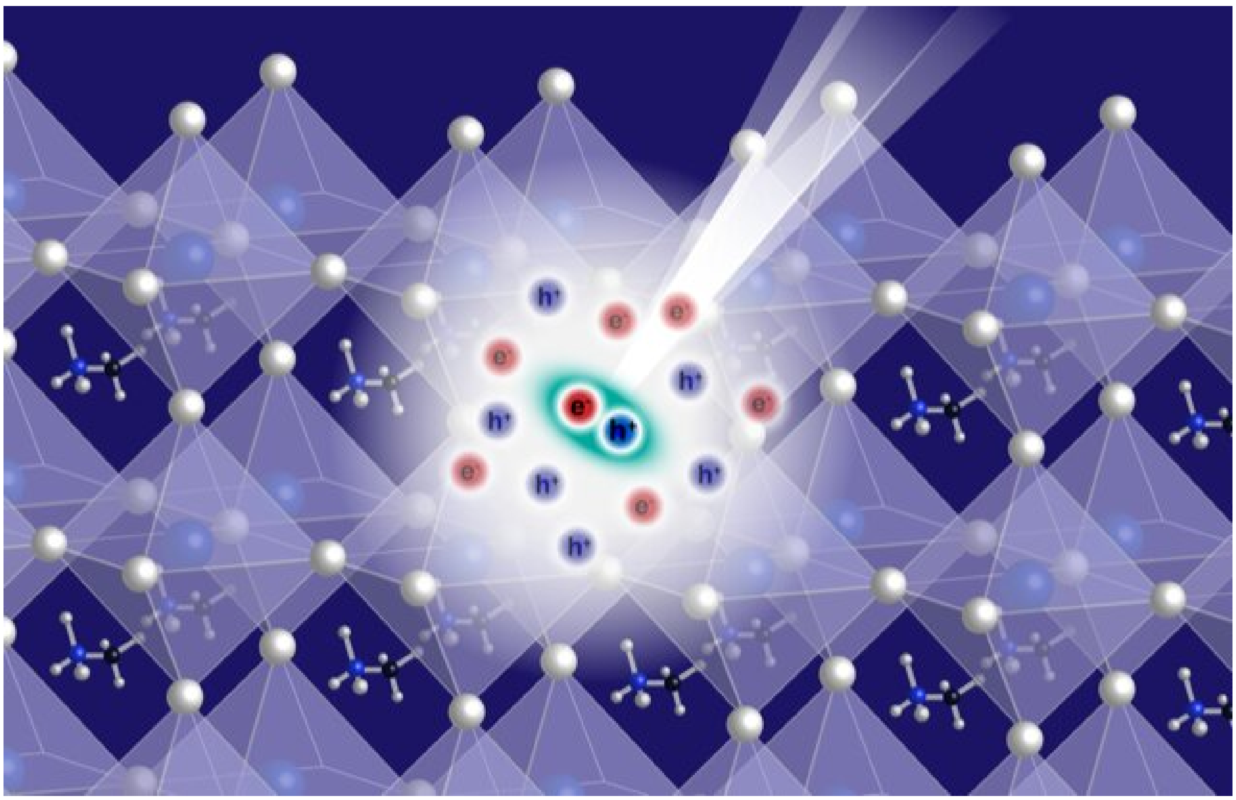

Illustration of the Mahan exciton forming in the dense electron-hole plasma upon photoexcitation of the hybrid perovskite. Credit: Tania Palmieri

Physicists from Switzerland and Germany have unveiled fingerprints of the long-sought particle known as the Mahan exciton in the room temperature optical response of the popular methylammonium lead halide perovskites.

The optical properties of semiconductors are governed by the so-called "excitons," which are bound pairs of negative electrons and positive holes. Excitons are important because they transport energy (with no net charge) across materials and thus they play a crucial role in a number of optoelectronic devices. The ability to control the excitonic properties of semiconductors (by tuning parameters such as temperature, pressure, charge density, electric and magnetic fields) is key to broadening the range and diversity of applications. In particular, when the density of charge carriers (electrons and holes) increases, excitons tend to melt and a semiconductor eventually turns into a metal at the so-called Mott density.

However, back in 1967, Gerald Mahan predicted that a different type of exciton can still persist above the Mott density. Despite years of research, this so-called Mahan exciton has not been observed, let alone under the normal operating conditions of devices.

This has now just been achieved by the group of Majed Chergui at EPFL, in collaboration with Alexander Steinhoff (University of Bremen), Ana Akrap (University of Fribourg), and the group of László Forró (EPFL). Publishing in *Nature Communications*, the teams uncovered signatures of Mahan excitons in the very popular lead-bromide organic-inorganic perovskite. The researchers mapped how the material's optical properties modify at increasing densities of charge carriers with a temporal resolution of tens of femtoseconds (one femtosecond is one millionth of a billionth of a second). Mahan excitons emerged in the optical properties with the distinctive features predicted by theory.

What is remarkable is that this quasiparticle has now been observed in a room temperature lead-halide perovskite, a cheap and abundant semiconductor that is intensely investigated for applications such as photovoltaics, luminescent materials, and lasers. The latter two applications strongly rely on high densities of charge carriers. Furthermore, on the fundamental side, these findings deepen our knowledge of many-body phenomena in condensed matter systems, paving the route toward the use of perovskites for the Bose-Einstein condensation of hybrid states of light and excitons.

"We were studying how the excitons in the perovskite react to the presence of a high charge carrier density," says Edoardo Baldini (previous Ph.D. student at the EPFL and now postdoctoral researcher at MIT). "Suddenly we observed a spectroscopic feature that could not be explained in the framework of other phenomena known in semiconductors." "Digging into the theory we realized it could have been due to the excitons predicted by Mahan long ago," adds Tania Palmieri, the Ph.D. student that led the project. "This discovery further demonstrates that hybrid perovskites are special materials not only for optoelectronic applications but also for unveiling new fundamental processes."

More information: Tania Palmieri et al. Mahan excitons in room-temperature methylammonium lead bromide perovskites, *Nature Communications* (2020). DOI: 10.1038/s41467-020-14683-5

Provided by Ecole Polytechnique Federale de Lausanne