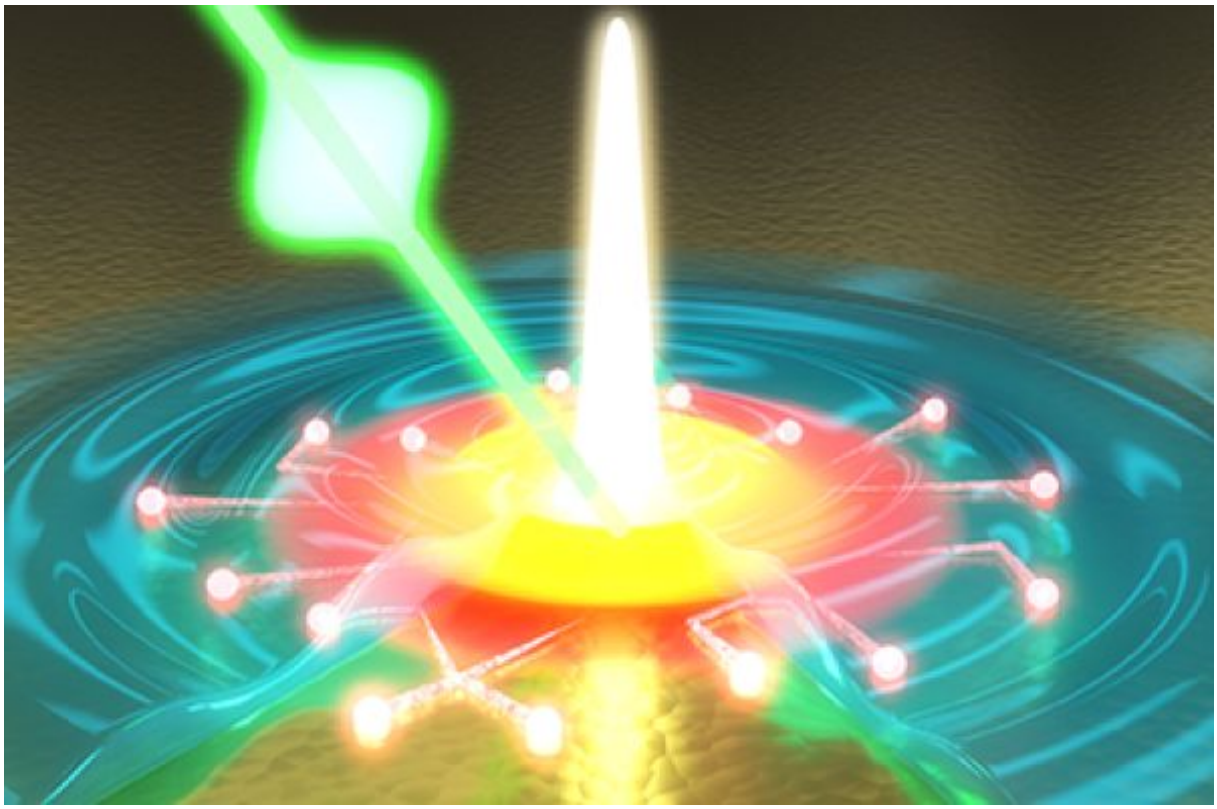


Watching nanoscale heat transport

ICFO researchers use ultrafast thermo-modulation microscopy to understand how heat diffusion occurs in solids on ultrashort timescales.

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Being able to understand and control the transport of charge and energy in electronic devices is of major importance for the development and optimization of solar cells, artificial photosynthesis, or optical detectors, among others. When entering the nanoscale length scales and ultrafast switching regimes, heat management becomes particularly important, since heat diffusion at ultra-fast timescales is governed by non-equilibrium dynamics in conducting materials, such as metals.

When light interacts with a metal, it excites the electrons in the material converting them into "hot electrons". To cool down and dissipate their energy within these ultrashort timescales,

these charge carriers transfer their energy through the metal by interacting with other electrons or lattice vibrations (phonons). That is, in a first few picoseconds the heat dissipation seems to occur due to the interaction between the electrons and the phonons of the lattice as well as the diffusion of these hot electrons.

Previous studies were not able to separate these two components, thus neglecting carrier diffusion when studying thin film systems. Thus, in a recent study published in Science Advances, ICFO researchers Alexander Block, Dr. Matz Liebel, Renwen Yu, led by ICREA Professors at ICFO Niek van Hulst and Javier Garcia de Abajo, in collaboration with researchers from Ben-Gurion University of the Negev, have been able to measure and track the evolution of locally induced hot electrons on a gold thin film, and observe how they distribute and cool down within the metal on the nanometer length scale and with femtosecond time resolution.

In their experiment, the researchers took a 50 nm thin film of gold and illuminated it with a on optical pump pulse. They resolved changes in the sample with a 20 nm spatial precision and 0.25 ps temporal resolution using ultrafast thermo-modulation microscopy, to identify two regimes of heat diffusion and understand how metals at such scales are capable of managing heat dissipation.

They saw that at early times, an initial diffusion occurred very quickly on a timescale of a few picoseconds and which was dominated by hot electron diffusion and by the interplay or coupling between electrons and lattice phonons. After the thermalization of the electrons and the lattice occurred (the system reached thermal equilibrium), the diffusion slowed down approximately 100-fold, permitting heat transfer from the hot end to the cold end of the material at longer time scales. This regime is known as a phonon-limited thermal diffusion phase.

Alongside, to complement the experimental results, they developed a three-dimensional theoretical model, based on a two-temperature model and thermo-optical response, taking into account the effect of electron-phonon coupling. Their simulations were able to describe and confirm the observed diffusion dynamics governed by the two diffusion regimes mentioned previously.

The results of this study pave a way to fully understanding heat management in metals at the nanoscale, which has proven to be essential for the design and development of efficiently operational optoelectronic devices. Even more, such results could have implications in applications that range from thermoelectric devices, broadband detectors, to efficient solar cells and even plasmon-enhanced photochemistry.