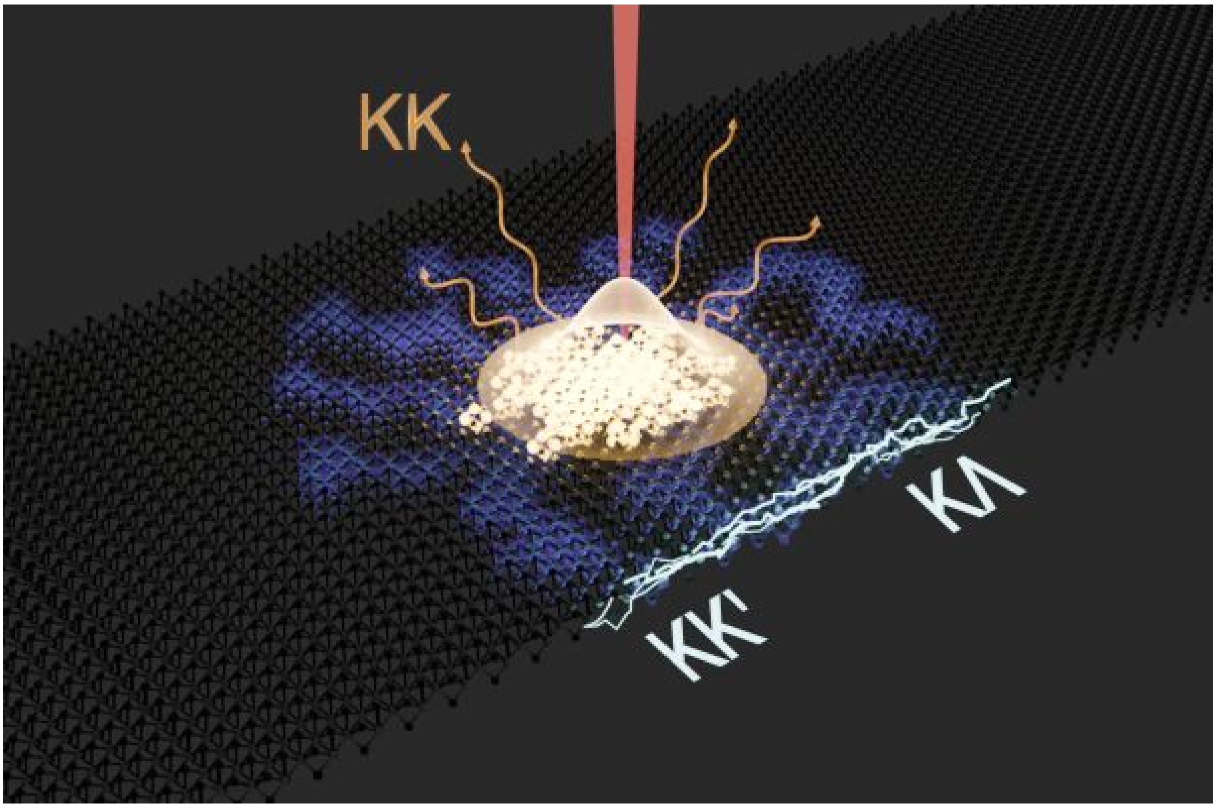

Unmasking the role of dark excitons in current generation

ICFO researchers, in an international collaboration, present a novel technique to track bright and dark excitons, the energy carriers in optoelectronic and photovoltaic materials, at room temperature.

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In the quest for efficient energy transport and current generation, it is essential to understand how energy carriers travel through optoelectronic and photovoltaic devices. These carriers are not electrons on their own. Instead, when an electron becomes excited, its promotion in energy leaves an absence of negative charge or a quasi-positive ?hole' behind. The electron and hole become bound together, forming what is known as an exciton - the true carrier of potential energy within the material. To convert this energy into electrical current, the electron and hole must be separated. Efficient ?charge separation' is a critical process to optimise within emerging materials.

Not all excitons succeed in the generation of current, though. In some cases, the electron loses energy by falling back to fill the hole again, producing a photon - a process called

recombination. These are known as bright excitons, since the emission of photons leads to photoluminescence. Other excitons, however, have a specific configuration which, according to the rules of quantum mechanics, is incompatible with recombination. Because they do not easily emit photons, they are known as dark excitons. The absence of recombination gives dark excitons more time to travel across the device, increasing their chances of reaching an electrode and generating current by undergoing charge separation.
While it has long been accepted that dark excitons play a key role in current generation, the lack of optical response makes them difficult to study. Experimental methods have mostly focused on bright excitons, precisely because they do emit photoluminescence, which can be conveniently detected; or have required cryogenic temperatures, which are far removed from real-world conditions, in order to spot any sign of dark excitons.
Now, ICFO researchers, **Joseph Wragg**, **Dr. Luca Bolzonello**, led by **Prof. ICREA Niek van Hulst**, as well as **Dr. Karuppasamy Pandian Soundarapandian**, **Riccardo Bertini**, led by **Prof. ICREA Frank Koppens**, in collaboration with European Laboratory for Non-Linear Spectroscopy, The School for Engineering of Matter, Transport and Energy (Arizona), and National Institute for Materials Science (Tsukuba, Japan), have developed **a method to track excitons in materials at room temperature**, both spatially and spectrally, **while also distinguishing between bright and dark contributions**. Published in Nano Letters, this new technique offers a powerful tool for understanding how different exciton states behave and opens new avenues for future materials research, including next generation electronics and photovoltaics.
To achieve these results, the team performed action spectroscopy, a method that tracks both the generated photoluminescence and photocurrent signals associated with bright and dark excitons, respectively. As a case study, they investigated WSe2, a two-dimensional semiconductor widely used in materials science. By comparing the two responses, the researchers could infer the role of each type of excitation in the material. Moreover, they examined how the number of material layers affects photoluminescence and photocurrent, exploring not only the interplay between bright and dark excitons at each thickness but the stability of each excited state.
ï¿½**This approach allows us to build a full picture of the creation, life and extinction of excitons in these kinds of materials**ï¿½, shares Joseph Wragg, first author of the article, w o recalls having observed transport over distances as long as several micrometers. And e adds: ï¿½Dark excitons have never been studied in this way before, and our ability to retr eve this kind of data at room temperature is really promising for future work
ï¿½ Overall, this novel technique offers a window into energy transfer mechanisms in mat rials critical for optoelectronic and photovoltaic technologies. The insight the work provides could play a role in unlocking their full pote

Reference:

Joseph Wragg, Luca Bolzonello, Ludovica Donati, Karuppasamy Pandian Soundarapandian,

ICFO

Riccardo Bertini, Seth Ariel Tongay, Kenji Watanabe, Takashi Taniguchi, Frank H. L. Koppens, and Niek F. van Hulst. Dual Action Spectroscopy Exposes the Bright and Dark Excitons of Room-Temperature WSe2. Nano Letters (2025)
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