A trick of light: UC Irvine researchers turn silicon into direct bandgap semiconductor

Discovery enables manufacturing of ultrathin solar panels, advanced optoelectronics.
Thursday, October 31, 2024
Brian Bell
UC Irvine News

UC Irvine’s Ara Apkarian, Distinguished Professor emeritus of chemistry; Dmitry Fishman, adjunct professor of chemistry; and Eric Potma, professor of chemistry, (from left) brought together decades of knowledge and experience on a project that resulted in the discovery of a new way light can interact with matter, specifically indirect semiconductors, like silicon, an important building block in computers, electronics and solar power systems. Their work will help to greatly improve the power, efficiency and usability of the second-most abundant element in Earth's crust.

Picture Credit:
UC Irvine

Irvine, Calif., Oct. 31, 2024 — By creating a new way for light and matter to interact, researchers at the University of California, Irvine have enabled the manufacturing of ultrathin silicon solar cells that could help spread the energy-converting technology to a vast range of applications, including thermoelectric clothing and onboard vehicle and device charging.

The development, subject of a paper recently published as the cover story in the journal *ACS Nano*, hinges on the UC Irvine researchers' conversion of pure silicon from an indirect to a direct bandgap semiconductor through the way it interacts with light.

The UC Irvine team, in collaboration with scientists from Russia's Kazan Federal University and Tel Aviv University, explored an innovative approach by conditioning the light rather than changing the material itself. They confined photons on sub-3-nanometer asperities near the bulk semiconductor, granting light a novel property – expanded momentum – that opens new interaction pathways between light and matter. By "decorating" the silicon surface, the researchers said, they achieved a boost in light absorption by orders of magnitude, along with a significant increase in device performance.

"In direct bandgap semiconductor materials, electrons transition from the valence band to the conduction band. This process requires only a change in energy; it's an efficient transfer," noted lead author Dmitry Fishman, UC Irvine adjunct professor of chemistry. "In indirect bandgap materials, like silicon, an additional component – a phonon – is needed to provide the electron the momentum necessary for the transition to occur. Since the likelihood of a photon, phonon and electron interacting at the same place and time is low, silicon's optical properties are inherently weak."

He said that as an indirect bandgap semiconductor, silicon's poor optical properties limit the development of solar energy conversion, and optoelectronics in general, which is a drawback considering that silicon is the second-most abundant element in Earth's crust and the foundation on which the world's computer and electronics industries were built.

“Photons carry energy but almost no momentum, but if we change this narrative explained in textbooks and somehow give photons momentum, we can excite electrons without needing additional particles,” said co-author Eric Potma, UC Irvine professor of chemistry. “This reduces the interaction to just two particles, a photon and an electron, similar to what occurs in direct bandgap semiconductors, and increases light absorption by a factor of 10,000, completely transforming light-matter interaction without changing the chemistry of the material itself.”

Co-author Ara Apkarian, UC Irvine Distinguished Professor emeritus of chemistry, said: “This phenomenon fundamentally changes how light interacts with matter. Traditionally, textbooks teach us about so-called vertical optical transitions, where a material absorbs light with the photon changing only the electron’s energy state. However, momentum-enhanced photons can change both the energy and momentum states of electrons, unlocking new transition pathways we hadn’t considered before. Figuratively speaking, we can ‘tilt the textbook,’ as these photons enable diagonal transitions. This dramatically impacts a material’s ability to absorb or emit light.”

According to the researchers, the development creates an opportunity to exploit recent advances in semiconductor fabrication techniques at the sub-1.5-nanometer scale, which has the potential to affect photo-sensing and light-energy conversion technologies.

“With the escalating effects of climate change, it’s more urgent than ever to shift from fossil fuels to renewable energy. Solar energy is key in this transition, yet the commercial solar cells we rely on are falling short,” Potma said. “Silicon’s poor ability to absorb light means that these cells require thick layers – almost 200 micrometers of pure crystalline material – to effectively capture sunlight. This not only drives up production costs but also limits efficiency due to increased charge carrier recombination. The thin-film solar cells that are one step closer to reality due to our research are widely seen as the solution to these challenges.”

Other co-authors on this study included Jovany Merham and Aleksey Noskov of UC Irvine; Kazan Federal University researchers Elina Battalova and Sergey Kharintsev; and Tel Aviv University investigators Liat Katrivas and Alexander Kotlyar. The project received financial support from the Chan Zuckerberg Initiative.

About UC Irvine's Brilliant Future campaign: Publicly launched on Oct. 4, 2019, the Brilliant Future campaign aims to raise awareness and support for the university. By engaging 75,000 alumni and garnering $2 billion in philanthropic investment, UC Irvine seeks to reach new heights of excellence in student success, health and wellness, research and more. The School of Physical Sciences plays a vital role in the success of the campaign. Learn more by visiting https://brilliantfuture.uci.edu/uci-school-of-physical-sciences.

About the University of California, Irvine: Founded in 1965, UC Irvine is a member of the prestigious Association of American Universities and is ranked among the nation's top 10 public universities by *U.S. News & World Report*. The campus has produced five Nobel laureates and is known for its academic achievement, premier research, innovation and anteater mascot. Led by Chancellor Howard Gillman, UC Irvine has more than 36,000 students and offers 224 degree programs. It's located in one of the world's safest and most economically vibrant communities and is Orange County's second-largest employer, contributing $7 billion annually to the local economy and $8 billion statewide. For more on UC Irvine, visit www.uci.edu.

Media access: Radio programs/stations may, for a fee, use an on-campus studio with a Comrex IP audio codec to interview UC Irvine faculty and experts, subject to availability and university approval. For more UC Irvine news, visit news.uci.edu. Additional resources for journalists may be found at https://news.uci.edu/media-resources.

UC Irvine News
Press Releases
Chemistry
The Future of Fundamental Science
View PDF