UC Irvine-led research team discovers new property of light

Photon momentum discovery unlocks novel, silicon-based optoelectronic capabilities.

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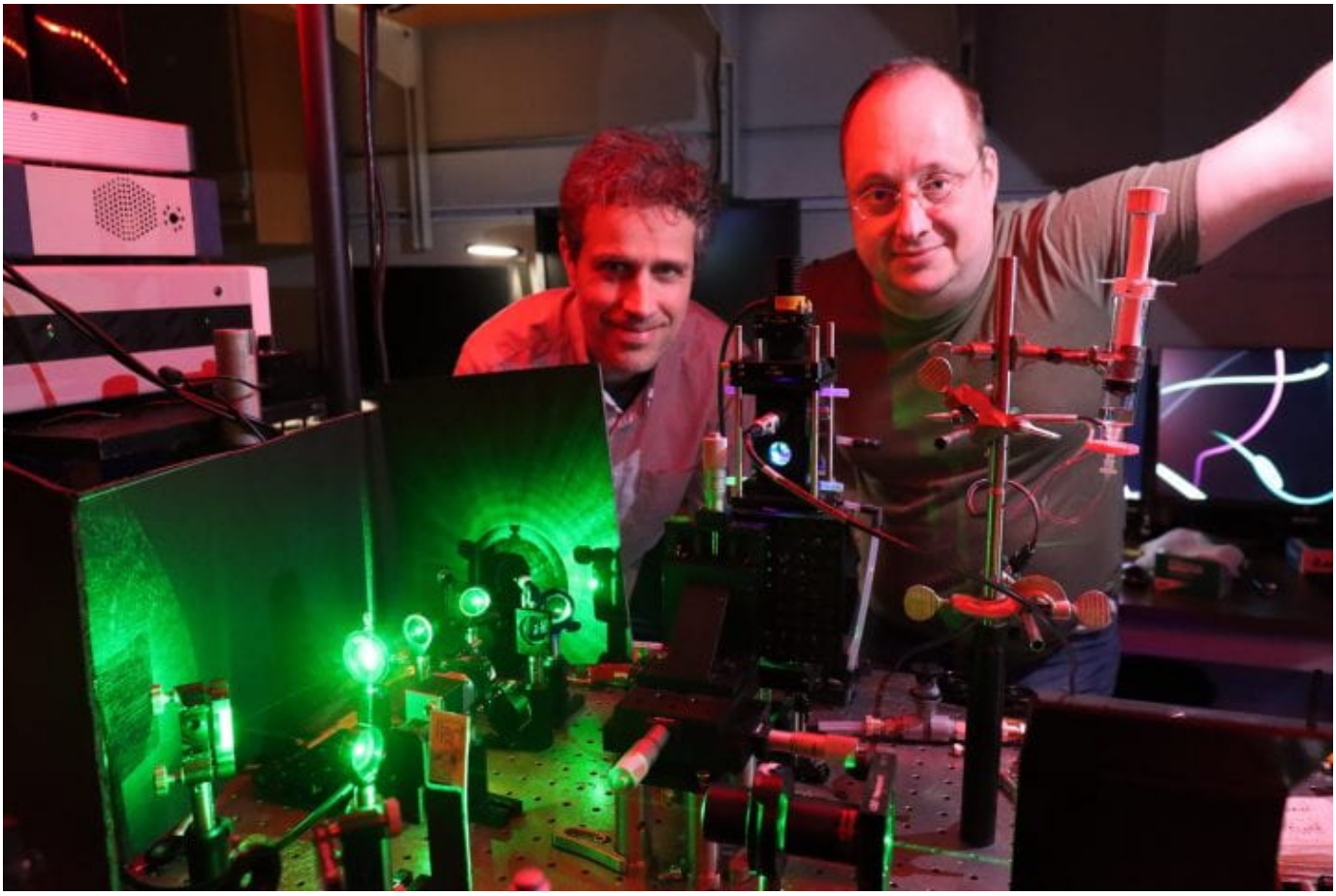

Dmitry Fishman (right) and Eric Potma, both professors of chemistry at UC Irvine, made a breakthrough discovery regarding the way light interacts with solid matter in silicon. Their work could lead to improved efficiency in solar electric systems, semiconductor lasers and other advanced optoelectronic technologies.

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Irvine, Calif., May 6, 2024 – A research team headed by chemists at the University of California, Irvine has discovered a previously unknown way in which light interacts with matter, a finding that could lead to improved solar power systems, light-emitting diodes, semiconductor lasers and other technological advancements.

In a paper published recently in the journal *ACS Nano*, the scientists, joined by colleagues at Russia's Kazan Federal University, explain how they learned that photons can obtain substantial momentum, similar to that of electrons in solid materials, when confined to nanometer-scale spaces in silicon.

"Silicon is Earth's second-most abundant element, and it forms the backbone of modern electronics. However, being an indirect semiconductor, its utilization in optoelectronics has been hindered by poor optical properties," said lead author Dmitry Fishman, UC Irvine adjunct professor of chemistry.

He said that while silicon does not naturally emit light in its bulk form, porous and nanostructured silicon can produce detectable light after being exposed to visible radiation. Scientists have been aware of this phenomenon for decades, but the precise origins of the illumination have been the subject of debate.

Artists rendering of photo illumination in silicon

"In 1923, Arthur Compton discovered that gamma photons possessed sufficient momentum to strongly interact with free or bound electrons. This helped prove that light had both wave and particle properties, a finding that led to Compton receiving the Nobel Prize in physics in 1927," Fishman said. "In our experiments, we showed that the momentum of visible light confined to nanoscale silicon crystals produces a similar optical interaction in semiconductors."

An understanding of the origin of the interaction requires another trip back to the early 20th century. In 1928, Indian physicist C.V. Raman, who won the 1930 Nobel Prize in physics, attempted to repeat the Compton experiment with visible light. However, he encountered a formidable obstacle in the substantial disparity between the momentum of electrons and that of visible photons. Despite this setback, Raman's investigations into inelastic scattering in liquids and gases led to the revelation of what is now recognized as the vibrational Raman effect, and spectroscopy – a crucial method of spectroscopic studies of matter – has come to be known as Raman scattering.

"Our discovery of photon momentum in disordered silicon is due to a form of electronic Raman scattering," said co-author Eric Potma, UC Irvine professor of chemistry. "But unlike conventional vibrational Raman, electronic Raman involves different initial and final states for the electron, a phenomenon previously only observed in metals."

For their experiments, the researchers produced in their laboratory silicon glass samples that ranged in clarity from amorphous to crystal. They subjected a 300-nanometer-thick silicon film to a tightly focused continuous-wave laser beam that was scanned to write an array of straight lines. In areas where the temperature did not exceed 500 degrees Celsius, the procedure resulted in the formation of a homogenous cross-linked glass. In areas where the temperature exceeded 500 C, a heterogeneous semiconductor glass was formed. This “light-foamed film” allowed the researchers to observe how electronic, optical and thermal properties varied on the nanometer scale.

“This work challenges our understanding of light and matter interaction, underscoring the critical role of photon momenta,” Fishman said. “In disordered systems, electron-photon momentum matching amplifies interaction – an aspect previously associated only with high-energy – gamma – photons in classical Compton scattering. Ultimately, our research paves the way to broaden conventional optical spectroscopies beyond their typical applications in chemical analysis, such as traditional vibrational Raman spectroscopy into the realm of structural studies – the information that should be intimately linked with photon momentum.”

Potma added: “This newly realized property of light no doubt will open a new realm of applications in optoelectronics. The phenomenon will boost the efficiency of solar energy conversion devices and light-emitting materials, including materials that were previously considered not suitable for light emission.”

Co-authors on this study included Jovany Merham, a UC Irvine junior specialist in chemistry, and Kazan Federal University researchers Sergey Kharintsev, Elina Battalova and Aleksey Noskov. The project received financial support from the Chan Zuckerberg Initiative and Kazan Federal University.

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.

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