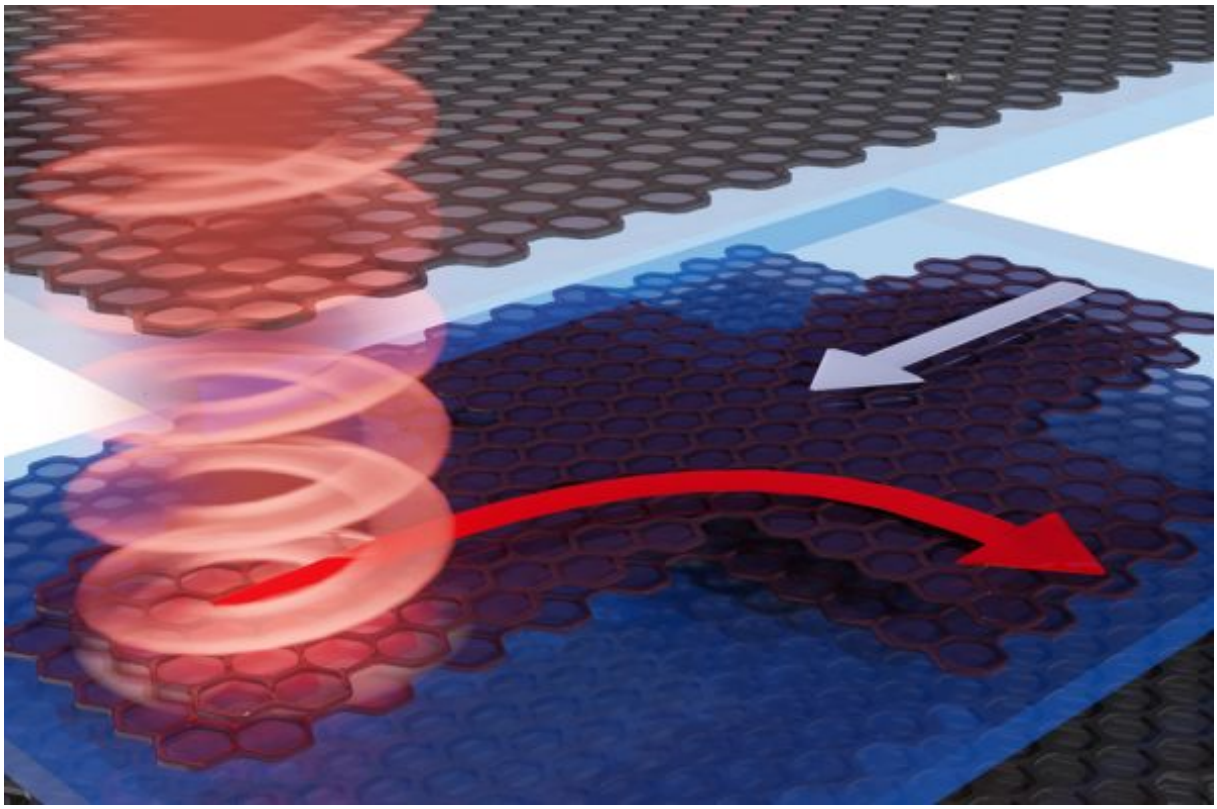


Light derails electrons through graphene

Researchers from ICFO in Barcelona, Columbia University, NTU in Singapore and NIMS in Japan, report in Science on experimentally achieving for the first time the bending of electrons in bilayer graphene with the use of light.

March 24, 2022

The way electrons flow in materials determine its electronic properties. For example, when a voltage is sustained across a conducting material, electrons start flowing, generating an electrical current. These electrons are often thought to flow in straight paths, moving along the electric field, much like a ball rolling down a hill. Yet these are not the only trajectories electrons can take: when a magnetic field is applied, the electrons no longer travel in straight paths along the electric field, but in fact, they bend. The bent electronic flows lead to transverse signals called i¿½Halli¿½ respon
es. Now, is it possible to bend electrons without applying a magnetic field? In a study rece
tly published in **Science**, an international team of researchers report that circular polarized light

can induce bent electronic flows in bilayer graphene. The study has been carried out by a team including ICFO scientists **Jianbo Yin** (currently researcher from the Beijing Graphene Institute, China), **David Barcons, Iacopo Torre**, led by ICREA Prof. at ICFO **Frank Koppens**, in collaboration with **Cheng Tan** and **James Hone** from Columbia University, **Kenji Watanabe** and **Takashi Taniguchi** from NIMS Japan and Prof. **Justin Song** from Nanyang Technological University (NTU) in Singapore.

Jianbo Yin, first author of the study, remembers how it all started. i¿½This collaborative study began in 2016 with a conversation between Justin Song and Frank Koppens at a scientific conference.i¿½ As Justin Song explains, i¿½Electrons are not just particles, but can have a quantum wave-like naturei¿½In quantum materials, such as bilayer graphene, the wave pattern of electrons can exhibit a complex winding often referred to as **quantum geometry**. i¿½Frank and I talked about the possibility of harnessing quantum geometry in bilayer graphene to bend the flow of electrons with light instead of using magnetic fieldsi¿½.

With this in mind, Jianbo Yin, a researcher in Frank Koppens' team, decided to take on the challenge of experimentally realizing this unusual phenomenon. i¿½Our device was very complicated to build. It took building many devices and flying to Columbia University to work with Cheng Tan and James Hone to improve the device qualityi¿?

Quantum geometry and Valley selectivity

In bilayer graphene, there are two pockets of electron valleys (K and K'): when a perpendicular electric field is applied, the quantum geometrical properties of electrons in these two valleys can cause them to bend in opposite directions. As a result, their Hall effects are cancelled out.

In their study, the team of scientists found that by applying circular polarized infrared light onto the bilayer graphene device, they were able to selectively excite one specific valley population of electrons in the material, which generated a photovoltage perpendicular to the usual electron flow. As Koppens highlights,i¿½ we now engineered the device and setup n such a way that current only flows with light illumination. With this, we were able to avoid t e background noise that hampers measurements and achieve a sensitivity in the detecti n several orders of magnitude better than any other 2D material.i¿½This development is significant because conventional photodetectors often require large voltage biases that can lead to i¿½dark currentsi¿½ that flow even when there is no li ht. Yin remarks that wi¿½can control the bending of the electrons with the out-of-plane electric field we apply. We can change the bending angle of these electrons, which can be quantified by the Hall conductivity. By controlling the voltage ?knob', the Berry curvature [one characteristic of quantum geometry], can be tuned, which can lead to a giant Hall conductivity.i¿

? The results of the study open a new realm of many detection and imaging applications, s Koppens finally concludes. i¿½Such discovery could have major implications in applications

for infrared and terahertz sensing since bilayer graphene can be transformed from semimetal to semiconductor with a very small bandgap, so it can detect photons of very small energies. It may be also useful, for example, for imaging in space, medical imaging, e.g. for tissue ski cancer, or even for security applications such as the quality inspection of materials¿?. The possibilities are manifold and the next steps of research focused on new 2D material, such as the moire material twisted bilayer graphene, may find new ways of controlling electron flows and unconventional opto-electronic propertie.

#

Reference: **Tunable and giant valley selective Hall effect in gapped bilayer graphene**, Jianbo Yin, Cheng Tan, David Barcons-Ruiz, Iacopo Torre, Kenji Watanabe, Takashi Taniguchi, Justin C. W. Song, James Hone, Frank H. L. Koppens, 2022, SCIENCE, Doi: 10.1126/science.abl4266

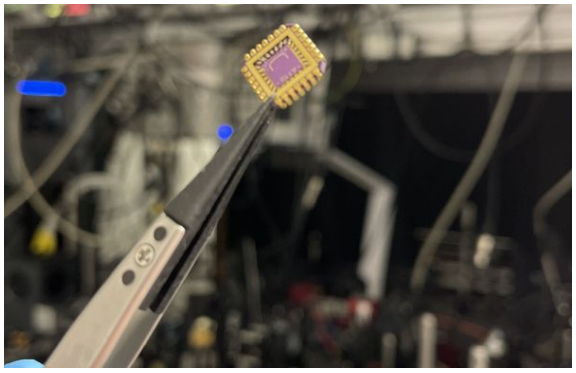
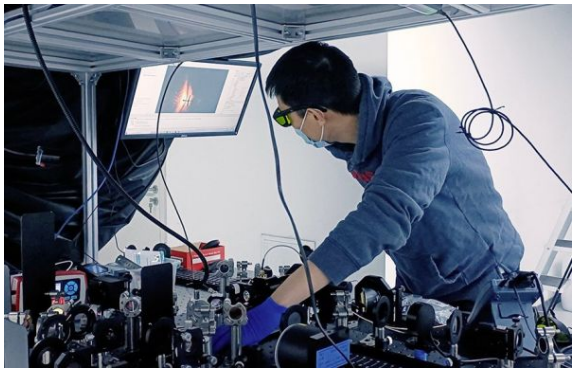
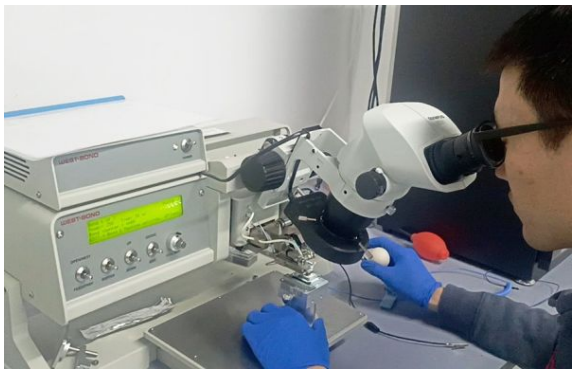


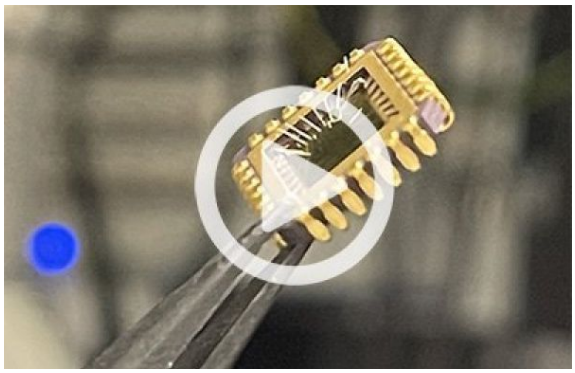
Image credit: ICFO



Jianbo Yin working in his new research lab at Beijing Graphene Institute in China, where he is continuing his research in the field.



Jianbo Yin working in his new research lab at Beijing Graphene Institute in China, where he is continuing his research in the field.



Video interview with Jianbo Yin, Frank Koppens and Justin Song