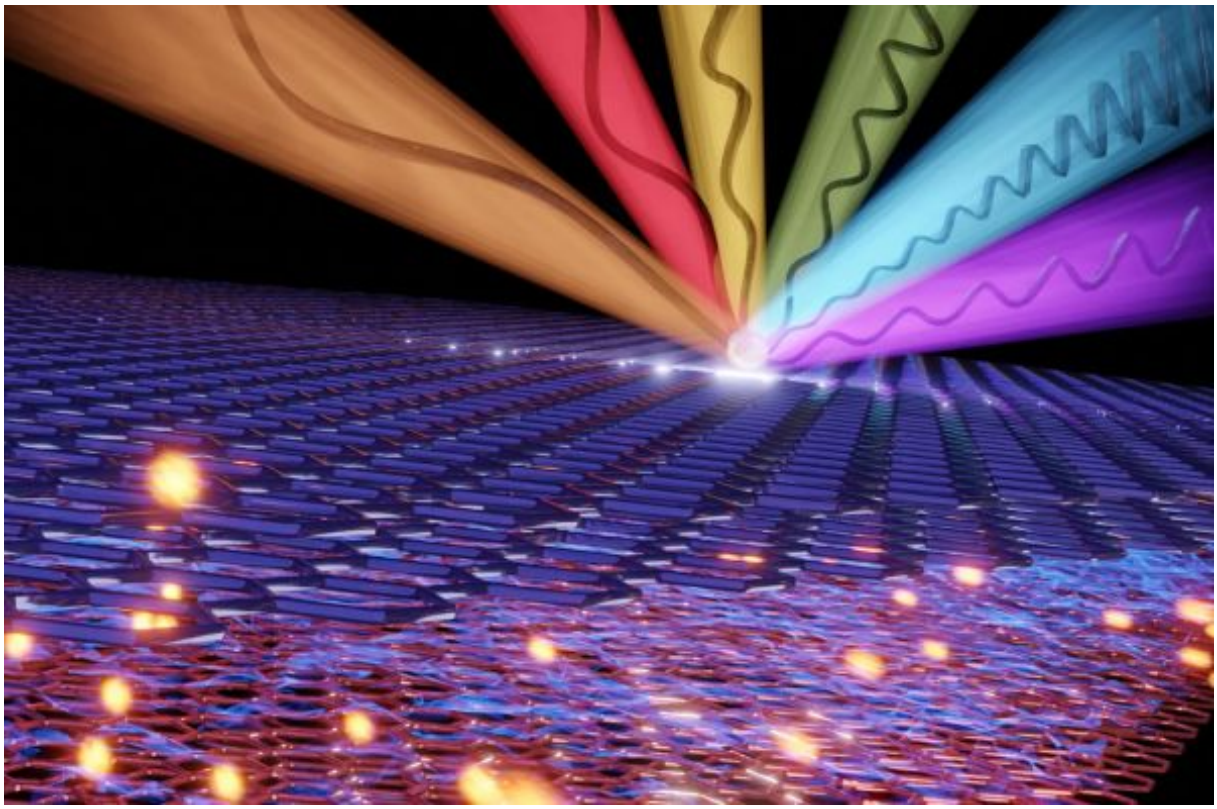


Researchers show radical improvement of ultra-broadband photodetection with a device based on Twisted Double Bilayer Graphene

An international team of researchers reports in Nature Photonics use Twisted Double Bilayer Graphene to develop an efficient detector capable of continuous imaging over an ultra-broad range of light spectrum.

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Hyperspectral imaging uses the full spectrum of light to give detailed insights on nature and its behavior. These insights open a realm for manifold applications, including autonomous driving, environmental monitoring, healthcare, space exploration or even agriculture and food processing.

Imaging from the infrared to the terahertz regime poses a technological challenge because it requires devices that are efficient and sensitive enough over the entire range of the spectrum. So far, the only ones that partially meet expectations are photoconductor array

based on mercury cadmium telluride elements. Although this is the most suitable technolog available currently, their performance efficiency in detecting light is not very broadban because they tend to be efficient absorbers for certain wavelengths but perform worse fo others and they simply do not have the capabilities for detecting the longest wavelengths o light in the terahertz regime, which is becoming more and more relevant for technology

As Frank Koppens, corresponding author of the study, mentions, i¿½**Twisting two-dimensional materials such as graphene has revolutionised the field of quantum materials, driven by the discovery of unconventional superconductivity. But recently, we have also been able to see that it's a platform for a wide range of applications, due to its unique and highly tunable properties**i¿½.

Therefore, in the past years, bilayer graphene (BLG) has been shown to be an impress ve photodetector when biased with external electric fields, although, because of its 2D natu e, the light absorption is rather limited. Interestingly, BLG is compliant with the existing sili on technology, a must for being introduced to the market. However, the need to apply elect ic field poses enormous difficulties in scaling up the fabrication in three dimensions, wh ch would be necessary to overcome the problem of low absorption of B

A new device

Twisted i¿½Doublei¿½ Bilayer Graphene devices (TDBG), on the other hand, have emerge as a unique material that can avoid these restrictions. TDBG is made of two bilayer grap ene stacks rotated or twisted by a large-angle (15 degrees) which have been recently show to create their own intrinsic electric field without the need of extra electrodes that compli ate the fabrication in case of BLG. This has opened prospects of broadband detection n a scalable system, however, up to now, the light detection capabilities of TDBG have not een tes

d. In a new study published in Nature Photonics, **ICFO researchers Hitesh Agarwal & Krystian Nowakowski,** led by the postdoc researcher **Dr. Roshan Krishna Kumar** and ICREA Prof. at ICFO **Frank Koppens**, in collaboration with researchers in the group led by ICFO Prof. Adria Bachtold, the group of Prof. Giacomo Scalari from**ETH Zurich, and researchers at University of Manchester, NIMS in Japan and CNRS in France**, report on the development of a novel **TDBG ultra-broadband photodetector** capable of detecting light very efficiently in a spectral range that spans from the far-terahertz (100 ?m wavelength, equivalent to 3 THz) all the way to near-infrared (2 ?m wavelength or 150 THz) and with a good continuous efficiency in all the range, without any gaps. The ultra-broadband photodetector has shown to have a **good internal quantum efficiency**, an enhancement of photoconductivity by interlayer screening, and **scalability** of TDBG because no gates are needed to apply the electric field in order to get the electronic bandgap.

In their experiment, the researchers carried out a thorough and comprehensible study of photoresponse in TDBG. They fabricated multiple devices of TDBG and studied their photoconductivity, i.e. how their electrical resistance changes under illumination. As first co-author Krystian Nowakowski comments, i¿½**the idea of this experiment arose after reading a study in which researchers had found a small electronic bandgap in Twisted Double Bilayer Graphene (TDBG) without the need of applying an external electric field, that is usually necessary to open an electronic bandgap in the common one stack of Bilayer Graphene (BLG). The presence of a bandgap makes Bilayer Graphene a good detector of light but the need to apply external electric field is a barrier for applications because of the complexity of scaling up the fabrication for industrial applications**.i¿½ After examining the literature, th y saw that no one had ever tested this with i¿½doublei¿½ BLG, or TDBG. So, the team put all their efforts into full motion to prepare the experiment. As itesh Agarwal, first co-author, recalls,i¿½**making TDBG samples is not a trivial task. We started from exfoliating flakes of graphene, continuing this process until we could find a big enough flake of Bilayer Graphene. Then we cut the flake in half with a micromanipulator, pick up one of the halves, rotate it by 15 degrees and stack in onto the other to create a TDBG stack**i¿½. The e devices were then cooled down to 4 kelvin temperature, to perform precise measurements f electrical resistance. Under illumination by mid-infrared light, they saw that the resistan e dropped significantly, which prompted the possibility of utilizing these devices s photodetector

Creativity in research

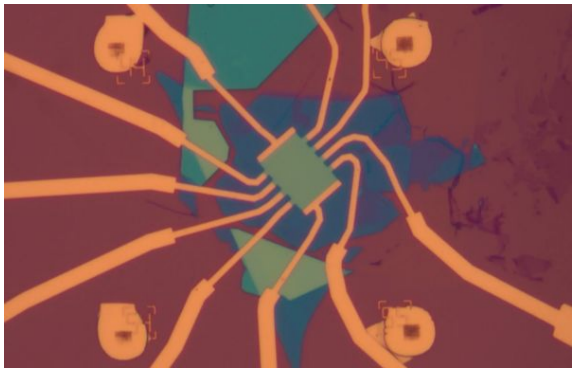
After several months of working intensively on the experiment, the team was obliged to search for logistics and experimental alternatives to overcome the restrictions imposed by the sudden shutdown in 2020 to continue the study, which included remote control of the equipment to continue measurements during pandemics. With an ingenious, inventive attitude, the team worked arduous hours to setup the experiment, measure as much as possible to allow them to collect and understand the type of data that they were getting and what it actually meant. i¿½**One of the big challenges we faced was to actually understand the origin of the large response and benchmark it reliably with commercial technologies**i¿ ? recalls Roshan Krishna Kumar, co-leader author of the stu y. After many months of analysing data, determining what had to be measured and why, learning how to distinguish between various hypotheses, and coming up with new ideas that could facilitate obtaining results, they were able to finally quantify the Internal Qu ntum Efficiency - indicator of the fraction of the absorbed photons that are converted int the measured change in electrical current - and found that the efficiency of most f the spectrum range was equal or above 40%, which is a good value and very promisin when combined with the ultra-broad spectral range and scalability of TDBG. Following the initial measurements, the researchers realized that the photodetector

could have long-wavelength capabilities extending down to 2 THz after they characteriz
d the intrinsic band gap of TDBG, which sets the cut-off frequency of their detectors. Motiva
ed by this tempting prospect, Hitesh Agarwal flew to Switzerland to perform measurements
n the lab of Giacomo Scalari, who are experts in terahertz technologies and strong collabo
ators with ICFO under the project PhotoTBG. Using their customized broadband measu
ement set-ups, they demonstrated the ultrabroad wavelength range reported in the
tudy. The researchers then i¿½focused on understanding the physical mechanism be
ind the measured signal. After long brainstorming with prof. Frank Koppens, we found
hat the response is mostly due to the photoconductive effect, where photons influ
nce the resistance by creating more electron-hole pairs directly rather than the bolometri
 effect where photons heat the sample up and that indirectly influences the resistanc
 by the change of tempera
urei¿½. The results of this study show that the described methods and results can serve
s a guide and a benchmark for other scientists using light for studying these very interesti
g twisted materials. The explanation of conductivity enhancement by interlayer screening,
he method to differentiate between bolometric and photoconductive response and the propos
d idea of 3-dimensional stacking may well be used as a basis for further researc
 on other two-dimensional m

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Optical image of a TDBG sample made into a Hall bar shape for precise measurement of electrical resistivity and photoconductivity.