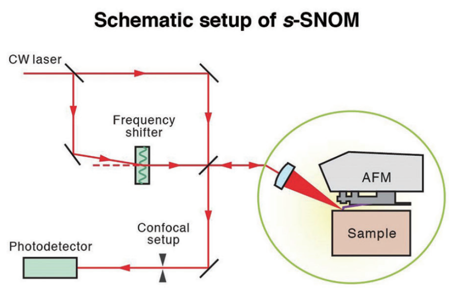
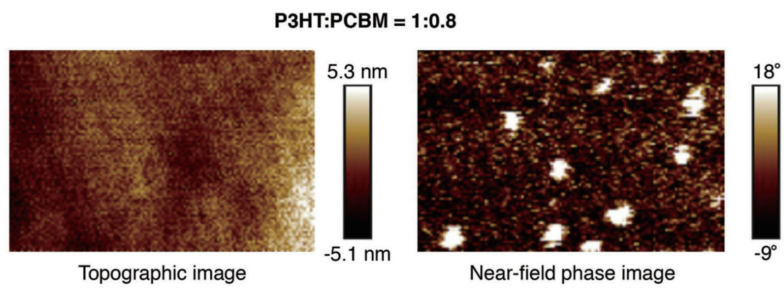
Investigating organic photovoltaics by innovative optical spectroscopy

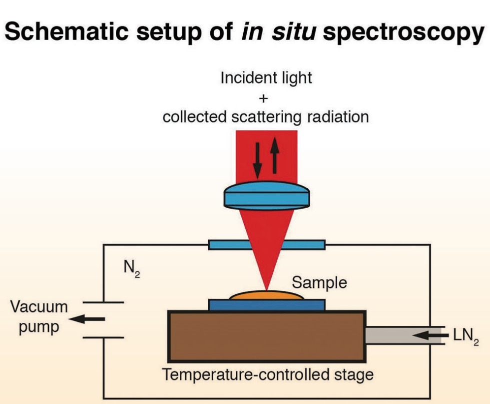
Optical spectroscopy reveals insightful physical happenings in photovoltaics

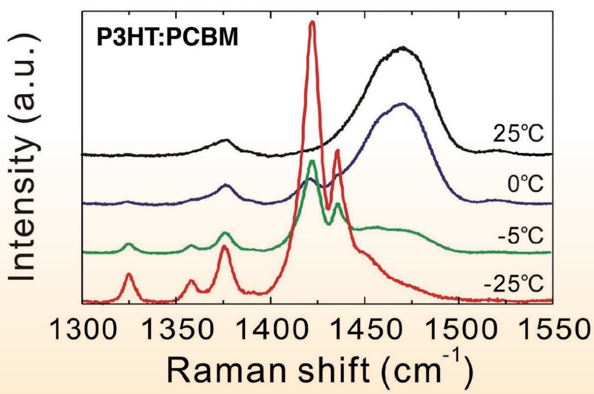
The fundamental processes underlying organic photovoltaic devices involve the following five processes: (1) exciton creation by light absorption, (2) exciton diffusion, (3) exciton dissociation, (4) charge conduction, and (5) charge collection. Among them, processes (2), (3) and(4) critically depend on the molecular alignment in the connected nanometer-scale morphology. Ordered molecular stacking can facilitate charge hopping via preferential intermolecular coupling, and the connected nanometer-scale morphology—the bulk heterojunction (BHJ) concept—can provide efficient conduction channels for separated electrons and holes to reach their respective electrodes. The research team led by Dr. Juen-Kai Wang at the Center for Condensed Matter Sciences, National Taiwan University, has developed two innovative optical spectroscopic tools to reveal such nanoscale morphology and molecular stacking.





Scattering-type scanning near-field optical microscopy (*s*-SNOM) probes the local dielectric propensity with sub-10 nm resolution by analyzing the scattering radiation from the near-field interaction between the nanoprobe and sample. The resolution is limited by the nanoprobe size and is much smaller than that of conventional aperture-type SNOM, which has a resolution of >50 nm. Poly(3-hexylthiophene) (P3HT) and [6,6]-phenyl-C_{61}-butyric acid methyl ester (PCBM)—used in prototypic BHJ photovoltaic systems—possess distinct optical constants, thus providing an imaging contrast mechanism in *s*-SNOM to identify their distributions in the BHJ blended layer. The clear contrast in the obtained phase images indicates the location of the PCBM nanodomains, which are not easily resolved with conventional microscopic techniques such as atomic force microscopy and transmission electron microscopy.





Dynamical cooling plus freeze-drying separate the solvent removal and molecular alignment during the fabrication of optimal BHJ organic solar cells. *In situ* Raman spectroscopy monitors the progression of molecular stacking of pristine P3HT and P3HT: PCBM in *o*-dichlorobenzene during the fabrication process. The results show that the P3HT polymer undergoes drastic ordered aggregation when the solubility limit of P3HT is reached, as evidenced by the emergence of pronounced redshifted narrow Raman peaks due to intermolecular coupling.

S-SNOM and *in situ* Raman spectroscopy were employed to study the nanomorphology and molecular stacking of P3HT blended with PCBM. These innovative optical techniques yield critical structural information of the active layer in organic photovoltaics, greatly facilitating the development of new organic semiconductors and their processing methods.

Dr. Juen-Kai Wang is currently leading a photovoltaic project that integrates the forces of photovoltaic studies at National Taiwan University, Academia Sinica, and other universities—specifically in materials development and in-depth analysis—to form an upstream research team with close collaboration. Complementary facilitation among new-generation photovoltaic technologies (organic, organic-inorganic hybrid perovskite, and inorganic metal chalcogenide) would engender the optimal photovoltaic performance in large-area devices via the best combination of their respective advantages. Additionally, the participation of a mid-stream research team from the Institute of Nuclear Energy Research in this project enhances the integration between fundamental research and mid-stream developments. In summary, the focus of executing this program is guided integration with a noble mission.

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2D materials: "holy grail" for photocatalytic CO_2 reduction into solar fuels

Artificial photosynthesis: a "killing two birds with one stone" approach for tackling energy and environmental challenges

A research group led by Li-Chyong Chen and Kuei-Hsien Chen at the Center for Condensed Matter Sciences, National Taiwan University, has created a way to trigger a chemical reaction in a synthetic two-dimensional (2D), specifically, graphene oxides (GOs) and hybrid GOs that convert CO_2 into solar fuels. This process is so-called artificial photosynthesis, mimicking the way plants convert CO_2 and sunlight into glucose. Here, solar fuels and solar chemicals are produced utilizing solar energy in the gas phase.

Inspired by what Mother Nature has been doing for billions of years, fuels produced from sunlight through artificial photosynthesis can serve as future energy sources that are an environmental friendly alternative to fossil fuels. As per current global energy and clean environmental policies, the production of alternative green-energy sources while reducing CO_2 emissions without affecting our energy demand is highly challenging. Taiwan's geography and climate provide an abundance of solar light and water as free natural resources. Professors Li-Chyong Chen and Kuei-Hsien Chen believe that the conversion of CO_2 and water into solar fuels via solar light is an approach capable of tackling both energy and environmental issues and addressing future prospects