Synthesis of Large-Area 2-Dimensional Molybdenum Disulfide Nanomaterial for Application in Solar Cells

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2-dimensional transition metal dichalcogenide (TMD) nanomaterials have been focused on in recent years because of their intriguing properties that are different from bulk materials [1]. Unlike graphene, there is an intrinsic band gap in TMD nanomaterials, which further becomes direct gap in their monolayer forms. As a representative of TMD nanomaterials, monolayer molybdenum disulfide (MoS_2) has a direct band gap of ~1.9 eV, and thus opens its exciting prospects for a variety of optoelectronic applications, especially for solar cells [2, 3].

In this research, monolayer MoS_2 has been synthesized by chemical vapor deposition. The as-synthesized large-area MoS_2 film (cm level) shows high quality through the characterizations of Raman and photoluminescence spectroscopy (Figure 1). The monolayer MoS_2 film has been further applied to heterojunction solar cells using single-walled carbon nanotube (SWNT) film as hole transport layer (Figure 2). MoS_2 film functions as light-absorbing and electron-hole pair generation layer. The properties and mechanisms of MoS_2-SWNT solar cell will also be discussed.

References: [1] A. Geim *et al.*, *Nature* **499**, 419 (2014). [2] Q. Wang *et al.*, *Nat. Nanotech.* **7**, 699 (2012). [3] A. Polman *et al.*, *Science* **352**, 6283 (2016).

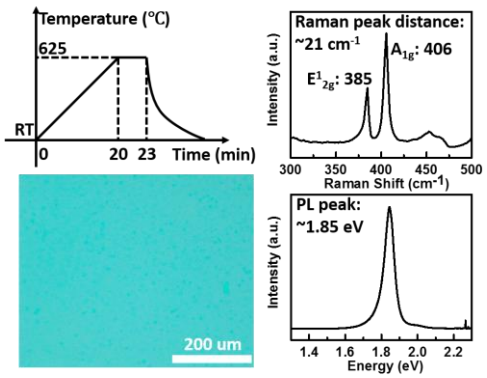

Figure 1. Synthesis of large-area monolayer MoS_2 film and its characterizations.

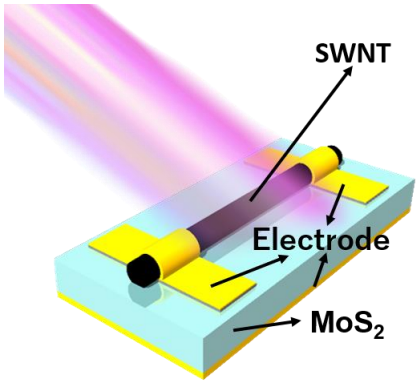

Figure 2. Schematic of MoS_2-SWNT heterojunction solar cell.

Synthesis of Advanced PANI Based Conductive Composites Using Methacrylate Groups Based Materials for Aerospace Applications

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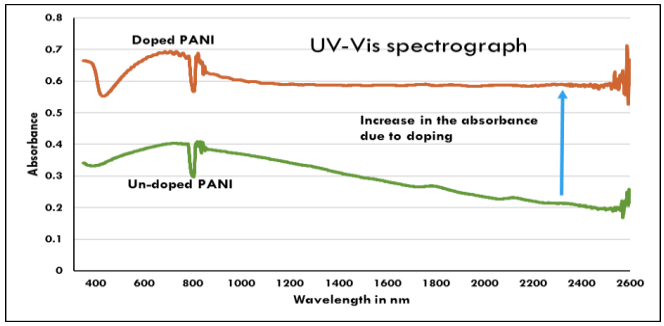
Introduction:

The aerospace industry is transforming significantly by adopting composites for the structure of the aeroplanes. Polyaniline(PANI) being a conducting composite already used in electrochemistry, sensors, conducting films can be used to make doped PANI based carbon fiber-reinforced plastics (CFRP) composites that can provide lightning strike protection, EMI shielding, corrosion resistance hence enhance the lifetime of the aircraft as well as improve fuel efficiency. Our team has been working on the fabrication of conducting composite using PANI with dodecylbenzene sulfonic acid (DBSA) and divinylbenzene (DVB). This research is based on the synthesis of a novel PANI based conducting composite material introducing a new material: 2-Methacryloyloxyethyl acid phosphate (P-2M).

Material Development:

P-2M has basically two types of chemical groups: the acidic group that aids in the doping procedure giving conductivity and the Polymethyl methacrylate(PMMA) like methacrylate group that facilitates in curing through radical polymerization that provides strength . The highest conductivity of 30.4 S/m was obtained and the curing of the matrix to form a high strength conducting composite was accelerated by adding another new material named Trimethylolpropane trimethacrylate (TMP). The detailed morphology, thermal properties and electrical properties were characterised using UV-Vis Spectroscopy, Thermal Microscope, Scanning electron microscope, Differential scanning microscope, Fourier transform infra-red spectroscopy, and electrical conductivity measurement.



Polymer Semiconductors showing Transport of Delocalized Carriers

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The low-cost solution process of electronic devices are gaining great attention, as it can contribute to the cheap energy harvesting devices or devices for Internet of Things (IoT) systems. Here π conjugated polymers, represented by poly-thiophene (fig. a), are candidate materials, showing high solution processability and mechanical flexibility.

For the electronic performance, high charge carrier mobility is expected through their conjugated backbones, which is important for various applications. Although, the actual performance has been reported to be low (1 cm^2/Vs) because of the disordered structures.

Recently, microscopic structures have been improved by the chemical synthesis approach and we have combined them with a new method to align to polymer chains macroscopically on the surface of ionic liquid. With this strategy, transport of delocalized carriers, band-like transport, was confirmed for the first time by the temperature dependence of mobility and Hall measurements (fig. b) [1, 2]. We are also working on methods to achieve adequate crystallinity and high carrier concentration doping at the same time, to inject carriers into delocalized states by the trap filling. These polymers with delocalized carriers are showing high mobility ~10 cm^2/Vs, which would open up possibilities for various applications.

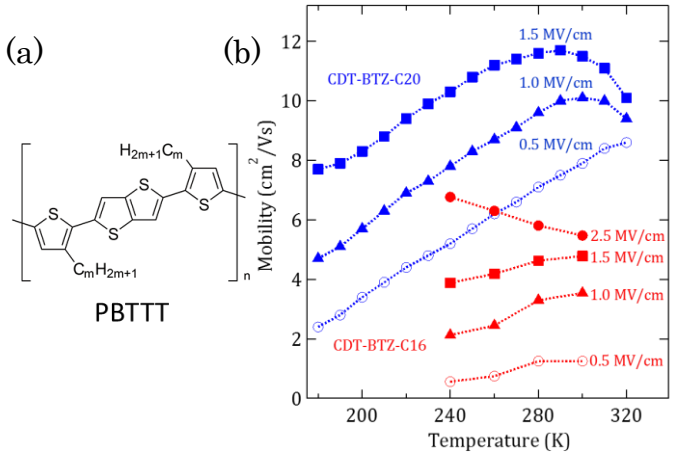

Fig. (a) molecular structure of a representing poly thiophene. (b) the temperature dependence of the mobility of aligned polymers measured by field-effect transistors.

[1] Y. Yamashita, *et al.*, *Adv. Mater.* 26, 8169–8173 (2014).
[2] Y. Yamashita, *et al.*, *Chem. Mater.* 28, 420 (2016).

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Research Topic: Study of optimal multijunction solar cell designs with uniform luminescent coupling for higher energy conversion efficiency

Research Abstract:

In photovoltaic solar cells, the multijunction solar cell (MJSC) has achieved the highest solar energy to electric power conversion efficiency. **The highest MJSC conversion efficiency attained so far was 46%.** This value is **getting close to 50%**, which is the **future target for photovoltaics (PV) community**. To reach the target conversion efficiency though, more refinement needs to be done to minimize losses in solar cells such as thermal loss, carrier thermalization and electron-hole pair (EHP) recombination resulting to light emission. Among these, **recycling of light emission** due to EHP recombination in MJSCs **can enhance the efficiency increase by 1.0%**. This is called the **luminescence coupling (LC) effect**. This is described as the absorption of photons emitted from a higher bandgap subcell to a lower bandgap subcell. However, preliminary measurements show that the **LC current distribution is spatially non-uniform**, with decreasing current generation towards the cell edges, causing **inherent reduction in energy conversion efficiency**. This can be possibly solved by **implementing novel GaAs/Ge dual junction solar cell (2JSC) designs** can improve the MJSC conversion efficiency which may result to energy cost reduction from solar power generation. One solution for non-uniform LC current generation can be a **Plateau GaAs/Ge 2JSC (P-2JSC) design**. Having the Ge bottom cell area to be larger than that of the GaAs top cell may compensate for the non-uniform current generation in the edges of its unexposed area. Because the side portions of the bottom cell are directly exposed to the sun, it can receive more sunlight. Another is **by embedding colloidal quantum dots (CQDs)** into the selected area near the edges of a 2JSC GaAs top cell. This is to allow larger amount of light emission towards the edges of the Ge bottom cell. This then may yield larger LC current generation near the Ge bottom cell edges. **These structures may improve the MJSC conversion efficiency**. Higher GaAs-to-Ge subcell LC efficiency increases conversion efficiency reduction of the limiting cell due to non-uniform LC current generation. At 69% LC efficiency, the conversion efficiency is found to reduce by 1.3%. This reduction implies that the same amount of efficiency can be gained if the LC current generation is made spatially uniform.

Study on the friction properties of a-C:H films in a microstructural point of view

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Hydrogenated amorphous carbon (a-C:H) films have been gathering attention recently for their high hardness, chemical inertness, low friction coefficient and high wear resistance, which enable a-C:H films to be a good coating materials in tribology fields. On the other hand, these properties are greatly influenced by microstructure of a-C:H films, and the microstructure is changed according to coating methods and parameters. In our previous study, Raman spectroscopy was used to clarify the microstructure of a-C:H films, and the mechanical properties (hardness, Young's modulus, internal stress) of the films were successfully correlated with the Raman parameters. In this study, the correlation between the microstructure of a-C:H films and their tribological properties was investigated.

From the evaluation of the microstructure of a-C:H films using Raman spectroscopy, it was found that the structure of a-C:H films can be classified into three main categories. i.e., polymer-like carbon (PLC), diamond-like carbon (DLC) and graphite-like carbon (GLC) structures. Since, it is well known that a-C:H films have strong dependency of relative humidity, we have conducted the friction tests at 10% RH and 75% RH in air.

In 10% RH, a-C:H films with DLC structure showed the highest friction coefficient among these three carbon structures. Also, the friction coefficient of DLC structured a-C:H film increases in proportion to their hardness. By investigating the friction surface, we found that chemical species generated during sliding are one of the main reasons which affect the friction coefficient.

In 75% RH, PLC-structure films show the highest friction coefficient among them. In high humidity condition, thick water layer forms on the friction surface, and no more correlation can be observed between the hardness of a-C:H film and its friction coefficient. QCM (Quartz Crystal Microbalance) measurement revealed that PLC-structure films form a thick water layer, which attribute to the high friction coefficient of PLC-structure films.

Mode-selective phonon excitation

using pulse-shaped intense ultrashort optical pulses

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Ultrashort optical pulses with a broad frequency component are able to excite phonons having a wide variety of phonon modes in solids through impulsive stimulated Raman scattering (ISRS) [1]. When phonons are excited effectively, atoms in the lattice vibrate intensively. This large displacement of atoms are expected to cause changes in phase of materials among solid, liquid and vapor. These ultra-short-pulse induced phase transitions are expected to cause non-thermal effects in solids on the time scale of sub-ps. These phenomena are quite different from the conventional models in phase transition and have gained attention for view point of not only physics but also various potential application, such as in laser material processing and ultrafast switching devices [2].

Conventional ISRS using Fourier transform-limited pulses excites phonons with different modes at the same time and it is difficult to characterize the contribution of each phonon mode to the phase transition. It is expected that the selective excitation of each phonon mode enable us to understand how each phonon mode modifies the property of the material. To excite a single phonon mode selectively, a pulse shaping technique has been used in the past [3]. The phonon mode resonating to the polarization-twisting frequency of the excitation laser pulses is selectively excited. Up to now, the polarization twisting pulses have been achieved by using a spatial light modulator (SLM). However, the damage threshold of most SLMs limits the pulse energy of the order of sub-micro J.

To generate polarization-twisted pulses with a high pulse energy without a SLM, I developed a new technique using grating pairs, a Michelson interferometer and a quarter-wave plate. Using this experimental setup, the energy of polarization-twisted pulses could reach up to 270 μJ which is enough to break down conventional dielectrics such as quartz with a moderate focusing. We successfully demonstrated the excitation of the specific phonon mode which is resonant with the twisting frequency of the laser pulses in quartz. We are now working for the control of ferroelectric polarization through mode-selective excitation of phonons for applications in, for example, ultrafast memory devices.

References: [1] L. Dhar *et al.*, Chem. Rev. **94**, 157 (1994). [2] R. Mankowsky *et al.*, Phys. Rev. Lett. **118**, 197601 (2017). [3] M. Sato *et al.*, Springer Proc. Phys. **162**, 206 (2015).