Honour projects in Centre for Translational Atomaterials (CTAM)

Direction 1: Photovoltaic energy storage using graphene supercapacitors

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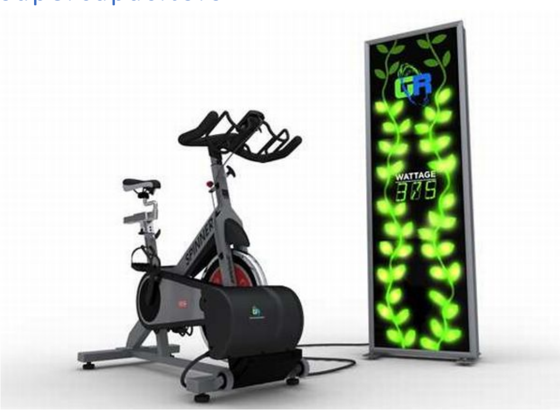
Renewables, including wind and solar, introduce unpredictable changes in the power supply. In addition, due to the limited charging speed of current batteries (e.g. Li-ion batteries, and lead-acid batteries). The efficiency in storing the harvest renewable energy is relatively low, <70% due to the removal of power peaks from the energy harvesting system. Supercapacitor energy storage systems address the fluctuations of renewable energy by rapidly injecting and absorbing power. In addition, graphene supercapacitors have high energy capacity[1-5], which is a promising candidate in replacing current batteries in renewable energy harvesting and storage to improve the efficiency.

In this project, the student will set up the renewable energy harvesting and storage system based on solar panels (from Swinburne) and graphene supercapacitors (from Swinburne), and record data under different weather conditions. The solar irradiance, humidity, temperature, instant power and stored energy will be recorded. According to the data, the student will need to design a circuitry (could be power or voltage or current regulation circuit) based on the characteristic of the solar panels and graphene supercapacitors to achieve high efficiency.

Project 1: Biomechanical energy harvesting gym equipment based on graphene supercapacitors



The Smart Energy Harvesting using physical exercising machines which are feasible enough to harvest power seems to generate a new source of renewable energy. Biomechanical energy harvesting constitutes a clean, portable energy alternative to the fossil fuels currently being used. Biomechanical energy harvesting is a novel approach for producing energy for small devices. The energy expended in a typical workout at the gym is usually wasted in the mechanics of the equipment. However, conventional batteries (e.g. Li-ion batteries, and lead-acid batteries) have limited the power capability, thus can only harvest a limit amount of energy. In addition, conventional batteries only have limited life cycles (hundreds of times), which make them unsuitable for this application requiring frequently charge and discharge and inevitably increase the maintenance cost. In comparison, supercapacitors, in particular graphene supercapacitors developed from CTAM at Swinburne[1-5] has high power capability and long life cycles (up to millions of times) are suitable for this application.

This project will harness the mechanical energy of the machine and convert it to electrical energy using a graphene supercapacitor based system. The student will connect the graphene supercapacitors to commercial power generation gym equipment (will be purchased) and study the energy harvesting efficiency of the system and record data from different exercising person. Furthermore, it is expected to design a new system with circuitry uniquely designed for graphene supercapacitors for further improving the efficiency.

Project 2: Concentrated solar thermal energy harvesting based on graphene film

Concentrated solar thermal (CST) is a solar energy technology that uses sunlight to generate heat. CST systems use mirrors (also called heliostats) to concentrate a large area of sunlight into a targeted location, producing high temperatures. This heat is captured using a fluid, such as oil or molten sodium, which can then be used to heat water to create steam for further applications. The heat can also be used directly to decarbonise some industrial processes. One of the benefits of CST is that the captured heat can be stored cost-effectively for long periods with little loss of energy. This means that CST can be used to generate electricity or provide heat when the sun isn't shining. Globally, most CST plants used for electricity production incorporate 3-15 hours of thermal energy storage.

The key material in CST system is the solar absorbing materials, which absorb sunlight and convert to heat. The properties of the materials, including absorbance, thermal conductivity and thermal capacity decides the efficiency of solar thermal conversion process. Conventional solar-thermal materials can only absorb around 90% of sunlight and have limited thermal conductivity. Based on the latest development in Swinburne university[6, 7], the ultrathin graphene film (nanometre thickness) can effectively absorb 99% of sunlight. And the ultrahigh thermal conductivity of graphene materials allows achieving high solar-thermal efficiency.

In this project, the student will set up the concentrated solar thermal system based on graphene film, (the system will be designed and manufactured in CTAM in Swinburne, the student will only need to set it up) and measure the temperature with different concentration factors with different flow rate of the media under different weather condition. According to the acquired data, the candidate will design and build up small prototypes for applications.

References:

1. Zhang, H., D. Yang, C. Lei, H. Lin, and B. Jia, *Ultrahigh heating rate induced micro-explosive production of graphene for energy storage.* Journal of Power Sources, 2019. **442**: p. 227224.
2. Wong, S.I., H. Lin, Y. Yang, J. Sunarso, B.T. Wong, and B. Jia, *Tailoring reduction extent of flash-reduced graphene oxides for high performance supercapacitors.* Journal of Power Sources, 2020. **478**: p. 228732.
3. Wong, S.I., H. Lin, J. Sunarso, B.T. Wong, and B. Jia, *Optimization of ionic-liquid based electrolyte concentration for high-energy density graphene supercapacitors.* Applied Materials Today, 2020. **18**: p. 100522.
4. Wong, S.I., H. Lin, J. Sunarso, B.T. Wong, and B. Jia, *Triggering a Self-Sustaining Reduction of Graphene Oxide for High-Performance Energy Storage Devices.* ACS Applied Nano Materials, 2020.
5. Wong, S.I., J. Sunarso, B.T. Wong, H. Lin, A. Yu, and B. Jia, *Towards enhanced energy density of graphene-based supercapacitors: Current status, approaches, and future directions.* Journal of Power Sources, 2018. **396**: p. 182-206.
6. Lin, H., B.C.P. Sturmberg, K.-T. Lin, Y. Yang, X. Zheng, T.K. Chong, C.M. de Sterke, and B. Jia, *A 90-nm-thick graphene metamaterial for strong and extremely broadband absorption of unpolarized light.* Nature Photonics, 2019. **13**(4): p. 270-276.
7. Lin, K.-T., H. Lin, T. Yang, and B. Jia, *Structured graphene metamaterial selective absorbers for high efficiency and omnidirectional solar thermal energy conversion.* Nature Communications, 2020. **11**(1): p. 1389.

Direction 2: Photothermal manipulation for energy harvesting

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Project 1: Solar perfect absorber

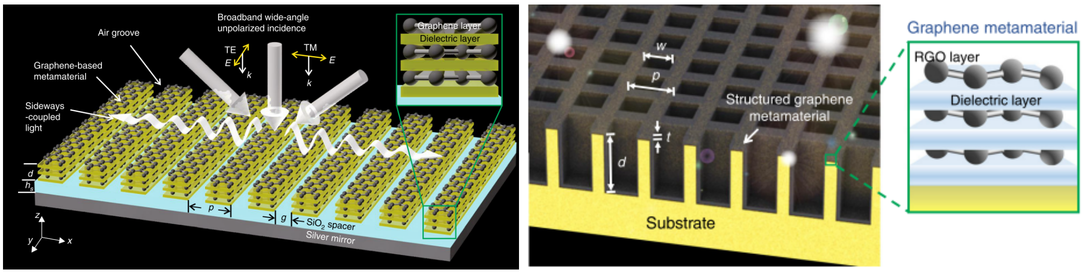
Broadband strong light absorption of unpolarized light over a wide range of angles in a large-area device is critical for applications such as photovoltaics, photodetectors, thermal emitters and optical modulators. Despite long-standing efforts in design and fabrication, however, it has been challenging to achieve all these desired properties simultaneously.

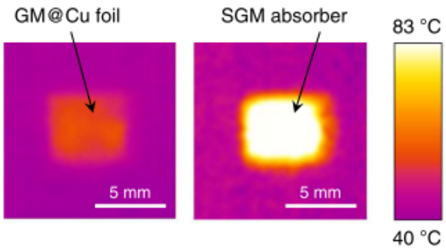
In this project, combining numerical simulations, nanofabrication and characterization techniques, we will study the light-matter interactions at nanoscale. This study will investigate the physical mechanism of photon-phonon-electron interactions at nanoscale, providing the details of photothermal manipulation by dielectric/plasmonic nanostructures. Also, we will study the photothermal performance of these developed nanostructures and directly integrate them into many practical applications, such as solar thermal harvesting, photodetection, and sensing.

Further reading

1. Han Lin, Björn C. P. Sturmberg, Keng-Te Lin, Yunyi Yang, Xiaorui Zheng, Teck K. Chong, C. Martijn de Sterke, and Baohua Jia "A 90-nm-thick graphene metamaterial for strong, extremely broadband absorption of unpolarized light" ***Nature Photonics*** 2019, 3, 270−276. [SCI Q1, **IF: 38.771**]

2. **Keng-Te Lin**, Han Lin, Tieshan Yang, and Baohua Jia "Structured graphene metamaterial selective absorbers for high efficiency and omnidirectional solar thermal energy conversion" *Nature Communications **2020**, 11, 1389.* [SCI Q1, IF: **14.919**]





Direction 2: Spectroscopic investigation of novel fluorescent materials – perovskite nanostructures

Project 1: Perovskite quantum dots embedded in Metal Organic Framework (MOF)

Project 2: 2-dimensional (2D) layered perovskites

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Recent years metal halide perovskites have emerged as the most promising semiconductors and attracted considerable research interest due to the enormous potential for highly efficient optoelectronic applications, such as solar cells, light-emitting diodes (LEDs), lasers and photodetectors. Metal halide perovskites have superior optoelectronic properties over the conventional semiconductors and therefore very prospective for low-cost fabrication and high efficiency fluorescent materials for LEDs, lasers, solar cells and photodetectors. Particularly, perovskite nanostructures, from 3D confined quantum dots and 2D layered quantum wells, exhibit intriguing photophysical properties. It is essential for further photonic applications to understanding their optoelectronic properties. In this project, combining absorption spectroscopy, fluorescence spectroscopy and time-resolved fluorescence spectroscopy, you will investigate various optoelectronic properties and understand the potential applications. During the project, you will have opportunities not only to involve in cutting-edge research of novel perovskite nanostructures, but also to learn various state-of-the-art spectroscopic techniques, from steady state to time-resolved fluorescence.

Further Reading:

1. X M Wen et al. Revealing Dynamic Effect of Mobile Ions in Halide Perovskite Solar Cells Using Time- Resolved Micro-Spectroscopy, Small Methods (2021) 2000731
2. X M Wen et al. Photophysics of Two-dimensional Organic-inorganic Hybrid Lead Halide Perovskites: Progress, Debates, and Challenges, Advanced Science (2021) 2001843
3. X M Wen et al. Triggering the Passivation Effect of Potassium Doping in Mixed-Cation Mixed-Halide Perovskite by Light Illumination, Advanced Energy Materials, 1901016 (2019)