The Department of Physics at Universiti Brunei Darussalam

The Department of Physics at Universiti Brunei Darussalam (UBD) was one of the three departments to be established in the Faculty of Science during the inception of UBD in 1985. The Department started as a service department, initially, for the physics content of the Bachelor of Science Education program. In 2005, the department introduced the Applied Physics program.

In 2008, UBD transformed from a Teaching university to a Teaching and Research-intensive university. One notable result of this transformation was the significant increase in research funding. Faculty members from physics managed to secure a significant injection of funds to establish the Energy Research Cluster. This eventually formed the UBD Energy group, and with the consent of His Majesty the Sultan of Brunei Darussalam the UBD Energy group became the Centre for Advanced Material and Energy Sciences (CAMES).

UBD CAMES was established in March 2014 as one of eight research institutes and centres in UBD. It is the premier institute for research in material and energy sciences in Brunei with core research areas in dye-sensitized solar cells, perovskite solar cells, nano-technology applications in sensors, catalysis and photonics, biomass, solar PV and wind energy. It is through this close cooperation between faculty members in Physics and CAMES that substantial strides in research have been made over the last few years in these areas as well as other areas such as solid oxide fuel cells and energy modelling. We aim to establish more international collaborations in the near future in order to continue this productive period and contribute to more impactful research nationally and internationally.

A wide range of characterization techniques are available in the Applied Physics program:

- UV – Vis – NIR spectroscopy
- Scanning Electron Microscopy (SEM)
- Scanning Tunnelling Microscopy (STM)
- Fully-Automated Optical Microscopy
- Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA)
- Particle Size Analysis
- Rotational Viscometry
- Tensile Testing

This is complemented by the characterization techniques and research facilities available at CAMES which are:

- Electrochemical Impedance spectroscopy
- Solar simulator
- Incident Photon to Current Conversion Efficiency (IPCE) spectrum analyser
- UV – Vis – NIR spectroscopy
- X-ray Diffraction (XRD) and X-Ray Fluorescence (XRF)
- Fourier Transform Infrared spectroscopy (FTIR)
- Liquid column chromatography and Mass spectrometry
- Physical vapour deposition (PVD)(RF sputtering, Electron beam deposition)
- Mini Electron beam vacuum deposition system
- Atomic Force Microscopy (AFM)
- Surface Profilometry
- Thermomechanical Analyser (TMA)
- Laser Flash Analysis
- Glovebox
- Spincoater
- High temperature furnaces

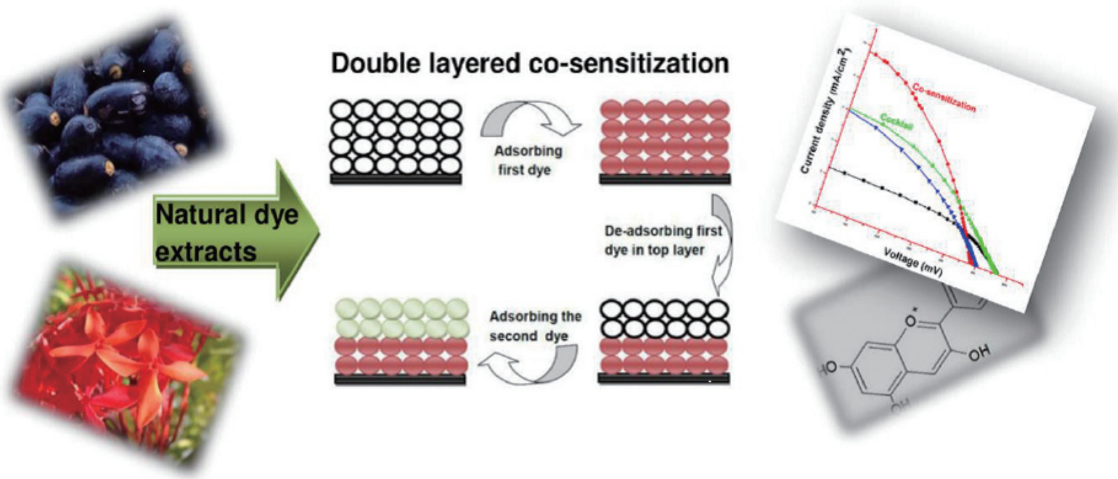
- Screen-printing
- Wind tunnel testing
- Ultrahigh Performance Liquid Chromatography (HPLC)
- Ultra Nanoindentation
- Nanosizer and Zeta potential analyser

In terms of teaching, the Applied Physics program is currently offering a Bachelor of Science degree program in Applied Physics and a Masters degree program by research as well as a PhD in Applied Physics. Additionally, CAMES is offering a Masters degree in Energy Studies by research and a PhD in Energy Studies.

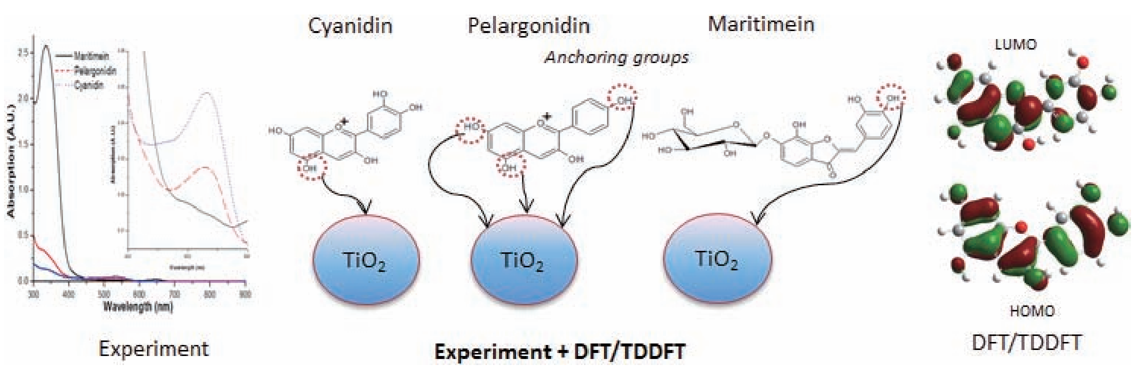
RESEARCH AND HIGHLIGHTS

1. Solar Cells

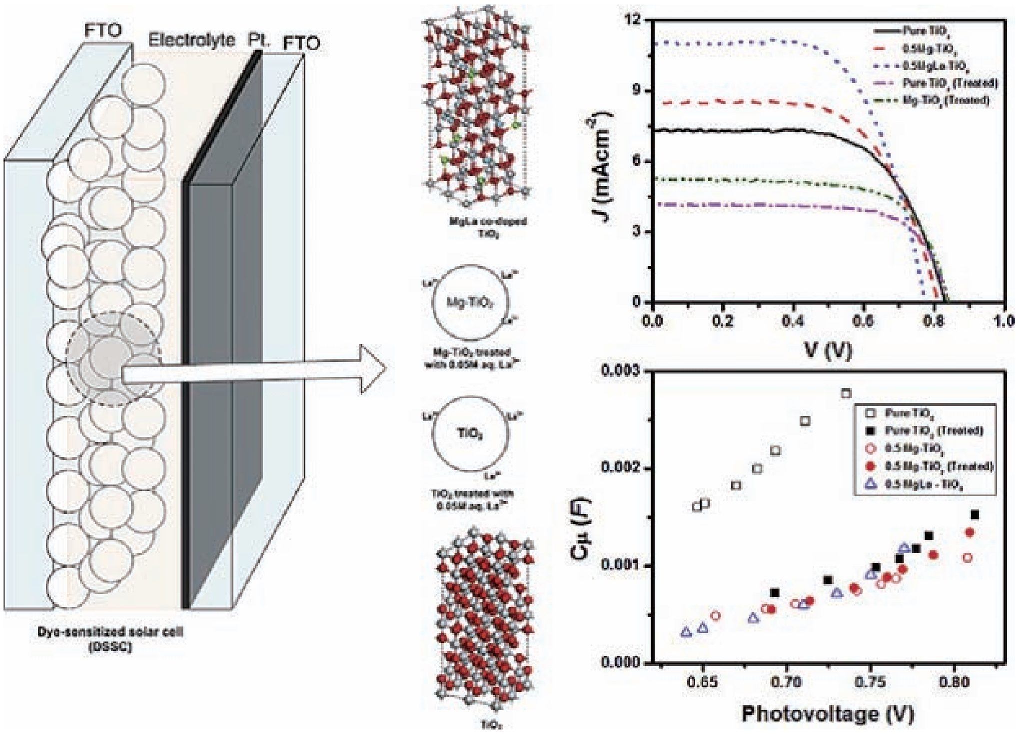
Dye-sensitized solar cells (DSSC) and Perovskite Solar Cells (PSC): Dye sensitized solar cells (DSSCs) have become attractive and inexpensive devices for the conversion of solar energy into electrical energy using the principles of the photochemical phase of photosynthesis. The areas of focus include using natural pigments replacing environmentally hazardous synthetic dyes and using a cheaper route to develop Titanium dioxide based nanostructured complexes with high surface area, porosity, specific morphology and appropriate trap concentration for supports and electron channels in DSSC and hybrid solar cells. Also under investigation is the application of multiple dyes which allows the solar cell to absorb a broader spectrum of Sunlight. Our DSSC&PSC team employs both experimental methods and Density Functional Theory (DFT) calculations simultaneously to investigate the anchoring possibilities of dyes onto semiconductor particles, their energy states, light absorption and conversion capacities. Novel anode structures, HTMs and back contacts for efficient and durable PSCs are also under investigation.



Graphical depiction of co-sensitization methods (*Journal of Alloys and Compounds 581(2013) 186-191*).



Graphical depiction of the investigation of anchoring possibilities of anthocyanin constituents using both experimental methods and Density Functional theory (DFt) calculations (*Chemical Physics Letters 585(2013) 121-127*).



Graphical depiction of *La* modified photoanode and its effect on DSSC performance (*Materials Chemistry and Physics 72 (2015), 105-112*)

State-of-the-art equipment is used to fully examine the structural, optical and charge transfer properties of the individual materials that make up the cells. A full check of the photon to current conversion efficiency of the fabricated DSSC with respect to each modified layer is undertaken to investigate reasons for possible enhancement.

The research in the DSSC group comprises both experimental and theoretical investigations. The DSSC&PSC project in the Department brings together a myriad of specialists from fields such as material science & devices, spectroscopy, ecology, botany and organic chemistry to contribute to the research.

Organic Photovoltaics: This area of research is focused on studying organic solar cells made from conjugated polymers or small molecules. We are currently interested in studying the fundamental factors and the key relationships in order to improve device function. In particular, we are interested in understanding the structure-property relationships that (i) govern exciton and charge dynamics and (ii) influence morphology as well as (iii) stability of the devices. These studies can help give us insight for optimizing device performance and also allow us to make more informed decisions in the molecular design and control of organic semiconductors that will lead us to better-performing devices. Building on the work done in DSSC&PS, various material, structural, optical and charge transport properties can be examined.

Fig. 1: 1 kW prototype of the UBD Flyer.

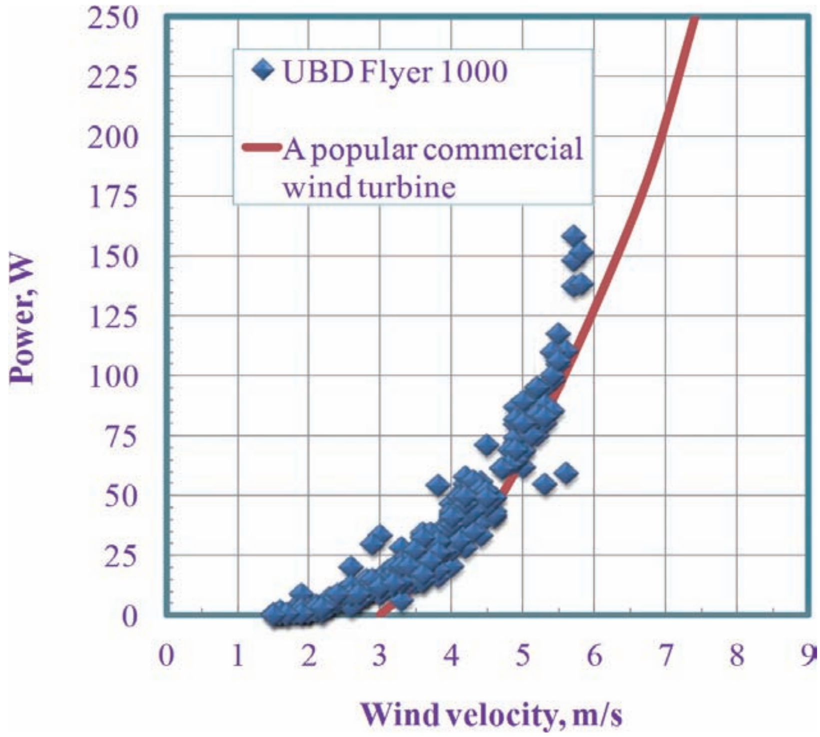


Fig. 2: Performance of the 1 kW prototype of the UBD Flyer at low wind speeds, compared with a market leading turbine of the same size.

Eventually, the goal is to identify the main challenges in the field of organic solar cells and to provide molecular design principles that can help overcome these challenges.

2. Wind Energy

Due to the high growth rate of the wind power sector in the last decade, sites with high wind speeds, available for potential wind power development, are getting scarce. Hence, future wind power developments would focus more on regions with low to moderate wind speeds. Several such sites are available in the ASEAN countries (as well as in other parts of the world), where wind energy can potentially be harnessed, if wind turbines working efficiently under low wind conditions are available. However, the turbines available in the market, which are mostly designed for high wind velocities, may show poor performances under low wind conditions. In view of this, the main focus of the wind energy research at the Faculty of Science (FOS), which is undertaken at the Centre for Advanced Material and Energy Sciences (CAMES), is to develop wind energy conversion technology for the low wind speed regions.

A novel low wind speed turbine design, named the UBD Flyer, has been successfully developed and tested under this initiative. With specially built airfoils and innovative design concepts, the UBD Flyer can start producing power at wind speeds as low as 1.5 m/s and shows impressive performance at low wind speeds. Novel features of the turbine are:

- Specifically designed for low wind speed regions
- Blades made with 'UBD 6166' airfoil for higher aerodynamic efficiency
- Built-in separation bubble controllers for better performance at lower wind speeds
- Designed with the innovative site 'specific design' concept for better field performance
- Better starting and improved efficiency through optimizing the design using the evolutionary design algorithm

A 1 kW prototype of this design has already been fabricated, and is shown in Fig. 1. Performance of the UBD flyer under low wind conditions has been tested and compared with other commercial options. Representative results are shown in Fig. 2. Apart from starting at low wind speeds, the UBD flyer could generate more power compared to the most popular commercial turbines, especially at lower wind spectra.

The design is scalable and a 5kW model is under development. Such small wind turbines can play a significant role, not only in meeting the energy demand of remote communities and applications, but also in supporting the current initiatives for building integrated renewables. The UBD 6166 airfoil with built-in separation bubble controller technology and the site specific design concepts are in the process of obtaining International patenting.

3. Production of Energy from Biomass

Biomass is one of the potential renewable energy options for Brunei Darussalam. The availability of its natural resources, rainforests, and agricultural activities can be useful and utilized for energy generation. They can be processed and converted into liquid fuels and gaseous products through chemical, biological, physical as well as hydrothermal means.

In a bigger scenario, the research interest would cover the whole scope of biomass energy research, from upstream to downstream processes, which involve the characterization and optimization of process-products, the synthesis of catalysts and their characterization, the testing of their catalytic performances in the flow reactors for biomass processes etc. Biomass research has been started quite recently by utilizing the waste products from local resources.

4. Thin Films and Coatings

Thin films for solar control applications: Buildings are said to be responsible for a large amount of the world's total annual energy consumption owing to the excessive use of lighting, air conditioning and heating. This energy consumption can be reduced by using thin film coatings on building glazing in which the amount of solar radiation entering or black-body radiation leaving a building is controlled.

The aim of this research is to deposit a multilayer thin film which will be transparent in the visible range and reflect in the infrared but absorb in the ultraviolet. These multilayered thin films will then be used in explosively driven experiments to investigate their dynamic behavior.

The project will mainly be of an experimental nature, but some theoretical modeling and design is required to support, and plan for, the experimental work.

Thermochromic glazing coatings: The aim of this research project is to study thermochromic materials for glazing, for which changes in optical properties are reversible with temperature. This study mainly investigates the transition temperature of various transition metal oxides, dopants and deposition technologies in order to obtain the closest transition temperature to room temperature.

5. Battery technology

The need to release society from its dependence on fossil fuels has stimulated the advent of batteries as a green energy solution. However, the shouldering of this task by such energy storage devices has been hindered due to them not yet having reached their maturity stage.

Several types of batteries are currently in existence. Recharging convenience and better runtimes have resulted in the use of rechargeable batteries as opposed to primary batteries in many portable applications. Eco-friendly rechargeable batteries have also found use in hybrid and electric vehicles (EVs), and the demand in such applications has shown an apparent increase.

The most common rechargeable batteries exist in the form of lead-, nickel- and lithium-based systems. Although such rechargeable batteries are very much in use, evolving generations of high performance electronic and portable devices, as well as high-end EVs, have driven the need for their further development. The department aims to contribute to research in this field, with initial efforts in the assembly and characterisation of nanomaterial-embedded electrodes as a means of improving electrochemical performance, in addition to owering the cost, of these power sources.

6. Nanostructured Semiconductors for Energy Conversion and Storage

Nanostructured semiconductor electrodes have many potential applications in the conversion and storage of energy, in areas as diverse as photovoltaics, fuel production, batteries, and supercapacitors. At the heart of many of these technologies lies a nanostructured semiconductor electrode immersed in an electrolyte solution. We are particularly interested in understanding the basic physics and chemistry occurring in this relatively new class of nanoscale composite systems, focusing on charge carrier generation and transport, heterogeneous charge-transfer reactions, and interfacial energetics. In addition to these more fundamental studies, we are actively involved in the development of new nanostructured materials and device architectures for energy conversion and storage applications. Some recent highlights of our research in this area include:

- **Determination of electron diffusion length in nanostructured solar water splitting cells:** Solar water splitting is an attractive approach for producing clean and renewable hydrogen fuel from nothing but sunlight and water. Using nanostructured semiconductor electrodes in these devices can reduce the distance photogenerated minority carriers need to travel before reaching an interface where they can react. This in turn allows cheaper materials with more defects to be used rather than those employed in traditional single-crystal photoelectrodes. However, nanostructuring also introduces problems of its own, such as the possibility of majority carriers recombining with acceptor species in solution on their tortuous journey through the nanostructured film. A key parameter in this regard is the *electron diffusion length*, which is simply the average distance an electron can travel in the film before recombining. We have recently made one of the first measurements of electron diffusion length in a nanostructured TiO_2 water splitting cell. We are presently working on improving the theoretical models and experimental techniques used for diffusion length determination in other emerging nanostructured water splitting devices, such as those based on Fe_2O_3, WO_3, and $BiVO_4$.
- **Electrochemical synthesis and characterization of nanostructured oxygen evolution catalysts:** We have developed a novel electrochemical approach for the facile synthesis of nanostructured metal hydroxides and oxides that involves the electrochemical dissolution of a metal, followed by precipitation of its ions by electrogenerated hydroxide ions. Besides providing a cost-effective route to nanostructured $Ni(OH)_2$, which has various technological applications, the resulting powders are found to be remarkably effective catalysts for the difficult oxygen evolution reaction, which is a key step in the production of hydrogen by electrolytic water splitting. We are currently focusing on extending this work to the synthesis of other technologically important metal hydroxides and incorporating our nanostructured $Ni(OH)_2$ catalyst into solar water splitting cells employing TiO_2, WO_3, and Fe_2O_3 photoanodes.

FUTURE PROSPECTS

The Applied Physics group has undergone a period of renaissance over recent years with a thriving research environment that is achieved through a concerted research effort with key research centres such as CAMES. The group is keen to expand its research efforts to broaden the scope of research and is seeking similar collaborations with other international institutions or research centres to further improve the quality of research. We are also looking to attract new faculty members in areas of theoretical physics, materials science and device physics to our Applied Physics group. For more information, we invite you to visit our website at http://fos.ubd.edu.bn/ as well as http://www.ubd.edu.bn/faculties-and-institutes/cames/about-us/.