Bringing all-polymer solar cells closer to commercialization

Project results and lessons learnt

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Executive Summary

Polymer solar cells have the potential to contribute to renewable energy generation, being utilised in installations and situations for which conventional silicon solar cells are not suited. In particular their light weight nature, mechanical flexibility, colourfulness and transparency may see them utilised in portable power applications, built-in photovoltaics, and situations where absolute cost of manufacture is the main concern. Limiting the development and commercialization of polymer solar cells is their relatively low efficiency and poor stability. This project seeks to address issues facing the commercialization of solar cells based on blends of semiconducting polymers by developing materials that are stable and that can be manufactured at scale. This project also seeks to employ novel techniques for the rapid screening of new materials foreshortening the development cycle.

This report describes progress and lessons learnt from the first half of the project. Specific outcomes to date include: (i) Study of the stability of common solar polymers revealing dramatic variations in inherent photochemical stability, (ii) Establishment of protocols for the rapid screening of new materials using time-resolved microwave photoconductivity, and (iii) Implementation of a laboratory-scale coating technique that is translatable to the large area and high throughput manufacture of polymer solar cells, ensuring that laboratory-scale efficiencies can be translated to factory-scale manufacture.

Project Overview

Project summary

Solar panels are based on photovoltaic (PV) cells that convert sunlight directly into energy. While silicon is the mostly widely used material for making PV cells, other materials can be used which have different properties. Polymer solar cells use light absorbing and electrically active polymers as the active material in PV cells instead of silicon. While solar cells based on silicon are commercially available and can be found on many rooftops across Australia, they are brittle, require heavy protective casings, and are opaque. Polymer solar cells on the other hand are light-weight, flexible, colourful, and can be easily manufactured. Polymer solar cells could see application in portable power applications, as semitransparent windows incorporated into buildings, and in general applied in situations where silicon solar panels are ill-suited.

However there are a number of challenges facing the commercialization of polymer solar cells including efficiency and lifetime. This project seeks to address these challenges by understanding stability issues and developing new materials for high efficiency polymer solar cells.

Project scope

To aid in the development of polymer solar cells, higher efficiency materials need to be developed. However efficiency is not the only parameter relevant to commercialization. Also of relevance are material cost, lifetime, and manufacturability. Hence the goal of this project is to develop new materials that are also stable and can be scaled up in synthesis and be processed at scale.

Surprisingly, little stability data is available for solar polymers, so one activity is focused on systematically studying their photochemical stability under solar illumination. In the same way that plastic clothes pegs on a washing line lose their colour, solar polymers can also lose their colour and light absorbing ability. Understanding which types of solar polymers are most resistant to this light-induced degradation is important.

Solar polymers are prepared using chemical synthesis – the linking of smaller chemical subunits into long chain molecules. In the same way that many different structures can be made using different lego bricks, there are many different polymers that can be made from the huge array of chemical building blocks that exist. Having a fast way to tell if a new polymer is promising is thus essential for the development cycle. A second activity of this project is the implementation of a fast screening technique to assess the photovoltaic potential of new materials. This technique, called “time-resolved microwave conductivity” uses fast laser pulses along with microwaves to check how good a polymer is at producing electricity without going to the trouble of making a complete solar cell device, significantly saving time in the development cycle.

Translating laboratory-based discoveries to the factory, so-called “lab to fab” can sometimes be challenging. In the laboratory, solar cell devices are typically fabricated which are much smaller (< 1 cm^2) than the solar panels that are employed on roof tops and in solar farms (~ 1 m^2). Sometimes the fabrication techniques used for laboratory-based devices do not scale up. This means that the efficiency of small, laboratory-scale cells cannot be replicated using the fabrication techniques needed for commercial manufacture. For polymer solar cells, the process of “spin-coating” is typically used for making small, laboratory-scale cells. This process works by dispensing the solution to be coated onto the surface of the substrate to be coated and then spinning at high speeds. This spinning spreads the liquid uniformly across the substrate and results in a uniform, thin film when the solution dries. While this works fine on a small scale, scaling up to anything larger than a dinner plate is essentially impossible. A lot of solution and material is also wasted when it is ejected at the edges during the spin-coating process. The production of large area polymer solar cells instead uses coating techniques that work similar to the printing of a newspaper: a long flexible support layer is fed by rollers through a coating machine which deposits a thin layer of solar material. Differences between how long it takes for films to dry in this "roll-to-roll" coating process compared to spin-coating can mean that good efficiencies achieved using spin-coating are sometimes not realised when large area coating processes are used. To ensure this is not a problem, a third focus of the project was to make all laboratory-scale cells using a coating technique that mimics the coating conditions used in a manufacturing environment.

In summary, this project seeks to develop new materials (polymers) with high efficiency that are stable and that can be manufactured at scale.

Outcomes

In the first half of this project:

(i) The stability of standard solar polymers has been assessed
(ii) Time-resolved microwave conductivity has been validated as a technique to screen new materials
(iii) The efficacy of a laboratory-scale coating technique that mimics larger area coaters assessed.

In addition, new polymers have been synthesised and initial tests on the new polymers performed.

<u>Stability of standard solar polymers</u>

Experiments have been performed to assess the stability of seven common solar polymers under sunlight. Surprisingly, 2 of the most common solar polymers used were found to lose all their colour under a few hours of sunlight. In contrast, other polymers showed much better stability, lasting for over 500 hours. Of course, these materials are expected to spend many years under sunlight, and will be protected by encapsulating layers in a commercial device. However these results indicate large differences in inherent stability with future work to focus on understanding what causes such differences in intrinsic stability.

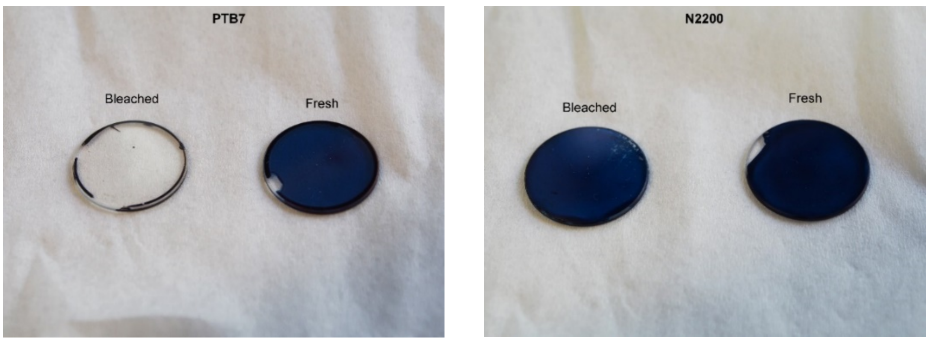

Figure 1. Examples of poor (left) and good (right) photochemical stability.

Implementing rapid screening of new materials

A range of different polymer solar cells based on different solar polymers have been made and tested. The photovoltaic performance of these materials was then compared with the analysis of these materials with "time-resolved microwave conductivity", a technique that in principle can assess the potential of a material to generate electricity from sunlight without having to make a complete device out of it. Results indicated that this rapid microwave-based screening technique can indeed identify high performing materials. From this study protocols and thresholds have been developed for identifying promising new materials through this rapid screening methodology. This will help in the second half of the project to focus on only the most promising new materials developed.

Laboratory-scale coating with large area compatibility

Traditionally spin-coating has been used to prepare layers of solar polymers for use in polymer solar cells. In this part of the project, polymer solar cells have been made using both spin-coating and blade-coting. Blade-coating is a laboratory-based coating technique that replicates the conditions of large area coating that are used in commercial coating. Encouragingly, good correspondence was found between the efficiency achieved with spin-coating and the efficiency achieved with blade-coating. This result indicates that the efficiencies achieved with small, lab-based cells can be readily translated to large area manufacture. This result is different to what has been seen for other types of organic solar cells such as those based on fullerene molecules.

Transferability

Knowledge regarding the stability of solar polymers will be relevant for application in other types of organic solar cells, and the application of these materials in other organic optoelectronic devices. Knowledge gained may be also transferrable to the development of large area photodetectors.

Knowledge gained is being shared through communication of results at national and international meetings such as at the annual symposium of the Australian Community for Advanced Organic Semiconductors and the Asia-Pacific Solar Research Conference. Detailed technical reports are being made available through the research repository figshare.

The Flexible Electronics Laboratory at CSIRO in Clayton also has an activity in printed solar cells funded through ARENA, and we will be working with them in the second half of the project to realise large area printed polymer solar cells based on the materials developed in the project.

Conclusion and next steps

The initial outcomes from this project have set the stage for the development of high efficiency, stable polymer solar cells. Polymers with higher intrinsic stability have been identified, and the protocols for the rapid screening and large area coating of materials developed. The next half of the project will focus on developing and testing new materials, assessing thermal stability and producing large area (> 1 cm^2) cells and certifying their efficiency.

The development of efficient, robust polymer solar cells may help to see photovoltaic technology employed in areas and applications currently off limits to traditional silicon solar cells. The knowledge gained from this project will also assist the international organic solar cell community in bringing organic solar technology closer to fruition.

Lessons Learnt

Lessons Learnt Report: Stability of solar polymers

Project Name: *Bringing All-Polymer Solar Cells Closer to Commercialization*

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Solar PV
State/Territory:	NSW and Victoria

Key learning

The photochemical stability of common solar polymers was found to vary drastically, with some polymers completely photobleaching in under 10 hours and some lasting longer than 500 hours.

Implications for future projects

Photochemical lifetime was being assessed through UV-Vis absorption spectroscopy, which requires good control of film thickness for consistent results. Two problems encountered were variability in film thickness between different samples, and variability in film thickness across different samples. Variability in film thickness across the same sample led to variability in plots of absorbance vs. time since measurements were taken on slightly different spots on the sample which had slightly different thickness. Some films prepared were too thick which took too longer to photo bleach and were hard to characterise. The light source used also should have been benchmarked earlier in terms of its output in the UV and calibrated or benchmarked to a solar simulator. Budget-allowing, a dedicated solar simulator with environmental control would have been beneficial to ensure good spectral correspondence and better control of temperature and humidity.

Knowledge gap

While different common solar polymers have been found to exhibit vastly different stabilities, the underlying chemical differences are not obvious and need to be established.

Background

Objectives or project requirements

The objective of this stage of the project were to establish the protocols for studying the photochemical degradation of solar polymers. The stability of common solar polymers was to be assessed, with knowledge gained to inform the development of new materials with higher stability, and to ensure that only materials with good intrinsic stability were used for future work.

Process undertaken

Thin film samples of solar polymers were prepared on quartz-glass substrates and aged by placing under simulated sunlight. A custom-built light source was made producing light that closely matches the brightness and colour of the sun. A rotating sample stage ensured that all samples were subjected *to a uniform light intensity. After specific times, the colour of the film was measured using an absorption spectrometer. This instrument also measured the absorption strength of the film. By recording how absorption strength decayed as a function of ageing under simulated sunlight, the time required to degrade the different polymers was determined.*

Supporting information

Full technical details can be found in the technical report "Characterization of the photochemical stability of all-polymer solar cells," published on figshare, DOI: 10.26180/5d11bb1a8810a, and available online at:

https://monash.figshare.com/articles/Characterization_of_the_photochemical_stability_of_all-polymer_solar_cells/8319947

Lessons Learnt Report: Rapid screening of solar polymers

Project Name: *Bringing All-Polymer Solar Cells Closer to Commercialization*

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Solar PV
State/Territory:	NSW and Victoria

Key learning

Time-resolved microwave conductivity (TRMC) can be employed to identify promising new all-polymer photovoltaic systems. Good correlation between the TRMC figure of merit and short circuit current in solar cells was found.

Implications for future projects

Film thickness and film uniformity were important parameters that affected the quality of TRMC data early in the project. Better feedback between measurement requirements (from researchers at Macquarie University) and film preparation (performed at Monash University) could have improved data quality by better controlling and optimising these parameters.

Knowledge gap

While good correlation between the TRMC figure of merit and cell short circuit current was found, fill factor is less predictable, and does not correlate very well with cell short circuit current. Understanding the origin and requirements for high fill factors in all-polymer solar cells is a current knowledge gap.

Background

Objectives or project requirements

The development of polymer solar cells relies upon the development of new materials. There are almost a limitless number of different solar polymers that can be synthesised, making it hard to identify which materials are the most promising. Historically the potential for a solar polymer to work in a photovoltaic cell has required the fabrication and optimisation of solar cells, a time-consuming and costly approach. However, time-resolved microwave conductivity is a contactless technique that can assess the potential of new solar materials by measuring the photoconductivity in a film using microwaves. Following excitation of the sample with a laser pulse, the interaction between the sample and microwaves in a cavity can infer the photocurrent generation yield and photocarrier lifetime. While TRMC has been demonstrated for other systems, its feasibility and the protocols for application to all-polymer solar cells had not been undertaken. The objective of this part of the project was to validate TRMC for the screening of all-polymer blends by comparing the efficiency of established polymer solar cells with the TRMC response of films.

Process undertaken

A custom TRMC setup was developed and commissioned at Macquarie University. 8 different types of polymer solar cells were prepared, optimised, and characterised at Monash University. Films *corresponding to the active layers of these devices were sent to Macquarie University to be tested in the TRMC setup. The TRMC figure of merit (related to the photocurrent generation yield) was determined and correlated with solar cell parameters.*

Supporting information

Full technical details can be found in the technical report "Validation of Time-Resolved Microwave Conductivity (TRMC) as a screening tool for all-polymer solar cells," published on figsahre, DOI: 10.26180/5d106857726e5, and available online at:

https://monash.figshare.com/articles/Validation_of_Time-Resolved_Microwave_Conductivity_TRMC_as_a_screening_tool_for_all-polymer_solar_cells/8313068

Lessons Learnt Report: Laboratory scale coating of solar polymers with relevance for large area manufacturing

Project Name: *Bringing All-Polymer Solar Cells Closer to Commercialization*

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Solar PV
State/Territory:	SA, NSW and Victoria

Key learning

The efficiency of all-polymer solar cells processed using blade-coating matches well the efficiency of all-polymer solar cells processed using spin-coating, once thickness has been optimised.

Implications for future projects

This part of the project worked smoothly with few things that would have been done differently in hindsight. The larger substrate geometry could have been adopted earlier which would have improved coating quality. "Green" solvents could also have been tested earlier. The implantation of in-line (in-situ) monitoring of coating quality could also have been adopted.

Knowledge gap

No new major knowledge gaps were identified.

Background

Objectives or project requirements

In order to make sure laboratory-scale solar cell results were translatable to the large area manufacture of polymer solar cells, we sought to implement a laboratory-scale coating technique whose conditions were relevant to large area manufacture. Blade coating was identified as a promising technique that uses a blade (such as a glass slide, silicon wafer or knife edge) to coat a layer of solution across a substrate. The coating and drying conditions for blade coating are similar to large area printing techniques such as slot-die coating, so that if good efficiencies can be achieved in the laboratory, they can be translated to larger area coating processes.

Process undertaken

To demonstrate the viability of blade-coating, a series of solar cells based on different all-polymer systems were optimised and fabricated using both spin-coating and blade-coating. Most deposition processes (solvent, weight ratio, concentration) had been optimised for spin-coating, so these needed to be checked and potentially re-optimised for blade-coating. Blade-coating parameters also needed to be optimised such as temperature and coating speed. It was found that the solution parameters used for spin-coating (solvent, weight ratio, concentration) generally worked well for blade-coating once the thickness was optimised. The efficiencies achieved with spin-coating were generally reproduced with blade coating, indicating that all-polymer blends are a rather robust technology *where the efficiency can be reproduced using different coating technologies. A new device geometry was also developed to enable larger area cells to be produced.*

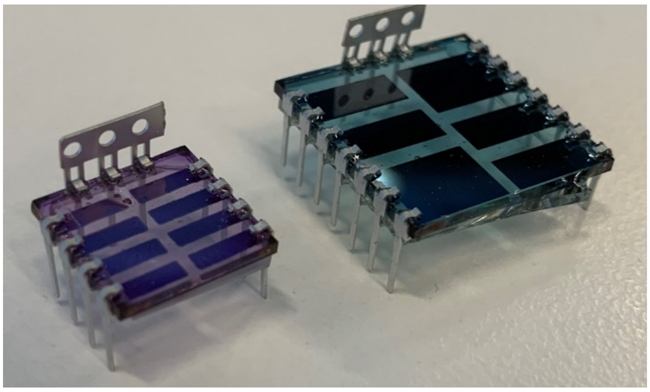

Figure 1: Images of polymer solar cells, old 12 mm by 12 mm substrate geometry, left, and new 19 mm by 19 mm substrate geometry, right.

Supporting information

Table 1: Comparison of the performance of all-polymer solar cells produced using spin-coating and blade-coating.

System	***Method***	***V_{OC} (V)***	***J_{SC} (mA/cm^2)***	***P_{max} (%)***	***FF***	***PCE (%)***
PTB7-Th:P(NDI2OD-T2)	*Spin Coating*	*0.79*	*11.73*	*4.48*	*0.48*	*4.48*
	Blade Coating	*0.79*	*11.22*	*4.57*	*0.52*	*4.57*
PTB7-Th:PNDI-T10	*Spin Coating*	*0.81*	*12.58*	*5.04*	*0.49*	*5.04*
	Blade Coating	*0.81*	*12.67*	*4.74*	*0.46*	*4.74*
PTB7-Th:P(NDI2OD-T2F)	*Spin Coating*	*0.71*	*13.79*	*5.06*	*0.52*	*5.06*
	Blade Coating	*0.71*	*14.12*	*5.12*	*0.51*	*5.12*
J52:P(NDI2OD-T2)	*Spin Coating*	*0.81*	*14.40*	*7.26*	*0.62*	*7.26*
	Blade Coating	*0.79*	*14.56*	*6.70*	*0.58*	*6.70*
PBDB-T: PNDI-T10	*Spin Coating*	*0.81*	*11.89*	*4.86*	*0.50*	*4.86*
	Blade Coating	*0.83*	*11.66*	*5.14*	*0.53*	*5.14*