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ARENA

Printing solar cells – A manufacturing proposition for Australia

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Name:	Dr David Jones
Title:	Project Coordinator VICOSC
Email:	djjones@unimelb.edu.au
Phone:	03 8344 2371
Website:	www.vicosc.unimelb.edu.au

Victorian Organic Solar Cell Consortium Australia

Project summary

Organic photovoltaics (OPVs) have emerged as a dynamic new technology that promises a low-cost way of mass-producing solar cells through the use of commercial printing presses. Significant developments are required in the performance profile of this exciting new technology to allow commercialisation, with improvement in solar cell efficiency and durability. The Victorian Organic Solar Cell Consortium (VICOSC) has developed a world leading printing capability in the two key emerging technologies, bulk heterojunction solar cells (BHJ) and dye sensitised solar cells (DSC) technologies. The consortium is aiming to bring the technology to a level where it can be commercialised through an iterative process where the printed module performance is matched to

product requirements throughout commercialisation, with product development leading to cost competitive products and finally to printed modules rivalling traditional silicon solar cells.

The technologies.

Bulk Heterojunction Solar Cells

An **organic solar cell** is a type of flexible solar cell made with polymers, large molecules with repeating structural units, or small organic molecules. Polymer solar cells are organic solar cells (also called "plastic solar cells") and are one type of thin film solar cell.

Compared to silicon-based devices, polymer solar cells are lightweight, potentially disposable and inexpensive to fabricate, flexible, and customizable on the molecular level, and they have lower potential for negative environmental impact. An example device is shown in Fig. 1. The disadvantages of polymer solar cells are also important to note, they used to offer only about 1/3 of the efficiency of traditional solar cells, and they are relatively unstable toward photochemical degradation.

However, organic solar cells promise of extremely cheap production and, through further development, higher efficiency values has led them to be one of the most popular fields in solar cell research. Therefore, in this project one key Milestone was to improve the performance of lab based BHJ devices (single junction) to over 10% power conversion efficiency to allow translation to VICOSC's large scale printing program.

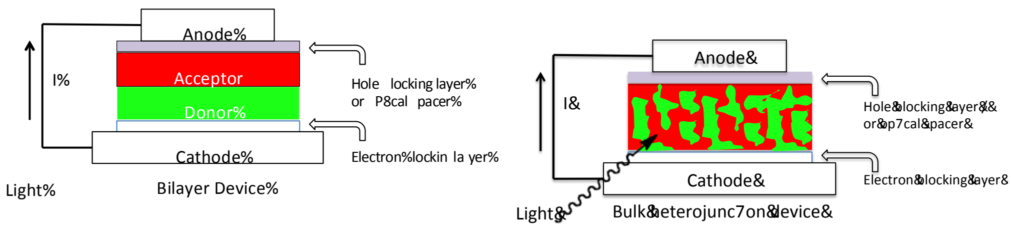


Figure 1. Bulk heterojunction solar cell device architectures. The simple bilayer device lays the acceptor on the donor but is restricted by the diffusion length of charge carriers in the organic

materials. The bulk heterojunction device overcomes the limitations of the bilayer device by forming a mixed phase deposited from a printable ink.

Dye Sensitised Solar Cells (DSSC)

Dye-sensitized solar cells (DSSC) are an efficient type of thin-film photovoltaic cell. The use of nanoparticles of titanium dioxide covered with a light harvesting dye has lead to the description of an artificial leaf, Fig. 2.

DSSCs are easy to manufacture with traditional roll-printing techniques, and is semi-transparent and semi-flexible, allowing a range of uses that are not applicable to rigid photovoltaic systems.

Most of the materials used are low-cost, however a handful of more costly materials are necessary, such as ruthenium and platinum. There is a significant practical challenge involved in designing the liquid electrolyte for DSSCs, which must be able to remain in the liquid phase in all kinds of weather conditions.

Even though the conversion efficiency of dye-sensitized PV cells is lower than that of some other thin-film cells, their price to performance ratio is sufficient to make them an important player in the solar market, particularly in building-integrated photovoltaic (BIPV) applications. The target for this project was to develop new DSSC devices with power conversion efficiencies greater than twelve percent and look at new device architectures to simplify printed devices.

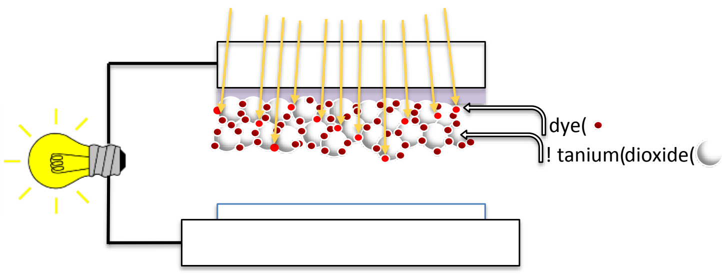
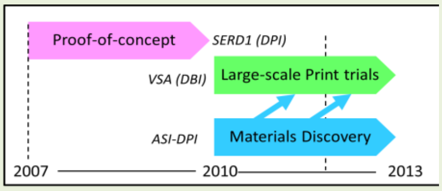


Figure 2. Simplified schematic for a dye sensitised solar cell device (DSSC). The use of high surface area nanoparticles of titanium dioxide covered with light harvesting dyes leads to high collection efficiency of absorbed light.

VICOSC continues to examine the two technologies as no clear decision can be made as to which technology will ultimately lead to the best printed solar cell. In fact the development of an integrated printing program where any new high performance material can be “dropped into” the printing process adds extra value and flexibility to the development and translational program.

Project scope

VICOSC has set up two complementary R&D activities in order to accelerate R&D into organic solar cells and to significantly reduce the cost of solar energy generated from Organic Photovoltaics. How these research activities interact, and how they relate to earlier VICOSC work is shown in the accompanying vignette.



OPV proof of concept was demonstrated during SERD1 (funded by the Department of Primary Industries, DPI). The current project (jointly funded by ASI-DPI) focuses on developing new materials and new device

Materials and device architectures developed within the ARENA-DSDBI project need to satisfy a set of preliminary 'screens' before they are escalated into the DSDBI-funded large-scale print trials. The combined selection criteria for these two activities then defines the feed-back loop for the overall process and, hence, of progress towards our goal. The first material has been transferred to the printing program validating the stage gate parameters and decision making process.

It remains difficult to 'pick a winner' between the competing technologies of Dye-sensitized Solar Cells (DSC) and Bulk Hetero-Junction solar cells (BHJ) – as each technology still has both positive and negative attributes associated with them. Therefore we continue vigorously to pursue both technologies at this time.

This project is developing new materials and device designs with enhanced performance that will significantly improve the efficiency and durability of OPV solar cells.

Outcomes

The consortium has delivered on all project milestones with high solar cell power conversion efficiencies (PCE). The current very best performance for a p-type polymer, developed in the consortium, stands at 10.3% PCE (although the average of all samples of the material average PCE 9.0-9.3%) and will be among the best, and only the second of two reported BHJ single junction devices with a reported efficiency of over 10% PCE.

The consortium has reached the final goal of 12% PCE for a DSC device based of perovskite materials and is in the process of translating this technology to our parallel printing program where perovskites offer a “drop-in” high performance material for the printing program.

Development of high performance materials and devices has brought commercialisation a step closer where

The consortium has become recognized as a world leader in the field with the unique capacity of having a fully integrated team that is capable of developing new materials and device architectures and taking the results through to large scale fully printed modules.

In addition, the VICOSC consortium has established a high profile through publication of results in leading international journals, and through lectures and articles in both trade magazines and the general literature.

Effectiveness

The consortium ensured success by initiating an effective management, communication and decision making process.

A management team was assembled and communication ensured by scheduled regular meetings between managers, work package leaders, and key researchers engaged on the project.

Equally effective was the installation of a stringent stage gating progress so that all members were aware of requirements before decisions were required.

The consortium instituted a stringent stage gating process in order to accomplish rapid discovery of new materials and rapid development of new device architectures. The stage gating process required critical analysis of the development process and identification of key materials or device properties. This lead to key parameters to be pre-set and developed materials or devices critically evaluated against the parameters. Materials or new device architectures could then be passed for development or rejected. For example, materials were evaluated against solubility, molecular weight, energy level, light absorption or synthesis stage gates before being progressed to further testing or modification. The process was backed up by extensive internal communication. The process was designed to ensure effort was directed toward the best candidates for further development.

For example, during the three-year program, the consortium synthesised over eighty-five new materials divided into p-type materials (fifty nine polymers and nineteen small molecules), and seven new n-type materials. Of these eighty-five new materials twenty were reject as they failed to pass the synthetic stage gate parameters, a further twelve were rejected as they failed to pass optoelectronic stage gates. A further twenty-nine were rejected as they failed to pass initial device performance stage gates, see Fig.3 for a selection of materials and pass/fail matrix.

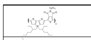
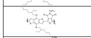
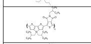
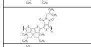
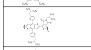
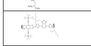
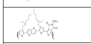
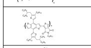
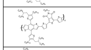
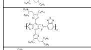
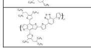
Material	Notes	Date Modified	Synthesis						pass synthetic requirements?	Optoelectronic				pass optoelectronic requirements?	Device					pass device requirements?	Status (terminated/ongoing)	Outcomes
			2 g synthesis possible?	synthetically reproducible?	Is it soluble to 30 mg/mL? (include solvent)	If no, what is its maximum solubility? (include solvent)	Mn (kg/mol)	PDI		HOMO (eV)	LUMO (eV)	Bandgap (eV) Is it ~1.5 eV?	ε (L mol^{-1} cm^{-1})ε (L mol^{-1} cm^{-1})		V_{oc} (V) ~1 eV?	J_{sc} (mA) ≥10 mA?	FF(%) ≥0.5?	PCE (%) ≥5%?	Mobility ≥10^{-3} ?			
p-Type Polymers																						
	Known, Benchmark	12/03/2012	Yes	Yes	Yes		24	1.4	Yes	-5.6	-3.9	Yes (1.7)		Yes	Yes (0.9)	Yes (10.8)	Yes (51)	No (4.95)		No	Ongoing as this is our benchmark material	Near 5% efficiency with benchmark material
	Known, Benchmark	12/03/2012	Yes	Yes	No	5mg/1mL chlorobenzene			No	-5.4	-3.7	Yes (1.7)		Yes	Yes (0.94)	Yes (10.00)	Yes (0.62)	Yes (5.85%)		Yes	Ongoing as this is our benchmark material	5.9% efficiency with benchmark material
	Unreported but minor change based on above 7.4% Eff. Polymer	12/03/2012	Yes	Yes	Yes (CHCl3)		13.6	1.2	Yes	-5.6	-3.9	Yes (1.7)		Yes	Yes (0.92)	Yes (11.7)	Yes (51)	Yes (5.5)		Yes	Terminated (material instability)	5% Milestone met with unreported material
	Unreported	12/03/2012	Yes	Yes	Yes ($CHCl_3$)Yes ($CHCl_3$)		7.8	1.2	Yes	-5.4	-3.8	Yes (1.6)		Yes							Terminated (Low peformance)	compound screening
	Unreported	12/03/2012	Yes	Yes	Yes		18	2	Yes						Yes (0.88)	No (6.1)	Yes (0.49)	No (2.65)		No	terminated (low PCE)	compound screening
	unreported	13/03/2012	Yes	Yes	Yes		28.5	2.2	Yes	-5.34					yes (0.94)	No (7.84)	No (0.45)	No (3.30)		No	terminated (low PCE)	compound screening
	unreported	13/03/2012	Yes	Yes	Yes				Yes	-5.25	-3.5	No (1.75)		No	yes (0.86)	No (4.4)	Yes (0.46)	No (1.70)		No	terminated (low PCE)	compound screening
	unreported	13/03/2012	Yes	Yes	Yes		22.1	1.4	Yes	-5.34	-3.76	Yes (1.58)		Yes	yes (1.02)	No (6.61)	Yes (60)	No (4)		No	terminated (Better Candidates)	compound screening
	unreported	13/03/2012	Yes	Yes	Yes				Yes	-5.28	-3.48	Yes (1.8)		Yes							terminated (Better Candidates)	compound screening
	unreported, large difference between suzuki and stille product MW	18/05/2012	Yes	Yes	Yes		72	2.4	Yes	-5.22	-3.55	Yes (1.67)		Yes	Yes (0.92)	Yes (16.0)	Yes (65)	Yes (9.6)		Yes	ongoing (milestone material)	7% Milestone met with unreported material, approaching 10%
	unreported	13/03/2012	Yes	Yes	No				No												terminated (solubility)	compound screening

Figure 3. Extracted section of the stage gated parameter matrix showing pass (green) or fail (red) points for various materials.

This was a very successful program where effort could be expended only on potential high performance materials or new device architectures allowing the consortium to reach all its project milestones.

It is important to note that information transferred from the parallel printing program allowed modification of stage gating parameters with a focus on developing materials or device architectures which could be transferred to that printing program.

Transferability

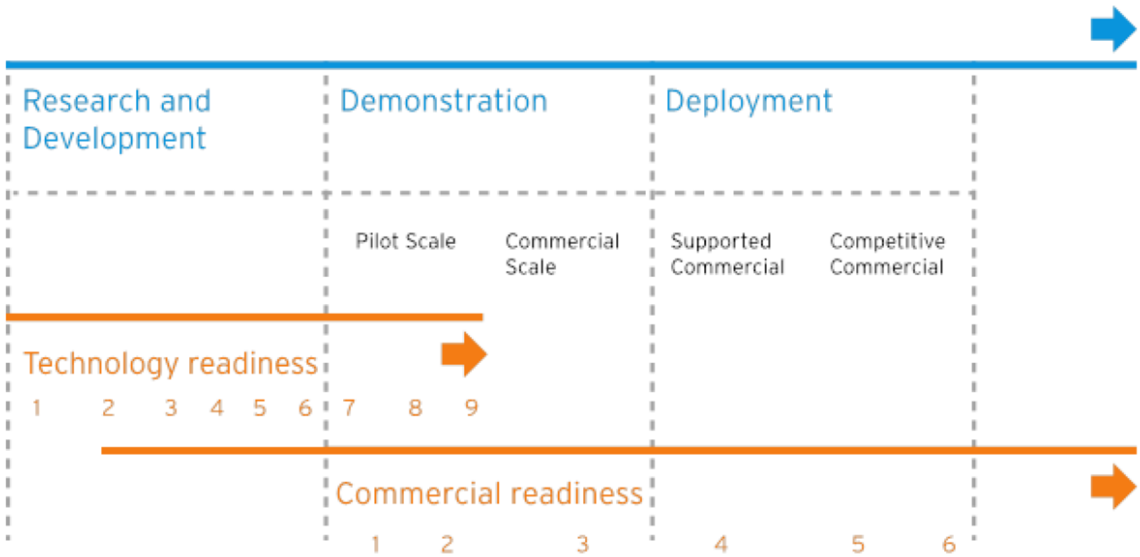
The technology currently developed by the end of the project has matured to a level that is suitable for certain near term applications, such as providing portable power for short duration applications.

These near term applications are seen as stepping stones along the way towards the longer term goal of development and deployment for BIPV applications.

The technology and detailed know-how has been developed on commercially available printing equipment, significantly de-risking entry by commercial partners facilitating transfer to industry.

According to the Technology Development Chain sourced from ARENA (see diagram: www.arena.gov.au/resources), we estimate that the VICOSC program of work has shifted our technology from ca TRL1 to ca TRL5-6, which is still in the early – yet useful – stages of commercial readiness.

Figure 2: **TRL and CRI mapped on the Technology Development Chain**



Conclusion and next steps

The consortium has developed an integrated program ranging from materials and device architecture development, large-scale printing, module encapsulation and durability testing. Key to commercialization success is the development of high performance materials and simplified device architectures to enable rapid printing and therefore translation to commercialization.

The consortium has had a very successful publicity campaign after installation of the large-scale printing capability that has raised the general public's knowledge and awareness of the consortium while also providing a continuous stream of interested new business and industry players. The consortium stands ready to take the technology to the next stage of manufacturing with a commercial partner and suitable government/commercial funding.