Accelerating Industrial Solar Cells Efficiency by Development of Plasma-Enhanced Chemical Vapour Deposition (PECVD) – based Metal Oxides

Project results and lessons learnt

Lead organisation:	University of New South Wales
ARENA ID:	2017/RND001
Project commencement date: 3 January 2018	**Completion date:** 30 September 2021
Date published: 28 August 2019	
Contact name:	Ziv Hameiri
Title:	Dr.
Email: Ziv.hameiri@unsw.edu.au	**Phone:** 02 9385 9475
Website:	Ziv Hameiri

This project received funding under the Australian Renewable Energy Agency (ARENA) Solar Research & Development Program (Round 3).

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Executive Summary

In our project we are aiming to develop plasma enhanced chemical vapor deposition (PECVD) processes for metal oxides. To achieve this goal, in phase one of the project we set out to modify an existing PECVD tool (AK-800, Meyer Burger) to enable the development of PECVD-based metal oxides focusing on titanium oxide (TiO_x) and tungsten oxide (WO_x). So far, we were able to successfully deposit TiO_x from titanium (IV) isopropoxide (TTIP) using the modified AK-800. However, our process is not yet ready to be used for material development as it is not reproducible. This is due to the hardware configuration which was designed for the proof-of-concept only.

For the second phase we are therefore planning to install a more sophisticated system. To that end we discussed with our partners at Meyer Burger (Germany) who are helping us design an advanced precursor delivery system that will ensure a controllable and constant precursor flow, which is the weak point of the initial home-built system. This new system is currently being fabricated at Meyer Burger's facilities in Germany and should be delivered within the next 6-8 weeks.

Project Overview

Project summary

We modified our main deposition tool, the AK-800, to be able to deposit metal oxides. In the first stage we focused on TiO_x which we successfully deposited.

Project scope

This main goal of our project is to develop industry-ready deposition processes for metal oxides for either electron- or hole-collecting layers in silicon-based solar cells. In the past the potential of these materials was already shown. However, so far mostly evaporation and atomic layer deposition (ALD) where used to apply them on samples. Yet, these methods are not readily available in industrial settings. Therefore, we are focusing on developing processes that are based on PECVD systems that are already commonly used in industry. Besides their availability PECVD also brings certain advantages with respect to processing. In comparison to the conventional deposition techniques mentioned above, PECVD exhibits a wider parameter space, with *e.g.* temperature, pressure, power, gas ratios, additional precursor gases. In a first step, we are striving to generate knowledge about how these parameters influence the growth of the materials (TiO_x and WO_x) and its properties. Once the processes are put in place, the materials will be implemented in photovoltaic devices and the influence of the material properties on the device performance will be assessed.

Outcomes

So far, we were able to show that it is possible to deposit TiO_x by PECVD. Unfortunately, not much more was achieved as we lost access to the AK-800 due to major maintenance works at UNSW.

Transferability

Developing processes for the deposition method that is already used in industry and widely used in research, it should be relatively easy to benefit from our work and implement it on different tools, be it in research or industry. This will open new paths to designing photovoltaic devices which may help to further reduce costs while enabling highly efficient devices.

Our main knowledge sharing activities are (1) internally, through seminars at our university; and (2) externally, through publication of journal papers or presentations at conferences.

Conclusion and next steps

The project is still running, and we hope that by the end of September 2021 we will be able to provide a more meaningful conclusion and advise future researchers.

Lessons Learnt

Lessons Learnt Report: Modification AK-800

Project Name: *Modification of the AK-800*

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

Key learning

After the first modifications of the tool (AK-800) we started to test the precursor delivery system (PDS) and managed to deposit titanium oxide. During this phase we learned that the simple PDS we built and used for the proof-of-concept was insufficient for the next phase. Using a simple cartridge that was heated supplied a certain pressure for the precursor to be diffused in the processing chamber, yet, due to the lack of a precise flow control device, once the valves on the line were opened the entire pressure was released. Furthermore, even though we used a linear shower head to disperse the precursor within the processing chamber, we only obtained a deposition on the side the precursors were fed in. Thereby, we learned that for what we want to do a **bubbler system**, consisting of a precursor-filled cartridge with a carrier gas in- and outlet would be crucial for our project. This advanced PDS would ensure constant precursor flows as well as a sufficiently high pressure to fill the linear shower head and thus enable us to start the development of the materials based on a *reproducible process* and a more *uniform deposition*.

Implications for future projects

We might have lost some time not thinking ahead early enough, *i.e.* during the proof-of-concept phase with the in-house-built PDS we should already have thought of how to improve the system for the next phase. This is something to consider in future projects.

Knowledge gap

We are currently not certain of how to administer the precursor for tungsten oxide which is a solid. In contrast to the liquid titanium oxide precursor that we will vaporize simply by heating it inside the bubbler system, the way the tungsten oxide precursor is vaporized is different. We are currently discussing different options.

Background

Objectives or project requirements

The technical milestones we set out to achieve during this stage of the project were: (1) to modify the AK-800 and (2) deposit TiO_x or WO_x.

Process undertaken

First, we installed the preliminary PDS on the system together with our technical team, connected it to the necessary air extraction and the processing chamber. Once installed we tested it using harmless deionized water to check if the PDS performs as it should. This test showed that indeed we managed to deposit SiO_x from a mixture of water and silane (SiH_4). This convinced us that the system works and was ready for the deposition of TiO_x layers. Hence, we proceeded with the TiO_x precursor, filled the cartridge and successfully performed our first depositions.

Supporting information

The photograph on the left (Figure 1) shows the interior of the PDS we built for the AK-800. The cartridge and the line are wrapped in thermal insulation foam to ensure a uniform temperature along the line to avoid condensation of the liquid precursor.

The photograph below shows the interior of the processing chamber with the linear shower head installed.

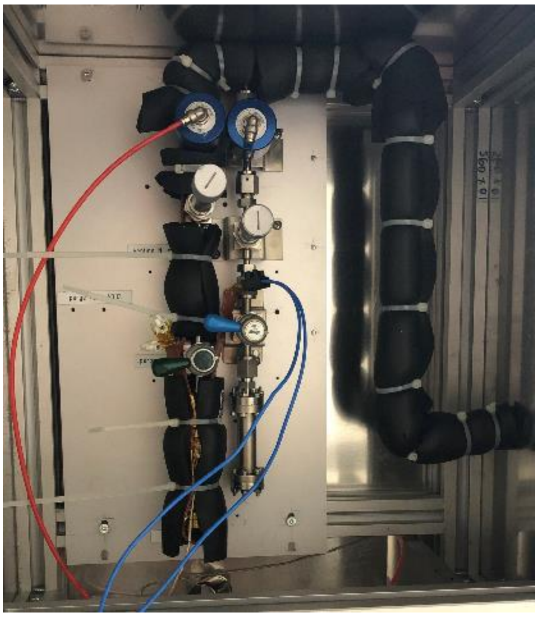

Figure 1 Interior of the precursor delivery system (PDS) with the left line in operation. From bottom to top: (1) cartridge, (2) 1/4-turn isolation valve, (3) needle valve for flow control and (4) diaphragm valve (red tube with compressed air connected to it).

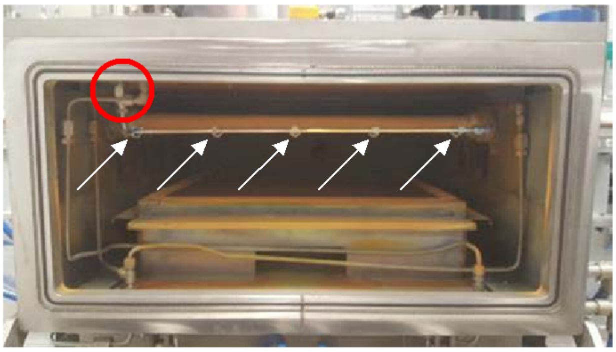

Figure 2 Interior of the processing chamber with the precursor inlet in the top left corner (red circle) and the linear shower head exhibiting five precursor nozzles (arrows).

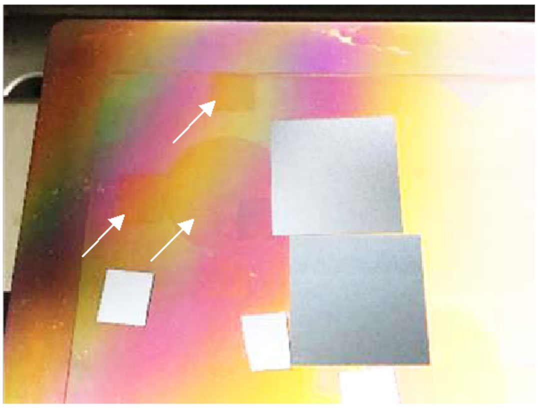

Figure 3 Susceptor plate after the deposition of the first TiO_x layers. The shadows of the samples indicate that the deposition was successful.

With the configuration of the machine shown above we managed to deposit our first TiO_x layers as shown in Figure 3. The photograph shows the susceptor plate that is used to transport the samples into the processing chamber. The deposition was successful as can be seen by the shadows on the plate, where samples were positioned during the deposition. Furthermore, note the coloured lines that seem to be centred in the top left corner of the susceptor plate. From this nonuniformity of the deposition we learned that the precursor only exits the first nozzle on the linear shower head.

Lessons Learnt Report: Work function study with ANU

Project Name: *Work function study with ANU*

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

Key learning

We set out to study the effect of metals on the recombination at the surface of a passivated silicon wafer. In collaboration with ANU, Canberra, samples were fabricated and characterized with tools at UNSW. We learned that depending on the metal work function the presence of the metal can indeed influence the recombination statistics, *i.e.* reducing or increasing the number of charge carriers lost to recombination.

Implications for future projects

This study is still ongoing at this point. Yet, what we can already say is that for very thin passivation layers that are capped by a metal layer, it is important to choose the metal with respect to its work function in order to avoid additional losses in a photovoltaic device.

Knowledge gap

In the second part of this study we will include different passivation schemes, *i.e.* materials with a high amount or a lower amount of fixed charges, aluminium oxide and silicon oxide, respectively. This will help us understand the role the amount of fixed charges plays in the passivation of silicon in this kind of structures.

Background

Objectives or project requirements

The aim of this study is to generate knowledge about the effect of the presence of metal on recombination of charges. This will enable choosing the best dielectric-metal combination as well as optimal layer thicknesses.

Process undertaken

The samples were fabricated at ANU, Canberra, and characterized at UNSW using a measurement method based on photoluminescence.

Supporting information

The sketch and photograph in Figure 4 show the setup of the tool that we used. The working principle is relatively straight forward. The sample is placed on a stage and illuminated by a laser pulse. This pulse generates excited carriers inside the sample that return to their initial state under the emission of light (photoluminescence, PL). This PL signal is then picked up by a special detector and recorded. From the PL signal it is possible to learn something about the recombination processes within the sample.

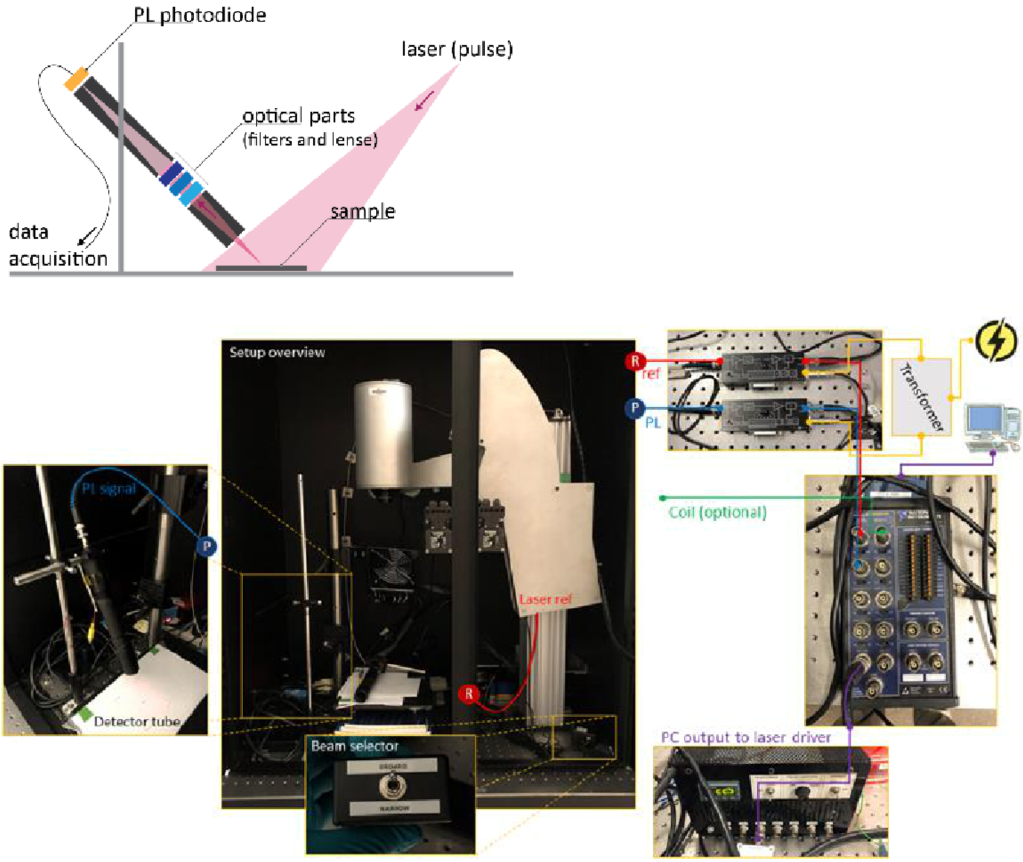

Figure 4 Setup used for the characterization of the samples fabricated by ANU.

Using this system we measured the above-mentioned samples and obtained the injection-dependent effective minority carrier lifetime shown in Figure 5.