A pilot-scale plant for the production of solar anti-reflection (AR) coatings [Project 1-US018]

Brisbane Materials Technology (BMT) has developed a unique anti-reflection coating technology that can increase the energy delivered from solar photovoltaic (PV) and solar thermal power systems. The coating works by eliminating reflections from air-glass or air-plastic interfaces which are normally wasted in the solar conversion process. In this ARENA Project, BMT has created and qualified a pilot-scale plant for the production of large area solar AR coatings for application to PV modules. This pilot-scale plant served multiple purposes: it proved that the BMT technology can be successfully scaled; it allowed BMT to develop and test processes, equipment and manufacturing methods; it produced manufacturing relevant batches for customer test and qualification; and finally, it provided the blueprint for the first BMT AR Coating Manufacturing Plant. This successful ARENA Project has substantially advanced the commercial prospects of BMT to such an extent that we are in negotiations with a major solar PV module manufacturer to purchase a plant.

Why do photovoltaic modules need AR coatings?

In a typical PV module, sunlight is converted directly into electricity by an array of semiconductor solar cells. These cells, plus accompanying electrical circuitry are encapsulated beneath a protective glass cover plate – this plate prevents the delicate and valuable semiconductor junctions from environmental damage.

The laws of Physics dictate that a portion of the incoming light will be reflected from the top surface of the glass cover plate whilst the rest is transmitted. This reflection arises because there is a difference between the refractive index of glass ($n_{glass} \approx 1.5$), and that of air ($n_{air} \approx 1.0$). This is demonstrated in Figure 1.

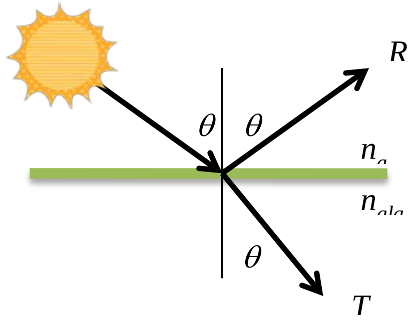

Figure 1 - The reflection of sunlight from a glass-air interface. A fraction of the incident light is reflected and the remainder is transmitted. The precise amount of reflected light depends upon the angle of incidence (θ_i) and refractive indices.

A simple set of equations govern how much of the incoming light is reflected (R) and how much is transmitted (T) as a function of the angle of incidence, the polarisation of the light and the refractive indices. These equations (called Fresnel's equations) predict that ~4% of the sunlight is reflected at normal incidence (i.e. when the sun's rays make an angle of 90° with the cover plate surface which we define as $\theta_i = 0$). This reflection increases "off-normal" and can be greater than 20% when θ_i is large – for example when the sun is low in the sky in the morning or evening. Figure 2 shows how this effect can clearly be a significant issue for PV modules where every photon counts.

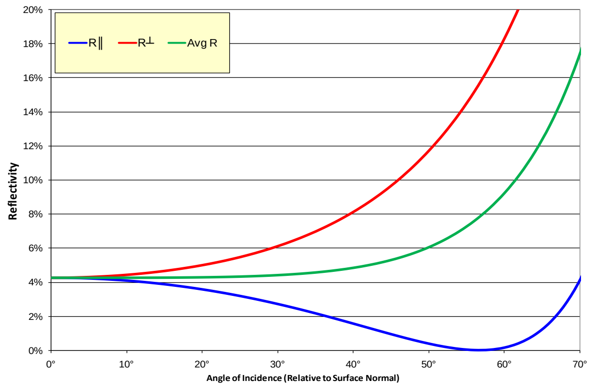

Figure 2 - Calculated reflectance from the glass-air interface as a function of angle of incidence. The graph shows the reflectance for light polarised parallel (blue) and perpendicular (red) to the plane of incidence, and the average of the two (green). Assuming that it is unpolarised, the green line shows the expected reflectance for sunlight.

The benefit of AR coatings on PV modules

The solution to the problem of unwanted reflections has been known for many decades – an anti-reflection coating. Ideally, the AR coating must be effective over a large range of angles and have a broad spectral response, i.e. be effective over as much of the solar spectrum as possible. The simplest and in fact optimal AR coating is a so-called "single quarter wave" coating show in Figure 3 where the anti-reflection coating has a refractive index n_{film}.

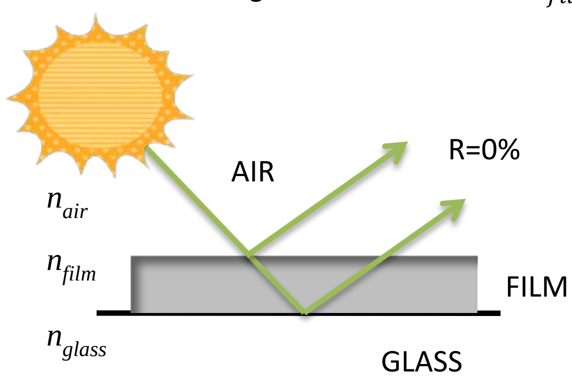

Figure 3 - A simple single quarter wave anti-reflection coating for the glass-air interface.

The conditions to satisfy zero reflectance are that the film refractive index (n_{film}) must be adjusted to be the geometric mean of the refractive indices of air (n_{air}) and the glass (n_{glass}), and the film thickness (d) must be an "optical quarter wave" at the AR design centre wavelength (λ_0). This means for an air-glass AR coating designed for the visible, $n_{film} \approx 1.25$ and $d \approx 100$nm. A properly designed AR coating can in practise reduce the normal incidence reflectance to <1% per interface. Figure 4 shows an example of a Brisbane Materials AR coating designed for the visible which achieves >99% transmittance through a piece of standard 4mm solar float glass at the design wavelength (560 nm).

The AR coating performance directly translates to increased power and energy output. The output power of a solar cell is linearly related to its short circuit current, which in turn is directly proportional to the amount of light falling on the solar cell junction.

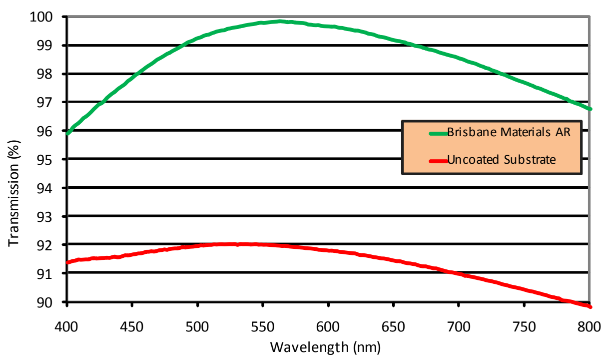

Figure 4 - The measured transmittance of solar glass with (green) and without (red) a Brisbane Materials AR coating.

BMT's AR coating manufacturing process – ARENA Project 1-US018

One of the major advantages of the BMT technology is that our AR coating process is conducted at room temperature and pressure using simple, low cost, safe chemicals. The coatings shown in Figure 4 were produced in the laboratory on a small scale (up to 30 cm x 30 cm). BMT's challenge is translate this performance into a viable product and manufacturing process. This is the focus of the ARENA Project whose basic objectives are to:

i) Demonstrate that the BMT processes can be scaled to PV module size (ideally coating areas of 120 cm x 80 cm and above);
ii) Develop a viable manufacturing process which delivers sufficient yield, product performance and cost for a PV applications;
iii) Create a pilot-scale production plant that can be used to qualify the manufacturing process and produce customer batches for testing;
iv) Deliver a design for BMT's first, full-scale manufacturing plant.

Project activities, outcomes and achievements

BMT's Project Partners: In this ARENA Project, BMT engaged with a number of global PV module manufacturers from both the crystalline silicon and thin film segments of the industry. Ultimately, one customer emerged as a lead candidate whose AR-product needs closely matched the BMT value proposition and strengths. Product and plant design focussed on this customer as the Project matured. BMT's equipment partner (a European manufacturer of semiconductor processing equipment) were key collaborators in the Project which ultimately delivered a pilot plant (at BMT Brisbane) and a prototype manufacturing plant (at the equipment manufacturing partner site).

Project Outcomes: The Project delivered the following important outcomes –

i) BMT developed a spray process suitable for large area coating applications and with the potential to deliver the necessary yield, throughput and low cost;
ii) This process was integrated into a manufacturing pilot plant created at BMT's Brisbane facility;
iii) Preliminary sample batches were produced using the Brisbane pilot plant for internal testing and for initial customer engagement activities;
iv) Full engineering trials were conducted on the Brisbane pilot plant and those learnings transferred to our equipment partners for the design and construction of a prototype production plant at their site; a photograph of this plant is shown in Figure 5;
v) Qualification sample batches were produced using both the Brisbane pilot plant and prototype production plant – these batches

were subject to internal and lead customer external performance and stability testing with successful outcomes;

vi) A manufacturing plant design and specification were constructed and multiple modifications made to the prototype production plant to assess engineering challenges;

vii) Scope, plans, design, throughput and cost were delivered for BMT's first manufacturing plant for PV module applications and are the subject of current contract negotiations with a major, global PV module manufacturing company.

In additional to these substantial achievements, BMT has generated new know-how and internal intellectual property. We already had a market leading technology, we now have the manufacturing process to deliver the market leading product. The Project funds helped support 11 high value technical jobs in Brisbane.

Figure 5 – Prototype production plant at BMT's international equipment manufacturing partner.

Summary & where next?

This ARENA funded Project has greatly assisted BMT in moving its market leading technology from the laboratory to manufacturing. A pilot and prototype production plant have been built and a viable manufacturing process developed. A lead customer emerged during the course of the Project and has received and tested the all-important qualification batches. BMT's first full manufacturing plant (to be delivered by our equipment partner) has been designed and this is currently (June 2015) the subject of advanced negotiations with a lead customer – a global PV module manufacturer. BMT is close to securing this solar customer and is also diversifying into other AR coating applications.

Acknowledgements

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