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Development of large area photovoltaic dye cells at 3GSolar

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ABSTRACT

Dye solar cells (DSCs) are a low-cost alternative to photovoltaic silicon and thin film cells on the basis of materials (bulk titania powder in place of high purity semiconductors such as silicon) and process costs (simple screen printing and oven treatment in air in place of vacuum deposition). 3GSolar Ltd., with a novel DSC design based on a robust silver-free current collecting grid, have developed commercial size, sealed prototype glass-based cells of area 225 sq cm and assembled them into multicell prototype PV modules. Performance data are presented for these prototypes, which are on schedule towards pilot production (2010) and industrial production (2011) of cells and modules.

1. Introduction

Dye cells since their invention [1] by Michael Graetzel in 1987 offer a route to low-cost PV because not only the raw materials are cheap (titanium dioxide powder is the main photoactive material, and this is a commodity powder used in paints and toothpaste) but also cell manufacturing is potentially of low cost (print and bake in air). The technology is disruptive since there is no need for expensive materials (such as pure silicon) or costly production methods (use simple *screen printing* rather than vacuum processing) as in other types of PV. Dye cells are based on a thin (typically 15 μm) porous layer of nanocrystalline titania supported on a conductive transparent support and facing a catalytic counter electrode. The titania is coated with a sensitizing dye and is impregnated with an iodine-based redox electrolyte. Projected dye cell material costs and capital costs for economic production are a fraction of those typically associated with silicon and thin film cell production lines. Furthermore, small research dye cells have been reported as having a promising $>12\%$ conversion efficiency under one sun illumination [2]. Many companies and research groups are active in PV dye cells, which are considered to be third-generation PV technology. However, commercialization has been delayed because of scale up, materials and stability problems.

3GSolar Ltd. has set as its company goal the commercialization of dye solar cells, initially for the $2b off-grid market. The primary product is to be a 55 W glass-based module for solar home systems in developing countries. In the 3GSolar dye cell system prior technology limitations in the field have been overcome. A novel silver-free, robust, corrosion-resistant current collecting grid has been developed that allows scale-up to large area cells having increased stability and with reduced wastage of active area. A further cost saving element in the design is the need for only one conductive glass plate per cell. In this paper we indicate a new route to low-cost, robust cells and modules. Despite encouraging results with small cells by many workers, scale-up to larger cells of practical dimensions (~200 sq cm) has proven difficult. Basically, use of conductive glass alone in a dye cell allows effective current take-off only from long, narrow strip cells, which design wastes often over 30% of the cell footprint due to seal areas and edge effects. We found that use of printed silver conductors in the cell to withdraw current and enable construction of broad, large area single cells risks corrosion of silver by iodine in the cell electrolyte and the poisoning effect of silver on the dye. Even when the silver was protected using a layer of polymer or glaze it was difficult to completely prevent pinholes in large area, large throughput cell fabrication, and the silver would corrode. 3GSolar have developed [3–6] a system of *silver-free* proprietary *robust conductors* as an enabling platform for use in current take-off from large area cells, which materials are *intrinsically inert* to the cell electrolyte and to charge carrier recombination. Individual large area cells are sealed, mounted in a module and electrically connected. These proprietary conducting fingers effectively replace printed silver lines in rival DSC designs.

Presently we are at the cell and module prototype building & testing stage, but our near term goal for full sized (15×15 cm

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external or 20.5 × 11 cm aperture) cells for low-cost applications is to meet three main parameters:

1. 7.5% cell efficiency at cell level (providing an efficiency at the module level of 7%).
2. 7 year lifetime warranty.
3. $70 per sq m for bill of materials and labor.

This is consistent with our initial manufacturing entry cost goal (2011) of $1.40 per peak watt for an 8 MW dye cell plant. Our projected cost for such a plant is less than $10 M, giving a return on investment within two years. This capex is a fraction of that needed for rival silicon and thin film PV production plants, not only because of the lower cost of raw materials for dye cells (titania vs silicon) but also processing costs are lower because of freedom from vacuum processing and simplicity of technology (screen printing and air baking of active layers). The manufacturing cost within 3 years from initial production is projected to reach $0.7 per peak watt, based on economies of scale in multiple plant production and via incremental increase in cell efficiency through incorporation of new materials (such as dyes or titania pastes) and processes. In this time frame cell efficiency will be raised to 10% and lifetime will reach 15 years.

2. Experimental

Cells were built on Pilkington TCO glass, specially treated and fitted with 3GSolar proprietary metallic conducting fingers. Electrodes, including the titania photoanode, and the carbon-based counter electrode were applied layer-by-layer by screen printing. Printing inks were obtained from Dyesol and Solaronix, or prepared in-house (3GSolar proprietary light-scattering titania and carbon conductive and catalytic pastes). N719 dye (Solaronix or Everlight Chemical Industrial Corp.) was applied onto titania from ethanol solution, containing co-grafting agent with the dye (1:1 molar ratio of chenodeoxycholic acid, Sigma-Aldrich and dye). Dyesol EL-HSE electrolyte, gelled according to 3GSolar procedure, was used for filling of cells. Sequential polymer sealing was applied on the cell edges.

Ready cells were subjected to aging tests: 85 °C continuous heat stress under one sun illumination, and to outdoor testing in Jerusalem, Israel in a roof station. Photovoltaic parameters were measured under standard illumination of one sun (Solaronix Class C solar simulator, Keithley 2440 source meter, home-made IV-scan software). 4-point probe connection was applied during measurement because of cell high current output (2–3 A).

3. Results and discussion

Fig. 1 shows a full size 3GSolar rectangular form anode plate (size 20.5 × 11 cm) comprising tin oxide glass fitted with robust current collecting fingers. The plate shown has been printed with titania, followed by sintering and staining with the ruthenium dye N719. The robust current collecting fingers can be sintered without loss of conductivity or corrosion resistance in the cell electrolyte, and give low shading (presently ~7%) of active area.

Figs. 2 and 3 show full size prototypes of cells having rectangular and square geometry, enabled with robust conductors (square design has 225 sq cm footprint, where 90% is PV active area). Due to the large cell area, the rim seal takes up a relatively small fraction of the cell face, and about 90% of the cell geometric area can presently be made active, a significant improvement over many previous DSC designs.

Fig. 1. Anode plate with robust current collecting fingers.

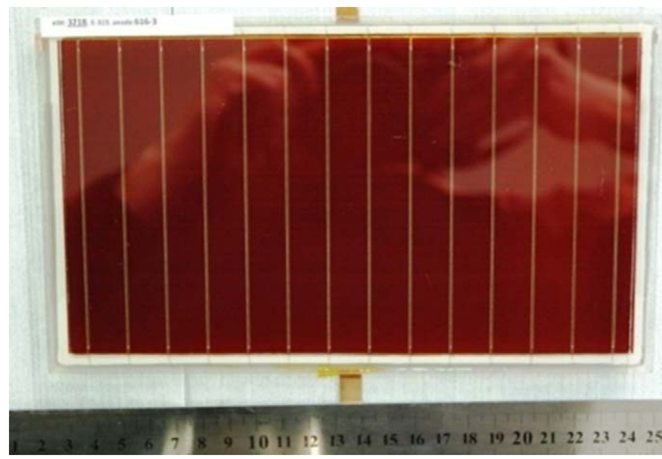

Fig. 2. Rectangular prototype for pilot production—225 sq cm cell (aperture) with robust conductors.

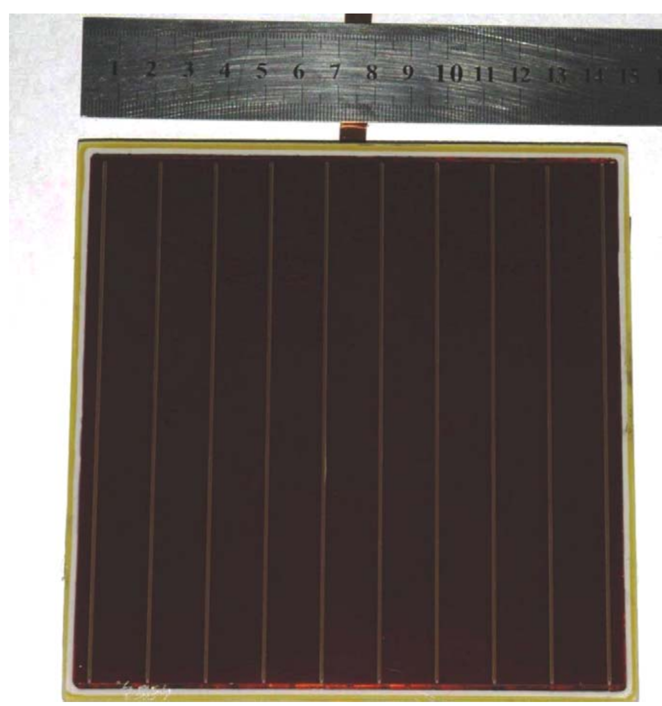

Fig. 3. Square prototype for pilot production—cell of 225 sq cm (footprint) with robust conductors.