PROCESS DEVELOPMENT OF SHAPE AND COLOUR IN LGBC SOLAR CELLS FOR BIPV APPLICATIONS

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Abstract

The use of photovoltaic modules in architectural applications is now firmly established and large modules of glass-glass construction produced specifically for the BIPV market are available. In 1995 Mason et al [1] investigated colour and efficiency of laser grooved buried contact (LGBC) solar cells as a function of the thickness of the low pressure chemical vapour deposition (LPCVD) silicon nitride antireflective coating (ARC). In the late 1990's the BIMODE project produced coloured solar cells using this technique and modules of efficiencies in the range of 6.3% to 12.1% [2,3,4] were fabricated. The HAVEMOR project which started in 2007 is aimed at understanding and controlling the processes that affect thickness and hence colour of the silicon nitride ARC to achieve maximum colour uniformity and reproducibility, thereby raising manufacturing yields. This process optimization is focused on allowing subsequent commercialization of coloured cells for use in the BIPV market. Initial theoretical background and results of preliminary experiments were presented by Roberts et al [5] on the formation of ARC's with thicknesses in the range 90nm to 400nm on LGBC solar cells. In this paper, recent experimental results on coloured multicrystalline LGBC cells will be reported, along with a study of the colour uniformity obtainable in large production runs and an investigation into the use of different shaped cells to allow intricate module design.

Coloured LGBC Cell Fabrication

The process steps required in the fabrication of LGBC solar cells were presented by Roberts et al [5], and it was shown that 5 of these steps influence the final colour of the solar cell. Colour uniformity is achieved by ensuring the final thickness of ARC across a wafer surface is kept essentially equal, and for batch production this control must be maintained for all wafers in the batch to prevent colour variation within the run lowering yield. Experimentation showed that tight control of the (LPCVD) process and heavy groove doping high temperature furnace steps were of primary importance. Wafers are placed in the furnace in quartz glass boats and are processed two wafers to a slot to give a total furnace capacity of 250 wafers. A series of trials were conducted in order to determine the effect of wafer position in the furnace, on final cell colour produced. These trials allowed furnace recipes to be tuned to give the greatest uniformity of deposition possible along the 250 slot furnace tube. Parameters which can be varied in the furnace include the gas flow, ratio and pressure. Also the temperature along the length of the tube can be controlled independently in 5 separate zones. These trials highlighted that wafers in early positions in the tube (slots 1 to 10) and late positions in the tube (slots 240 to 250) were critically effected due to variation in the thickness of the silicon nitride deposited at these positions, figure 1, the number below the wafer indicates furnace position of wafer during processing. For process runs these critically effected slots are simply filled with dummy wafers which can be used repeatedly and are not processed into final cells. The wafers in these positions, located at the two extreme ends of the furnace, experience different deposition due to the gas flow, gas is introduced at one end of the tube and allowed to flow to the other, and temperature control at these points. This can be less well maintained during the run, as compared to the 'main body' of the furnace where gas flow and temperature, and hence deposition, is more regular and hence more tightly controlled. By implementing the controls investigated, production size runs of upto

150 cells were achieved during the course of the project.

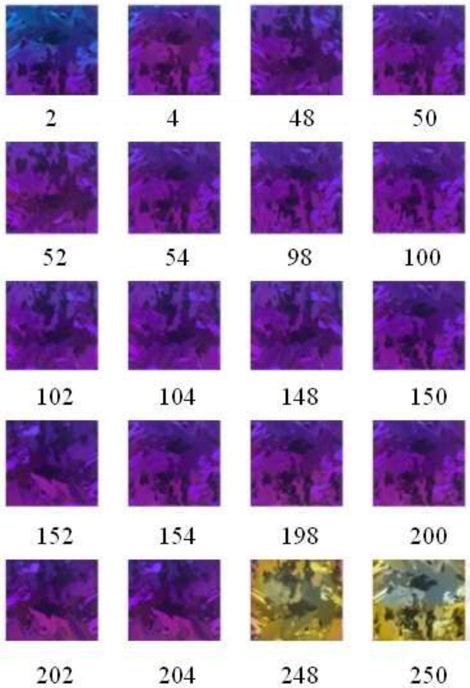

Figure 1 – Process run showing variation in cell colour obtained in relation to furnace position

Cell Colour and Efficiency

The range of colours achievable in practice was investigated by depositing a silicon nitride film of varying thickness onto a silicon surface. This was accomplished by placing 2 silicon wafers in close proximity in the LPCVD furnace, with a small angle between the wafer faces in order to achieve a varying degree of shading from the deposition process. The resulting spectrum of colours is shown in Figure 2.

Figure 2 - Interference colours in a silicon nitride layer of varying thickness on a non-textured monocrystalline silicon surface

Of this spectrum 6 colours were chosen to be studied in detail throughout the course of the project, these were black, dark blue, steel blue, gold, purple and green. It was found that excellent uniformity of colour across the cell could be achieved in all cases. The thickness and refractive index of silicon nitride was measured by ellipsometry on polished wafers processed alongside the cells of each colour. This data, together with the silicon nitride deposition time in the LPCVD process is shown in table 1. During the course of the project advances in processing techniques, primarily in the control of the plasma etch process, allowed final cell area after edge isolation to be raised from 149.6cm^2 initially, to full area 151.29cm^2.

Colour	Dep. Time (min)	Thickness (nm)	Refractive index
Black	28	74	2.03
Dark Blue	33	86	2.03
Steel Blue	42	109	2.03
Gold	54	148	2.03
Purple	74	211	2.03
Green	125	385	2.03

Table 1 – ARC properties corresponding to the 6 colours

The following best cell data achieved for each of the 6 colours produced over the course of the project is shown in table 2.

Colour	Jsc (mA/cm^2)	Voc (mV)	FF (%)	η (%)
Black	32.6	599	76.8	15.0
Dark Blue	30.6	582	73.6	14.7
Steel Blue	27.8	579	75.4	14.2
Gold	27.6	589	75.5	12.9
Purple	26.4	569	75.0	12.0
Green	24.8	562	74.6	10.4

Table 2 – Light-IV parameters of best achieved coloured cells on block cast multicrystalline wafers

Cell Shape

A variety of differently shaped cells were produced by modification of the standard edge isolation process step, this modification required reprogramming of the laser, but required that no additional processing equipment be used to that of a standard LGBC cell production line.. A range of regular polygon shaped cells and cells with curved edges were produced to demonstrate this, figure 3. The cell front contact design was also modified at the laser grooving process step, to optimise the front busbar, figure 4.

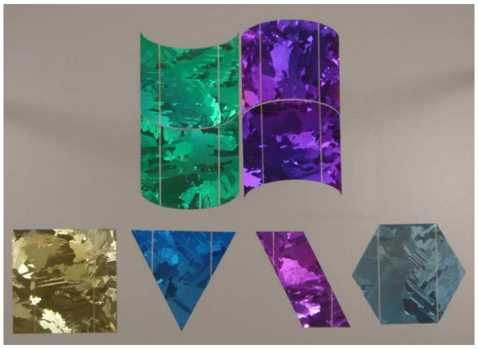

Figure 3 – Coloured and shaped cells

Figure 4 – Shaped cells with optimised busbars

Module design

The project demanded that intricate module design be investigated, and allowed the combination of shape and colour to be exploited. Several modules of differing construction where produced at the Romag production facility, including glass/ glass, glass/ white Tedlar and glass/ black Tedlar. Several process techniques were developed during this module construction exercise and both electrically active modules and ‘proof of concept’ laminates where produced to test these. A problem which can occur during module production is that of cell movement under vacuum lamination, where the cell string is incorporated into the glass/ EVA/ Tedlar or glass/ EVA/ glass module. Ordinarily some small cell movement could be tolerated in standard module production, but in the case of intricate design maintaining cell positioning is crucial or the design is lost. Processing techniques were developed to overcome this problem, and the production of the PV Crystalox and NaREC logo laminates, figure 5, demonstrated excellently how such control could allow very complicated design to be maintained under lamination. The PV Cyrstalox logo design combines screen printing on the module glass with a partial globe made up of 32 individual pieces. These pieces were cut from multicrystalline wafers which had an ARC coating tuned to give a blue colour. The NaREC logo is solely made up from pieces of cut multicrystalline wafer, the wording given an ARC to produce a black colour and the arrow an ARC to produce a steel blue colour. Electrically active modules or arrays of these designs could be made using these processing techniques, but would require scale up which lay outside the constraints of the HAVEMOR project.

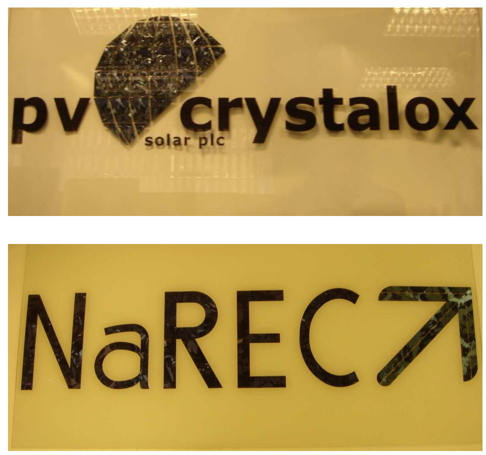

Figure 5 - Electrically inactive laminates produced to show design possibilities

The remaining designs were however electrically active modules and all achieved greater than the 10% efficiency HAVEMOR project target. The final module produced incorporated 6 of the colours developed during the project consisting of gold, pink, purple, green, steel blue and dark blue cells cut in a wave shape. The modules and their associated parameters are detailed in figures 6, 7 and 8.

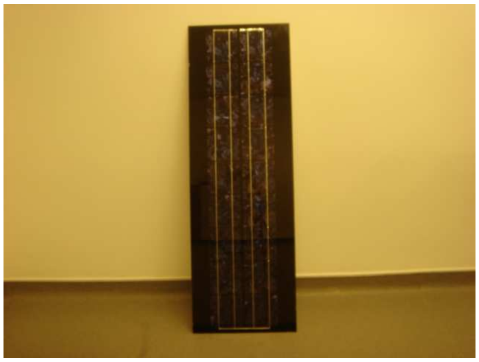

Figure 6 - 18 cell black test module

Voc =10.5V
Isc = 4.63A
Pmax = 71.95W
FF = 74%
Efficiency = 13.2%

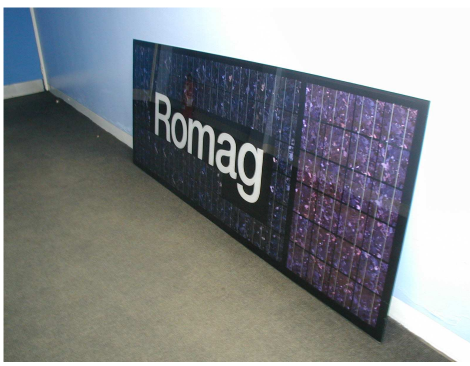

Figure 7 - Two colour 72 cell Romag module

55 cell dark blue string
Voc =31.5
Isc = 4.17A
Pmax = 95.2W
FF = 72%
Efficiency = 11.4%

24 cell purple string
Voc =13.4V
Isc = 3.94A
Pmax = 38.8W
FF = 73%
Efficiency = 10.6%

Figure 8 – 72 cell 6 colour wave module

Voc =40.2V
Isc = 3.60A
Pmax = 107W
FF = 74%
Efficiency = 10.8%

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