Barrier Layers Deposited at Low Temperature on Metal Carrier Foil for the Use in µc-Si Solar Cells

M.Späth [1], J. Löffler[1], W. J. Soppe[1] C. Devilee[1] , X. Niquille[2]
[1]ECN Solar Energy, P.O. Box 1, 1755 ZG Petten, The Netherlands, email: spath@ecn.nl
[2]Institut de Microtechnique, Université de Neuchâtel, Rue Breguet 2, CH-2000 Neuchâtel, Switzerland, email: xavier.niquille@unine.ch

Abstract: Barrier layer material deposited on stainless steel substrate has been under investigation. These layers are part of a film-Si module, presently under development at ECN. Low temperature (< 250°C) processing is required in order to avoid impurity diffusion from the stainless steel foil. Novel materials based on nano particles combined with organic/ inorganic polymers and SiO_x precipitated from the liquid phase have been deposited onto stainless steel foil. Nano particles with organic/ inorganic polymers reveal homogenous layers with voltage breakdown values exceeding 500 V. To test the functionality of the concept, thin-film Si solar cells are planned to be prepared by VHF-PECVD in combination with the different barrier layers.

Key Words: Thin Film Solar Cells, Barrier Layer Deposition, Low Temperature Processing.

1 Introduction

At ECN a PECVD method for high rate growth of intrinsic microcrystalline (µc) Si with a linear microwave source has been developed [1]. In addition to this, a novel type of thin-film Si PV device is under development. This solar module in n-i-p configuration will be manufactured in a 'roll to roll' process using stainless steel foil as a low cost substrate. An electrically insulating barrier layer between the foil and the n-i-p device is required for the series connection of individual cells. Present investigations focus on the selection of electrically insulating materials. Major issues are low temperature processing (< 250°C), cost aspects, industrial handling and scaling up of the production processes towards a width of 30 cm.

For monolithic series connection of thin film modules, a breakdown voltage of the isolation above 50 V is required. In case of applying the stainless steel carrier foil as a back sheet of the module, the IEC1646 design qualification and type approval tests specify a breakdown voltage value of 500 V for modules with V_{oc} below 50 V. The following parameters of the barrier layers have been identified: a) Insulation resistance > 50 MΩ and voltage breakdown capability 500 V b) Curing temperature $< 250^\circ$ C with uniform layer thickness. c) Prevention of chemical interaction with the substrate. d) Negligible outgassing of the barrier layer during subsequent PECVD steps of cell fabrication. e) Mechanical integrity; bendable (in radius ≥ 50 mm) without damage in the coating. f) The cost price of coating should not exceed 10 Euro/m^2.

Novel materials such as nano particles combined with organic/inorganic nano-composites to form coatings at relatively low temperatures have found a widespread usage on the market, offering the advantage of material with a defined quality in combination with a known cost price level. This counts also for SiO_x deposited from the liquid phase. In our investigations these materials are tested in order to meet the parameters mentioned above. Silicon Nitride (SiNx) layers were used as reference material.

2 Experimental

A description of the investigated barrier materials and processing techniques is presented in table I, together with the resulting layer thickness limited by these deposition processes.

Stainless steel foil of the type AISI 301 with a thickness of 0.076 mm has been used as the substrate. Low temperature processing (< 250°C) of the coating is anticipated in order to avoid excessive impurity diffusion. The procedure for the processing is identical for all barrier materials applied. The first step is the deposition of the layer onto the cleaned stainless steel substrate as described in table I. This is followed by thermal curing in an IR oven. A 2 µm SiN_x layer, deposited by microwave PECVD, is used as a reference. In order to measure the electrical insulation and breakdown voltage over the complete surface of a 100x100mm^2 stainless steel foil, a patterned 600 nm aluminum layer is applied by e-beam PVD. With the created aluminum squares (pads) two configurations can be tested. A total of 40 pads with the size 4 x 4 mm² and 25 pads of 10 x 10 mm² have been analyzed in order to obtain statistical distributions of the local resistance. Additionally, spot measurements have been carried out with a metal tip directly contacted to the barrier material. An isolation meter apparatus to determine the voltage breakdown was in use, which allows the determination of resistances between 1 MΩ and 10^6 MΩ while increasing a DC voltage stepwise from 100 V to 1000 V. The reported breakdown voltage represents the voltage where the resistance drops (at least for an instance) below 1 MΩ. These measurements were approved by breakdown voltage measurements carried out at Fraunhofer Institut für Elektronenstrahl- und Plasmatechnik (FEP), Dresden, Germany. To test the mechanical flexibility of the barrier layers, pre-bended steel/barrier layer samples have been coated with a top gold layer of 200 nm. These samples have been submitted to breakdown voltage tests. In order to analyse the morphology of the layers, scanning electron microscopy (SEM) was applied. Moreover, the layers are submitted to outgassing experiments in vacuum (10^{-6} mbar) at 200ºC and 260ºC. Thin-film Si solar cells will be manufactured to test the suitability of the barrier layers in the actual device.

Barrier layer material:	Deposition technique:	Thick-ness
SiN_x (Reference)	PECVD	2 µm
Layer A:Tethraethyl-silicate, (SiO_x)	Dip-coating	1 µm
Layer B: SiO_x nano particles combined with organic/ inorganic polymers	Spraying Rolling	4 µm
Layer C: Organic/ inorganic nano-composites (SiO_x)	Dip-coating	2 µm

Table I. Investigated barrier materials and their processing techniques, with indication of the layer thickness.

3 Results and Discussion

For the SiN_x reference, breakdown voltages as high as 1300 V have been obtained with the metal tip placed on random positions directly on the SiN_x surface. On the 4 x 4 mm² Al pads an average value of 506 V has been reached with a standard deviation of ± 185 V. In the following, results on the 4 x 4 mm^2 pads are presented. The distribution of the initial resistance R_{ini} on a logarithmic scale, measured with a multi meter before applying the voltage to reach breakdown, is shown in Fig. 1. Figure 2 displays on a logarithmic scale the resistance R_{100V} of the barrier layers measured at 100 V. A distribution of the breakdown voltage for all barrier layers is presented in Fig. 3.

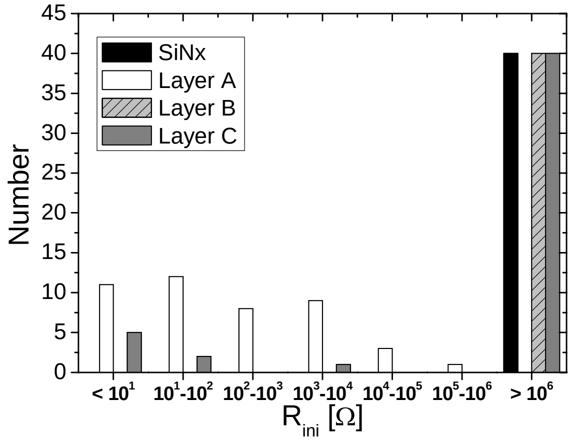

Fig.1. Distribution of the initial resistance of 4 barrier layers.

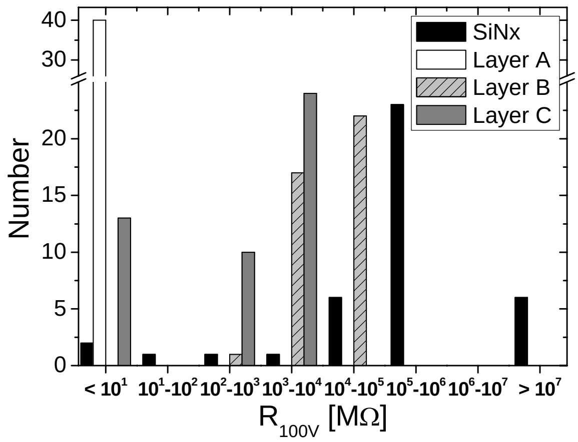

Fig.2. Resistance of the 4 barrier layers determined at 100 V.

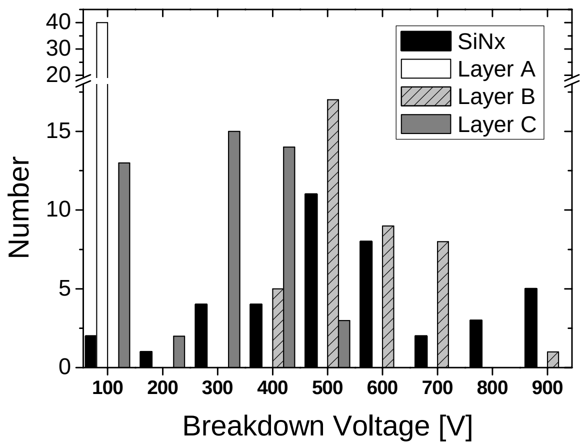

Fig.3. Breakdown voltage distribution of 4 barrier layers.

As can be seen in Figure 1, barrier layer A exhibits a broad distribution of resistances with a maximum of only 0.2 MΩ. Thus, already at an applied voltage of 100 V, breakdown as defined above is observed, and the resistance is too low to be measured with the isolation meter apparatus. Only when measuring with the metallic tip directly on the barrier layer, locally breakdown voltages between 200 V and 300 V have been found.

The layers B and C reach resistance values in the order $\geq 10^8\ \Omega$ which are too high to be measured with the multimeter. Note that 7 % of the measured pads on layer C exhibit resistances lower than 0.1 MΩ, probably due to pinholes in the layer. On layer B all 40 pads show excellent insulation. This is also reflected by a narrower distribution of the logarithm of (R_{100V}) around a higher average of this logarithm of 3.9, as compared to 3.1 for layer C. The same trend is observed for the distribution of the breakdown voltage, characterized by average and standard deviation of 560 ± 110 V for layer B, and 283 ± 131 V for layer C.

Morphology of the barrier layers, analyzed by scanning electron microscopy (SEM) with a magnification of 50.000x, reveals compact and homogenous cross sections without any cracks or pinhole structures for all materials. Bending experiments at a radius of 50 mm showed no significant deterioration of insulation properties. Outgassing experiments on the barrier layer materials in a heated vacuum chamber revealed no remaining volatile organic constituents. Cost calculations indicate that this barrier material can fulfill the requirement of material cost levels below 10 Euro per m^2.

4 Conclusions

Low temperature processed layers based on nano particles combined with organic - inorganic polymers are available on the market and meet the mentioned requirements for barrier layer purposes on stainless steel foil.

It was demonstrated with the breakdown voltage measurements that these nano particle layers show good insulation capabilities on sample sizes of 100 x 100 mm². High voltage breakdown resistance in combination with a narrow standard deviation value underlines the reproducibility of these materials. While the achieved resistance at 100 V is slightly lower than for the SiN_x, an even better breakdown behavior than for the reference material is observed.

No significant outgassing of organic constituents of the barrier layer material has been measured under comparable vacuum and temperature conditions as necessary for the deposition of µc-Si.

Acknowledgements

This work has been financially supported by the Dutch Ministry of Economic Affairs (Projectno. TSIN3043). Christoph Charton (FEP Dresden) is acknowledged for breakdown voltage measurements.

References

[1] W.J. Soppe *et al.*, Presented at the 20th European Photovoltaic Solar Energy Conference, Barcelona (2005).