DEVELOPMENT OF MICROMORPH CELLS IN LARGE-AREA INDUSTRIAL REACTOR

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ABSTRACT: The influences of the deposition pressure and silane depletion on the efficiency of single-junction microcrystalline silicon solar cells has been investigated. The efficiency is found to correlate with the ion energy which affects the density of states in the absorber material. Cell with efficiency of 7.3% at a deposition rate of 1 nm/s, and, respectively, 7.8% at 0.35 nm/s were deposited in R&D KAI-M industrial reactor. Silicon oxide based intermediate reflector layers were developed in KAI reactor for incorporation in micromorph devices. Material with an index of refraction of 1.7 at 600 nm and low lateral conductivity were deposited. Micromorph devices incorporating these intermediate reflector layers were fabricated with initial efficiency of 12.3% at a deposition rate of 0.35 nm/s and 10.8% at 1 nm/s.

Keywords: a-Si:H, micro crystalline silicon, tandem, light trapping

1 INTRODUCTION

Successful industrial development of micromorph modules are critically dependent on their cost to performance ratio. The improvement of the latter calls for an increase in the cell efficiency while reducing the deposition time by increasing the deposition rate. Progressing towards these objectives, micromorph tandem devices with initial efficiency of up to 13.3% have been recently obtained in small area reactor at IMT Neuchâtel [1]. Such high efficiencies were achieved thanks to the development of an in-situ silicon oxide based intermediate reflector (SOIR) layer [2]. Intermediate reflectors are used to increase the current density in thin top amorphous cells of micromorph tandem devices [3]. For that purpose a material with a low refractive index is necessary. The challenge in the optimization of these layers is to lower the refractive index without compromising the electrically conductive properties. These developments of the micromorph cells (including SOIR) in small area system operating at 70 MHz were transferred to an industrial R&D KAI-S and KAI-M systems operated at 40.68 MHz.

Deposition rate is a key issue for industrial application. In order to achieve high deposition rate with the least detrimental effects on the material quality, several regimes of deposition pressure and silane depletion have been studied for the deposition of single junction microcrystalline silicon (µc-Si:H) cells. Two regimes leading to a deposition rate of 0.35 nm/s and of 1 nm/s were selected for the development of micromorph tandem devices incorporating also SOIR layers. The effect of the inter-electrode on the efficiency of single-junction µc-Si:H cells was also investigated in the case of the high deposition rate regime.

2 EXPERIMENTAL

Single-junction and tandem micromorph solar cells were deposited in p-i-n configuration on AF45 glass substrate covered with ZnO:B deposited by LP-CVD (low pressure chemical vapor deposition) in industrial R&D PE-CVD (plasmas enhanced CVD) KAI-S or KAI-M reactor operated at 40.68 MHz. Similar ZnO:B layers were also used as back contact for all cells. A surface treatment of the ZnO front contact was applied and a dielectric white reflector was added to the back contact.

More details on the deposition conditions can be found in [4].

Degradation of the cells has been performed at 50°C under a white light illumination (at approx. 100 mW/cm²) from a metal halide HQI lamp and in open circuit condition.

SOIR layers were prepared from a mixture of SiH₄, CO₂, H₂ and PH₃ gases in our large-area (37x47 cm²) very-high frequency (VHF) PECVD KAI-S system at 40.68 MHz. The development of SOIR layers was done on layers of roughly 100 nm deposited directly on glass to assess the conductivity, the crystalline fraction through Raman scattering experiment and the refractive index value. The latter was found from fitting the ellipsometry measurements to a Tauc-Lorentz dispersion model including a surface roughness layer. The thickness was measured with a height profiler. Infrared (IR) absorption measurements were performed with a Nicolet 8700 system from Thermo on samples deposited on intrinsic, one-side polished wafers. The absorption spectra were normalized with the layer thickness.

3 RESULTS AND DISCUSSION

3.1 SiOₓ intermediate reflector (SOIR)

The influence of multiple parameters was studied in regard to the quality of the material, among which: deposition pressure, power density, total gas flow,

Figure 1: Refractive index n as a function of wavelength with n=1.7 at 600nm of a nc-SiOₓ layer obtained in the KAI-S system.
hydrogen dilution, and CO₂ fraction. As already observed in material deposited in small area systems [2], these layers are made of n-doped mixed-phase material which consists of silicon nano-crystallites incorporated into an amorphous SiOₓ matrix (nc-SiOₓ). These nano-crystallites most likely insure current flow through the layer. The main requirements for the use of this mixed-phase material when used in a micromorph cell, is to have the lowest refraction index while providing a phase material when used in a micromorph cell. The main requirements for the use of this mixed-crystallites most likely insure current flow through the layer. The main requirements for the use of this mixed-crystallites most likely insure current flow through the layer. The main requirements for the use of this mixed-crystallites most likely insure current flow through the layer. The main requirements for the use of this mixed-crystallites most likely insure current flow through the layer. 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marked improvement of the cell performance. The reduction of powder formation, combined with higher working pressures at 13 mm inter-electrode gap are probably the reason for can the better efficiency.

3.3 Micromorph tandem cells

A µc-Si:H cell deposited at 1 nm (as presented in section 3.2) was incorporated into tandem device. The respective component cell thicknesses are 220 nm for the top and 1.8 µm for the bottom one. The I(V) characteristics as well as the external quantum efficiency EQE are presented in Fig. 6. Light-soaking of the tandem reduces the efficiency by 11% resulting in a stable value of 9.6%. As seen in Fig. 6, most of the degradation can be attributed to the top cell even while a reduction of the infra-red response is due to the a smaller µc-Si:H bottom cell degradation. The relatively low overall degradation is here obtained thanks to the thin top cell. One can also observe that the cells are rather well “current matched” for both the annealed as the degraded state.

![Figure 6: I(V) characteristics and external quantum efficiency of our best micromorph device (thickness of 220 nm and 1.8 µm, 1.2 cm²) with a microcrystalline bottom cell deposited at 1 nm/s.](image)

μc-Si:H cells deposited at a lower deposition rate of 0.35 nm were also incorporated in a tandem devices. Best initial efficiency of 12.3% (see Fig. 7) was obtained so far with component cell thickness of 250 nm and 2.7 µm, and the implementation of a SOIR layer and a broad band anti-reflective coating on the glass substrate were also implemented.

![Figure 7: I(V) characteristics and external quantum efficiency of our best micromorph device (thickness of 250 nm and 2.7 µm, 1.2 cm²) with a microcrystalline bottom cell deposited at 0.35 nm/s. A SOIR and a broad-band anti-reflection coating on the glass substrate were also implemented.](image)

4 CONCLUSIONS

The efficiency of µc-Si:H single junction cell is found to correlate with the energy of the ions impinging on the growing surface. Lower ion energy ions reduces the material defect density. Consequently, the efficiency increases with increasing power and silane depletion.

For optimized devices the initial efficiency is decreased from 8.2% to 7.3% as the deposition rate increases from 0.3 nm/s to 1.0 nm/s. Incorporating such cell in a micromorph device (with an SiOₓ intermediate reflector), an initial efficiency of 10.8% and stable efficiency of 9.6% have been so far obtained with a microcrystalline cell of 1.8 µm deposited at 1 nm/s in an industrial R&D KAlM reactor.

At a lower deposition rate of 0.35 nm/s (also in a KAlM reactor), initial efficiency of 12.3% with a total current of 26.2 mA/cm² have been obtained for a micromorph tandem with an SiOₓ intermediate reflector and a 2.7 µm bottom cell.

Further improvement is expected from a better current matching of the device and further optimization of the µc-Si:H cell growth.

5. ACKNOWLEDGMENTS

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REFERENCES