High Efficiency Flexible CdTe Solar Cells on Polymer Substrates

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ABSTRACT

Development of flexible and lightweight solar cells is interesting for terrestrial and space applications that require a very high specific power (kW/kg). We have previously reported flexible CdTe/CdS solar cells with an efficiency of 11% on in-house processed polyimide substrates. We have now developed flexible solar cells where the in-house processed polyimide is substituted by a more conventional 10 μm thin Upilex© film. A process for the deposition of ITO (front contact) has been developed to have a stable front contact on the Upilex©. Post-deposition annealing treatments of the polyimide/ITO stacks bring a significant stability to the front contact, having almost the same sheet resistance at the beginning and at the end of the fabrication process. Solar cells with AM1.5 efficiency of 11.4% on Upilex© foils (highest efficiency recorded for flexible CdTe cell) have been developed. A comparison of the cells prepared on different polyimides is presented.

1. Introduction

Polycrystalline CdTe thin films solar cells have shown long-term stable performance and high efficiency up to 16.5% under AM 1.5 illumination [1]. Only a few micron thick materials are needed for the solar cell, therefore devices with high specific power (ratio of output power to the weight) are expected. The glass substrate may contribute to more than 90 % of the total weight of the solar cells.

To maximize the high specific power, the glass substrate should be substituted with a lightweight and flexible thin substrate, such as metal or polymer foils. This gives a flexibility to the solar panels to adapt to any kind of shape for integration in buildings, and for application in a variety of products. Flexible solar modules can facilitate low cost and easily deployable power generators in space. CdTe solar cells exhibit excellent tolerance against proton and electron irradiation. Therefore, flexible CdTe solar cells are interesting for terrestrial and space applications. However, not much effort has gone in the development of flexible CdTe solar cells. In this paper, we present two different processes for the fabrication of lightweight and flexible CdTe solar cells on polyimide films.

2. Experimental results and discussions

We have developed a process that is suitable for in-line processing of CdTe solar cells [2]. For the conventional CdTe/CdS superstrate solar cells commercially available tin oxide doped with fluorine (FTO) coated soda-lime glass is generally used as a substrate. CdS layers are grown in a high vacuum evaporation system at a substrate temperature of 150 °C, and subsequently annealed at 450 °C for recrystallization. Without breaking the vacuum CdTe is then deposited at a substrate temperature of 300 °C. Vacuum evaporation is used for the deposition of $CdCl_2$ layers on CdTe. The stacks are annealed at 430 °C for 30 minutes in air. Finally, the Cu/Au contact is applied by vacuum evaporation after etching the CdTe surface with Br-methanol solution. Solar cells in the efficiency range of 10 to 12% are routinely obtained with this low temperature process.

The choice of an appropriate substrate and its compatibility with the deposition processes are important for high efficiency flexible solar cells. We have developed a method in which, instead of using glass as substrate, a “specific” type of polyimide film (thin and transparent in order to minimize the absorption loss) is prepared in-house[3]. A thin buffer layer of NaCl is evaporated on a glass substrate then a polyimide layer is spin-coated and cured at about 430°C. The thickness of the polyimide film can be controlled by the spin-coating process, we have used about 10 μm thin polyimide films. A layer of ITO is deposited on polyimide by a RF magnetron sputtering method. The CdTe/CdS stacks are subsequently deposited and after the $CdCl_2$ treatment metallization for back contacting is provided. The NaCl layer is dissolved in water to lift-off the flexible solar cells from the carrier glass. The solar cells grown on spin coated polyimide exhibit an efficiency of 11% (AM1.5 illumination).

However, the application of a commercial polyimide film as a substrate would be more suitable for a roll-to-roll manufacturing process, and to reduce the production cost. For this reason, we have lately evaluated different polyimide films and found that a commercially available (such as Upilex) film thinner than 10 micron is sufficiently transparent and suitable for CdTe solar cells. As shown in figure 3, the average transmission of the polyimide films is more than 75% for wavelengths above 550 nm. There is a strong absorption of photons in the wavelength range of 300-550 nm.

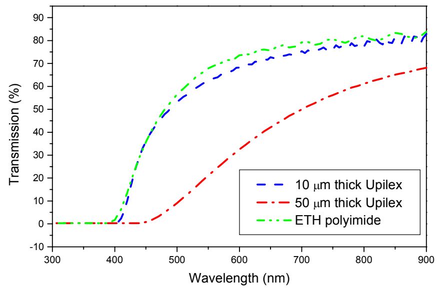

Figure 1. Transmission spectra of Upilex and in-house spin coated (ETH polyimide) foils of different thickness.

The ITO layers were deposited with an RF-magnetron sputtering system on the Upilex polyimide foils. A particular study of the ITO properties on the polyimide has been made. The ITO deposition was performed at the Ar/O_2 (0-3 vol. % O_2) pressure of $8*10^{-3}$ mbar and different power densities were tested, from 3000mW/cm^2 to 1200mW/cm^2. The successive steps of high temperature CdS/CdTe layer deposition and $CdCl_2$ annealing may cause a degradation in the optical and electrical characteristics of the ITO layer. Therefore, ITO film properties were investigated before and after annealing in air at high temperatures. An annealing of the ITO/Upilex stacks prior to the deposition of the subsequent layers improves the stability of the ITO to further high temperature processes. Annealing of these stacks in air at 450 °C, improves transmission (in the range of 500 to 900 nm) from 69% to 72% but also increases the sheet resistance from 5 to 12Ω/Square. Repeated annealing cycles in the same conditions increased the ITO sheet resistance by only 0.8-0.9 Ω/Square, with no degradation in transparency. The quantum efficiencies (fig.2) of cells made with annealed and non-annealed ITO/polyimide structures show that the difference in quantum efficiency is partly due to low transparency of not-annealed Poly/ITO layers in the spectral region of 0.6-0.8 μm. The overall lower quantum efficiency for both solar cells is mainly caused by the lower transparency of polyimide substrate.

Figure 3 shows the light I-V characteristics of 11.4% (AM1.5 measurement conditions) flexible solar cells on annealed Poly/ITO substrate (V_{oc}=756 mV, I_{sc}=20.9 mA/cm^2, FF=71%) comparable to the efficiency obtained on the in-house polyimide solar cells (V_{oc}=842 mV, I_{sc}=18.5 mA/cm^2, FF=70.9%).

3. Conclusions

A process for manufacturing of CdTe/CdS flexible solar cells has been developed.

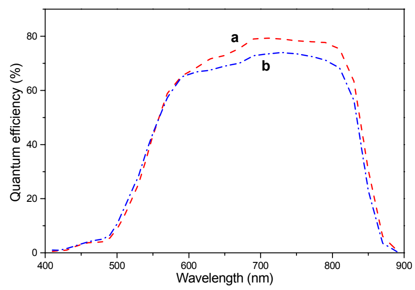

Figure 2. Quantum efficiency of flexible CdTe cells with annealed ITO/polyimide (a) and as-deposited ITO/polyimide stacks (b).

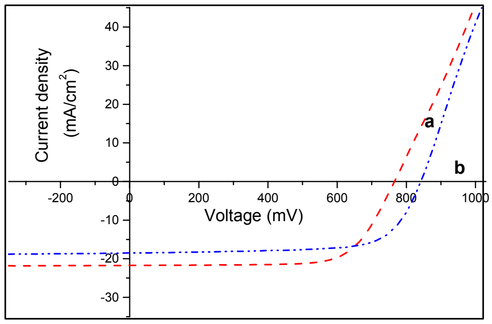

Figure 3. I-V measurements of CdTe solar cells on Upilex with 11.4% efficiency (a) and on in-house polyimide with 11% efficiency (b).

The process has been adapted for commercial polyimide (Upilex), which extends the possibility for a scalable roll-to-roll manufacturing process. High efficiency flexible cells on both polyimides show a specific power potential of ~2 kW/kg on the cell level.

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