Journal of Physics: Conference Series **572** (2014) 012049 doi:10.1088/1742-6596/572/1/012049

Semitransparent solar modules based on amorphous and microcrystalline silicon.

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Abstract. After modification of standard “Oerlikon” thin film solar cells producing technology we have managed to fabricate two experimental (10x10 cm^2) semitransparent solar modules based on amorphous and microcrystalline silicon with efficiency 6.5% and 6.7% and transparency about 20% and 9% in the visible range.

1. Introduction

According to Pike Research`s forecast [1] the global BIPV market will grow from just over 400MW in 2012 to 2,250MW in 2017 representing a five-fold increase. Thin-film solar cell technologies based on large areas are particularly well-suited to applications in the building industry. The use of a-Si modules in building-integrated photovoltaics (BIPV) is manifold and extends to all elements of a building shell, namely roofs, facades, windows and awnings. As a particularly attractive design option, thin-film technology offers the unique possibility of providing semitransparent modules by making very thin amorphous silicon layers on glass with transparent contacts. Obviously, the efficiency of semitransparent modules is reduced by the percentage of their optical transmission. However, besides electricity generation, they serve additional functions in terms of light and temperature management in buildings, i.e. by providing shading and thermal insulation [2].

Typical a-Si:H single junction solar cell is composed of five principal layers: Si p-i-n diode sandwiched between two conductive layers. Stacking two a-Si:H/μc-Si:H cells on top of each other forms the tandem junction structure, which is also sandwiched between the front and back contacts[3]. Figure 1 shows the schematic structure of single and tandem solar cells based on a-Si:H and μc-Si:H.

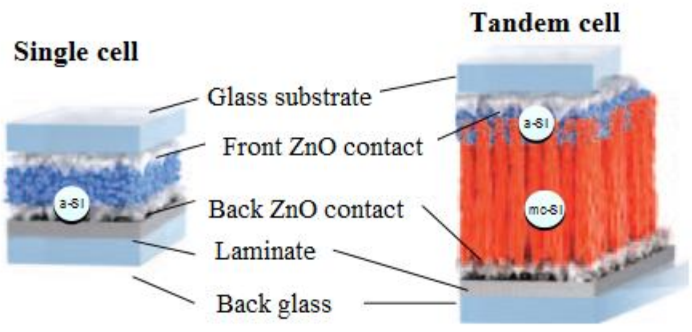

Figure 1. Structure of single and tandem solar cells based on a-Si:H and μc-Si:H.

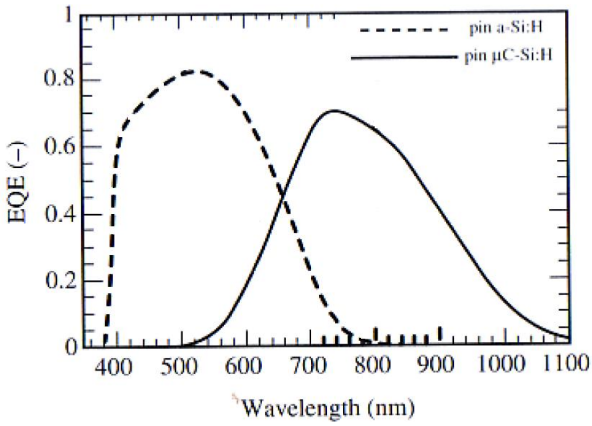

Figure 2. External quantum efficiency of a-Si:H and μc-Si:H pin structures (Source: IMT, Neuchatel) [4].

Figure 2 shows that a-Si:H layer absorbs short-wave solar radiation (380-700nm) and μc-Si:H layer makes better use of the long wavelengths (700-1100nm). The a-Si:H layer has a thickness of 0.3 μm, μc-Si layer - 2 μm.

«NovoVellum» laminate (figure 1) normally used at laminating stage has high reflectivity in spectral range 400-1100 nm. Thus it increases the optical path length and improves efficiency of solar cell.

2. Results and Discussion

We have replaced «NovoVellum» material to «Radeva» laminate, produced by Moscow company «Plastic». This material has high transparency within the visible and NIR range.

That allowed us to fabricate two experimental semitransparent solar modules 10×10cm^2 with single and tandem junction structure (figure 3). To compare the impact of reflecting laminate absence on electrical parameters two similar nontransparent solar modules were prepared as reference devices.

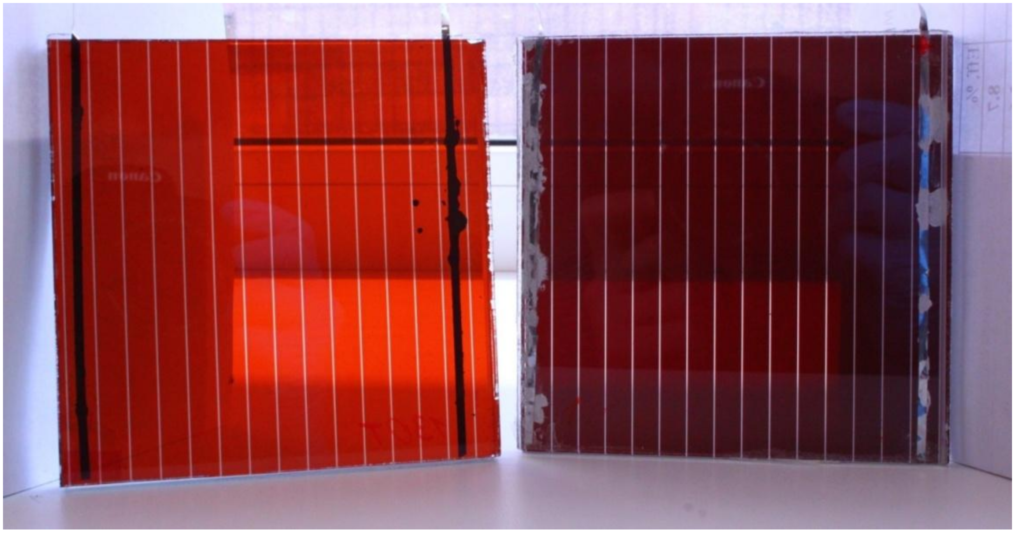

Figure 3. Semitransparent solar modules made with «Radeva» laminate. On the left, a-Si:H single junction cell; on the right, a-Si:H/μc-Si:H tandem junction solar cell.

Transmitted light has a red tint because the blue and green portion of the spectrum is absorbed in silicon layers. You can see it on figure 4, which shows transmission spectra of semitransparent solar modules.

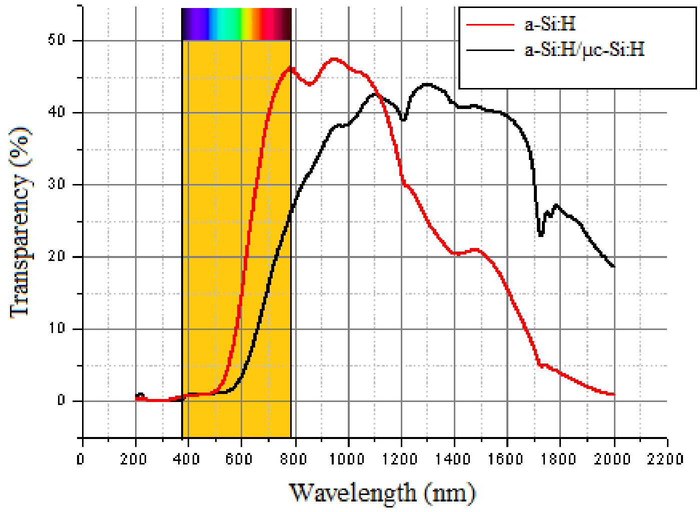

Figure 4. Transmission spectra of semitransparent solar modules.

a-Si:H semitransparent solar module has an average light transmission of 19.8% over the 400 to 800 nm range, and a-Si:H/µc-Si:H - 8.4%. It should be noted, that we can also increase color-neutral transmission up to 10% by laser scribing: the cell layers are removed along narrow lines perpendicular to the scribe lines of the integral series connection of the cells [2].

Figure 5 demonstrates the current-voltage (I-V) curves of semitransparent and nontransparent solar modules measured under simulated AM 1.5G illumination with intensity of 1000 W·m^{-2}.

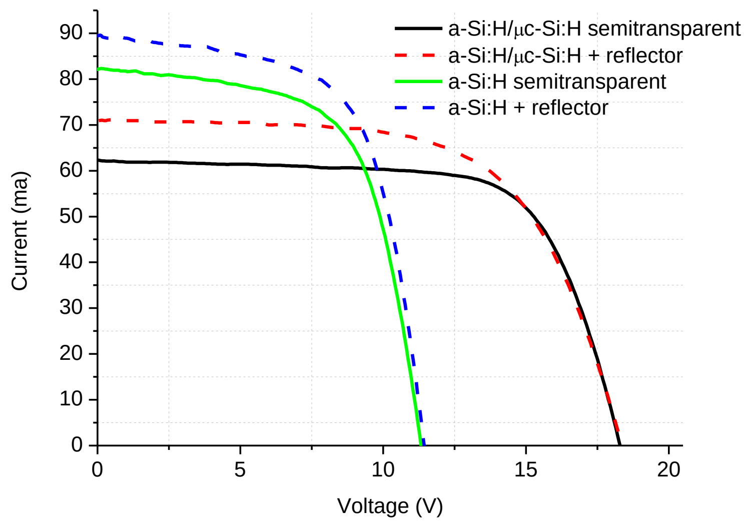

Figure 5. Current-Voltage characterization of semitransparent and nontransparent solar modules.

Electrical characteristics are demonstrated in table 1.

Table 1. Electrical characteristics of semitransparent and nontransparent solar modules.

Structure	Laminate	Isc (mA)	Uoc (V)	Pmax (mW)	Iopt (mA)	Uopt (V)	Seff (cm^2)
a-Si:H	«NovoVellum»	89.11	11.4	652	73.39	8.9	84,5
a-Si:H	«Radeva»	82.79	11.3	593	68.23	8.7	84,5
a-Si:H/μc-Si:H	«NovoVellum»	71.00	18.4	825	60.99	13.5	91
a-Si:H/μc-Si:H	«Radeva»	62.03	18.3	794	55.64	14.3	91

You can see that short-circuit current of nontransparent solar module is higher than I_{sc} of semitransparent analogue, because NovoVellum laminate acts like a reflector. Thus it increases optical path length and light absorption. However, if you take a look on table 2 you will see, that there is a slight efficiency difference between a-Si:H structures (1%). For a-Si:H/μc-Si:H structures this difference is greater (2%). This is due to the fact that most of the short-wave radiation is absorbed by a-Si:H layer before it reaches the laminate. Also after laminate replacement we have unbalanced photocurrents of the top and bottom cell in a-Si:H/μc-Si:H semitransparent solar module. Considering the fact that the bottom cell benefits from the light enhancement from the back reflector, while the top cell receives little benefit from the back reflector [5], the μc-Si:H cell limits the total current of semitransparent tandem junction solar module.

Table 2. Efficiencies of semitransparent and nontransparent solar modules.

Structure	Laminate	Efficiency (%)
a-Si:H	«NovoVellum»	7.5
a-Si:H	«Radeva»	6.5
a-Si:H/μc-Si:H	«NovoVellum»	8.7
a-Si:H/μc-Si:H	«Radeva»	6.7

In table 3 we compare characteristics of our a-Si:H module with characteristics of available BIPV products on the market [6].

Table 3. Comparison of the efficiency and transparency of semitransparent solar modules.

Solar module	Transparency (%) 400-800 nm	Efficiency (%)
a-Si:H (our)	20	6.5
Schott	10	5.2
SunTech	10	4.5
Smile Solar	10	7.1
Sun Well [7]	20	6.3
Tianwei [8]	20	4.9

In [9] research group from Korea demonstrated a-Si:H cell with efficiency of 5.5% and average transmittance of 21.7%.

Thus, our solar modules have quite competitive characteristics for international market.

3. Methods

Solar modules were obtained by PECVD in a KAI R&D reactor from the company Oerlikon Solar.

Optical and Electrical Characterization. The transmission spectra were recorded using a Cary 5000 UV-Vis-NIR spectrophotometer. Current-voltage characteristics of photovoltaic cells were measured using a Keithley 2400 source unit under a simulated AM1.5G spectrum with an Wacom WXS-90S-L2. The light intensity was ~100 mW·cm^{-2}, as calibrated using a Si photodiode.

4. Conclusions

We have achieved 6.5% power-conversion efficiency and transparency about 20% in visible range for a-Si:H semitransparent solar modules. The results in efficiency and transparency make these modules an extremely competitive product for BIPV technologies.

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