ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering
Tome XIV [2016] – Fascicule 1 [February]
ISSN: 1584-2665 [print; online]
ISSN: 1584-2673 [CD-Rom; online]
a free-access multidisciplinary publication
of the Faculty of Engineering Hunedoara

1. Milorad BOJIC, 2. Jasna RADULOVIC, 3. Vesna RANKOVIC,
4. Danijela NIKOLIC, 5. Ljubisa BOJIC, 6. Jasmina SKERLIC

FLEXIBLE THIN-FILM SOLAR PHOTOVOLTAICS: RESEARCH AND APPLICATION

1-6. Faculty of Engineering, Kragujevac, SERBIA

ABSTACT: It is expected that thin film photovoltaic technologies will play a major role in the world photovoltaic market in the near future. The use of flexible substrates offers new possibilities for the application of solar cells, for example for building integration. In addition, flexible cells are very thin and lightweight, which makes them also more flexible in use than rigid cells. One of the most important advantages of flexible solar cells, is the potential to reduce production costs. Development of photovoltaic thin film modules ensures a satisfying flexibility of the surface, and the possibility to design appropriate shapes. The future for efficient, lightweight, flexible and cost-effective thin film modules looks very promising.
Keywords: Flexible solar cells, building integration

1. INTRODUCTION

One of the most promising renewable energy technologies is photovoltaic (PV) energy conversion. PV energy conversion represents the direct conversion of sunlight into electricity. Commercial PV materials commonly used for PV systems include solar cells of silicium (Si), cadmium-telluride (CdTe), coper-indium-diselenide (CIS) and solar cells made of other thin layer materials. PV systems are still an expensive option for producing electricity compared to other energy sources, but many countries support this technology. Over the last five years, the global PV industry has grown more than 40% each year, [1].

Silicon is a leading technology in making solar cell because of its high efficiency. But many researchers, due to its high cost, are trying to find new technology to reduce the material costs for production of solar cells and thin film technology can be seen as a suitable substitution. However, the efficiency of solar cells based on this technology is still low, and researchers are intensively making an effort to enhance the efficiency, [2].

Flexible modules are light-weight and suitable for applications where weight is important, and they offer a much faster payback than products based on conventional photovoltaics [3]. It is expected that they will play a very important role in the world PV market in the near future. In this paper the advantages and perspective of the flexible thin film photovoltaic technology for building integration are pointed out.

2. ABOUT THIN FILM (TF) PHOTOVOLTAICS

Silicon is a leading technology in making solar cell due to its high efficiency. At present, over 80% of the world PV industry is based on c-Si and pc-Si wafer technologies. However, due to its high cost, in the past few years there have been efforts to reduce the material costs of production of solar cells and to till date, thin film technology can be seen as a good option. It is generally agreed that c-Si wafer technology would not be able to meet the low-cost targets, whereas thin-film technologies have the potential to provide a viable alternative in the near future.

Thin-film Si solar cells have few important advantages compared to crystalline cells: the thickness of Si can be drastically reduced to 50 μm, thin films can be deposited on low-cost substrates, thin films can be fabricated on module-sized substrates and in integrally interconnected structures, etc. Three materials that have been given much attention to under thin film technology are a-Si - amorphous silicon, CdTe and Cu(In,Ga)Se_2 - cadmium telluride and copper indium gallium selenide, but researchers are continuously putting in more effort to enhance the efficiency. Remarkable progress has been achieved in this field in recent years. CdTe and Cu(In,Ga)Se_2 thin-film solar cells demonstrated record efficiencies of 16.5% and almost 20%, respectively, [2].

3. FLEXIBLE SOLAR CELLS AND MODULES

Very important perspective of thin film PV technology is flexible modules with strategic space and military use, integration in roofs and buildings facades, etc. The ultimate advantage of thin-film technology is roll-to-roll manufacturing to produce monolithically interconnected solar modules leading to low time for energy payback because of high-throughput processing and to low cost of the overall system, [3].

3.1. A-SI flexible modules

Flexible a-Si solar cells are likely to be very popular and in demand for applications in the low to medium range of power, since they can be made in different shades (even semi-transparent), shapes, and sizes. At Figure 1.a schematic of a triple-junction structure containing amorphous silicon is present, [4]. Digital photograph of a-Si cell device deposited on patterned Al substrate is shown at Figure 1.b, [5].

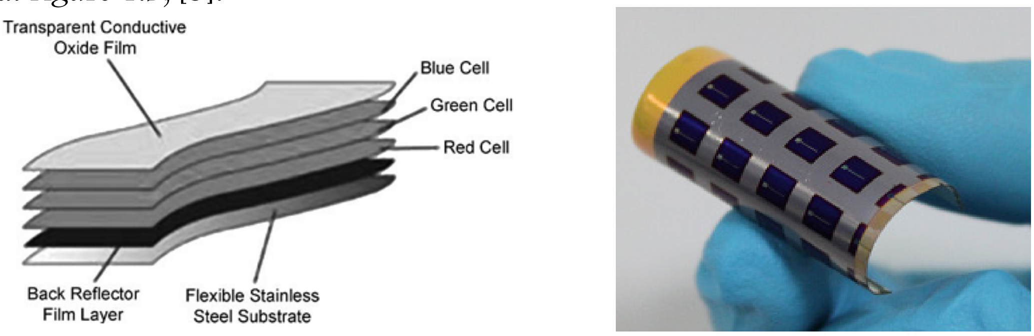

Figure 1. Flexible a-Si solar module

a) Schematic view of a-Si thin-film cell layer structure, [4]. b) photograph of a-Si cell device deposited on patterned Al substrate, [5].

Commercial solar cell devices based on hydrogenated amorphous silicon rapidly surpassed 10% efficiency, but suffered from light-induced degradation that leads to a reduction of the solar cell efficiency. The possibility to deposit a-Si at temperatures below 2000 enables the fabrication of light-weight, flexible laminates on temperature sensitive substrates, which is a unique feature that provides a competitive advantage in markets such as consumer products and BIPV, [6].

The best initial efficiencies of 13.7% and 9.8% were achieved on triple-junction cells and modules, respectively. However, stabilized efficiencies are still low, around 6–7% for the best commercial modules. Nevertheless, at present, about 8–10% of the worldwide PV production uses a-Si technology, [2].

The world's leading companies in a-Si TFPV manufacturing are undergoing rapid expansion from an annual production capacity of about 30 MW to 300 MW by 2010, to apply this technology as widely as possible and drive the expansion of its market share by applying its products to free-land applications and building-integrated photovoltaics (BIPVs) [4].

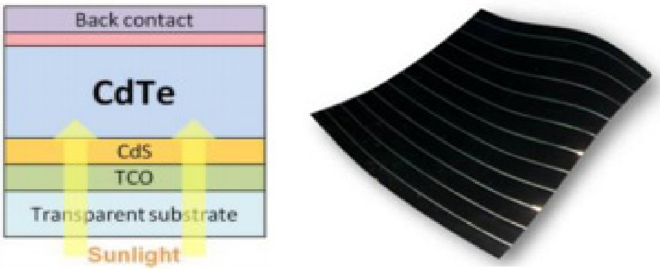

Figure 2 - Flexible CdTe solar module

a) Schematic view of CdTe thin-film cell layer structure, [7]. b) photograph of flexible CdTe solar modules, [8].

3.2. Flexible CdTe cells

Also, CdTe is one of the leading candidates for the solar cells due to its optimum band gap and the variety of film preparation methods. Figure 2.a shows flexible CdTe solar module configuration, [7] and Figure 2.b shows photograph of flexible CdTe solar module. Lab efficiency on plastic foil achieved 11.4% (single-junction cell), and on metal foil 8% (single-junction cell), [2].

These devices allow building integration in structures, which cannot take the additional load of heavy and rigid glass laminated solar modules. The flexible solar modules can be laminated to building elements such as flat roof membranes, tiles or metallic covers without adding weight and thus, the installation costs can be reduced significantly, [8].
The Swiss laboratory for thin films and photovoltaics EMPA is involved in the development of flexible CdTe solar cells on polymer films and metal foils. They have demonstrated 13.8% efficient CdTe solar cells on flexible polyimide films, [9].

3.3 . Flexible CIGS cells

A large number of activities on highly efficient, stable, and flexible thin-film modules based on CIGS has recently drawn much interest for flexible solar cells on metal and plastic foils, [12]. Apart from the expected high efficiency and long-term stability for terrestrial applications, flexible CIGS has excellent potential for space application because of their tolerance to space radiation, being 2–4 times superior to conventional Si and GaAs cells. Flexible CIGS cells can be grown on polyimide and on a variety of metals, e.g., stainless steel, Mo, and Ti, [3].

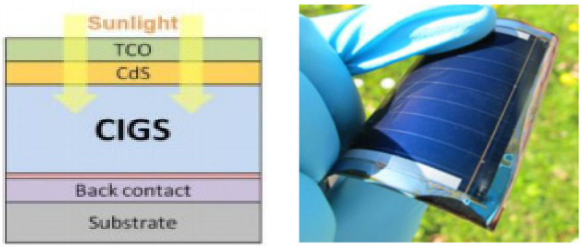

Figure 3. Flexible CIGS solar module
a) Schematic view of CIGS thin-film cell layer structure, [7]. b) Photograph of flexible CdTe solar modules, [8].

The basic schematic cross-section of a monolithic module on a polyimide substrate is shown in Figure 3.a, [7], and flexible prototype mini-module developed on polymer foil is shown in Figure 3.b, [8]. These devices allow building integration in structures, which cannot take the additional load of heavy and rigid glass laminated solar modules. [8].
Scientists at Empa, the Swiss Federal Laboratories for Materials Science and Technology, have developed thin film solar cells on flexible polymer foils, based on CIGS with a new record efficiency of 20.4% for converting sunlight into electricity. The technology is currently awaiting scale-up for industrial applications, [9] .
Flexible CIGS solar cells have the ability to both realize their potential as the most efficient thin film technology and to dominate the building-integrated photovoltaics (BIPV) market in the future, [7].

4. ADVANTAGES AND FUTURE PROSPECTS

The Building integrated Photovoltaics (BIPV) market, which got increased political support during the last years is still one of the big hopes for TF technologies. In this context, these modules have many advantages compared to c-Si ones: strongly reduced weight for the application to the building stock, see through property, adjustable optical transmittance, excellent building appearance, potential capability for applying flexible substrates, and less sensitivity to the degradation of light intensity and increasing temperature of the module [1].
Also, compared to traditional Si-based photovoltaics, flexible PV technologies offer a unique versatility that architects and engineers will harness to renew the facades of existing buildings, as well as in the construction of new buildings and in the development of power-generating products. Flexible solar cells provide building component manufacturers with thin and lightweight PV foils that allows integration with building materials of various architectural shapes, thus combining PVs and architecture, and also cost-effective PV integration, [4]. Flexible solar PV devices offer a convenient alternative energy source for indoor and outdoor applications. Besides being flexible and thus easily integrated with elements of various shapes and sizes for the design of innovative energy-generating products, these unbreakable flexible modules are light-weight and suitable for applications where weight is important, while they offer a much faster payback than products based on conventional PVs, [4].
There are some new material tehnologies, like dye-sensitized solar cells (DSC or DSSC), which are also applicable for building integration [1]. In combination with the feature that devices can be fabricated in a number of colors and levels of transparency, this makes them an attractive applicant for BIPV applications. Fortunately, cell efficiencies are stagnant at about 11% since more than 15 years and further optimization of any main component of DSSC devices is not likely to yield significant efficiency improvements.
In perspective, new photovoltaic thin film will be the only technology suitable to satisfy the requirements of the most advanced architectural theories, and also the development of new photovoltaic thin film modules will be able to match not only traditional architectures, but also the most innovative tendencies that favour envelopes characterized by free morphologies.

5. CONCLUSION

One of the main tasks of researchers is to develop highly efficient thin-film solar cells. They focus on novel concepts to improve the performance of solar cells, to simplify production processes and to improve the device structure of next generation solar cells with higher efficiency at lower cost. Flexible thin film technology is suitable for production of attractive modules which can be realized to be able to match not only traditional architectures, but also the most innovative tendencies, and also cost-effective PV integration.

Acknowledgement

This paper is a result of two projects: (1) TR33015, Investigation and development of Serbian zero-net energy house, supported by the Ministry of Science and Technological Development of Republic of Serbia and (2) COST action TU1205-BISTS, Building Integration of Solar Thermal Systems, supported by EU. The authors thank to the all institutions for their financial support.

Note

This paper is based on the paper presented at The 12th International Conference on Accomplishments in Electrical and Mechanical Engineering and Information Technology – DEMI 2015, organized by the University of Banja Luka, Faculty of Mechanical Engineering and Faculty of Electrical Engineering, in Banja Luka, BOSNIA & HERZEGOVINA (29th – 30th of May, 2015), referred here as[10].

REFERENCES

[1.] Radulovic J., Bojic M., Nikolic D., Skerlic J., (2014), Thin film photovoltaic technologies: status and perspectives, 45. International Congress and Exhibition on Heating, Refrigerating and Air-Conditioning, december 3-5, Belgrade.
[2.] Razykov, T. M., Ferekides C. S., Morel D., Stefanakos E., Ullal H.S., (2011) Solar photovoltaic electricity: Current status and future prospects, Solar Energy 85, 1580–1608.
[3.] Kessler, F., Rudmann, D., (2004), Technological aspects of flexible CIGS solar cells and modules, Solar Energy, 77 685–695.
[4.] Pagliaro, M., Ciriminna, R., Palmisano, G., (2008), Flexible Solar Cells, ChemSusChem, 1, 880 – 891.
[5.] Huapeng Xiaoa, H. Wanga, J., Huang, H., Lub,L., Linc, Q., Zhiyong Fanc, Z., Chenb, X., Jeongd, C., Zhua, X., D, Lib, D., (2015), Performance optimization of flexible a-Si:H solar cells with nanotextured plasmonic substrate by tuning the thickness of oxide spacer layer, Nano Energy, 11, 78–87.
[6.] Abermann, S., (2013), Non-vacuum processed next generation thin film photovoltaics: Towards marketable efficiency and production of CZTS based solar cells, Solar Energy, 94 37–70.
[7.] Jelle, B.P., Breivik, C., (2012), The path to the building integrated photovoltaics of tomorrow, Energy Procedia.
[8.] Zhu L., Hurt R., Correa D., Boehm R., Jelle, B. P., Breivik, C., Røkenes, H. D., (2012), Building integrated photovoltaic products: A state-of-the-art review and future research opportunities. Solar Energy Materials & Solar Cells, 100, 69–96.
[9.] http://www.empa.ch/plugin/template/empa/*/112136
[10.] Milorad Bojic, Jasna Radulovic, Vesna Rankovic, Danijela Nikolic, Ljubisa Bojic, Jasmina Skerlic, Flexible thin-film solar photovoltaics: research and application, The 12th International Conference on Accomplishments in Electrical and Mechanical Engineering and Information Technology – DEMI 2015, 409-412