COST Action TU1205 (BISTS)
Building Integration of Solar Thermal Systems

Proceedings of COST Action TU1205 Symposium

Combined with EURO ELECS 2015 Conference, Guimarães, Portugal

Edited by: Soteris A. Kalogirou

This book may be cited as:

Proceedings of COST Action TU1205 Symposium

ISBN: 978-9963-697-17-5

Publication date: July 2015

Contents:

Flexible Thin-film Photovoltaic Technologies in Building Integration

Milorad Bojic
University of Kragujevac, Faculty of Engineering, Department of Energy & Process Engineering, Kragujevac, Serbia
milorad.bojic@gmail.com

Jasna Radulovic
University of Kragujevac, Faculty of Engineering, Department for Applied Mechanics & Automatic Control, Kragujevac, Serbia
jasna@kg.ac.rs

Danijela Nikolic
University of Kragujevac, Faculty of Engineering, Department of Energy & Process Engineering, Kragujevac, Serbia
danijela1.nikolic@gmail.com

Ivan Miletic
University of Kragujevac, Faculty of Engineering, Department for Mechanical Constructions & Mechanization, Kragujevac, Serbia
imiletic@kg.ac.rs

ABSTRACT: New PV technologies that may advance new innovations, which may be developed into building integrated photovoltaics, might be found in flexible thin film solar cells. The use of flexible substrates offers new possibilities for the application of solar cells for building integration. 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. In a past few years producers offered various products and new ways to integrate lightweight, flexible solar modules into buildings to achieve cost-effective and high-performance solar power.

Keywords: photovoltaics, flexible solar cells, building integrated photovoltaic

1 INTRODUCTION

Photovoltaic (PV) is one of the most prominent renewable energy technologies, characterized by a world-wide abundant available fuel source – the sun. Solar photovoltaic technologies are an attractive option for clean and renewable electricity generation – it is the direct conversion of sunlight into electricity. Photovoltaic devices are rugged and simple in design requiring very little maintenance. Solar energy using contributes to more efficient use of the countries own potentials in generating electrical and thermal energy, reduction of the greenhouse emission, reduction of importing and use of the fossil fuels, development of the local industry and new job openings (Pavlovic, 2013). PV systems are still an expensive option for producing electricity compared to other energy sources, but many countries support this technology.

Starting from 1990 industry of photovoltaic conversion of solar irradiation shows constant annual economical growth of over 20%, and from 1997 over 33% annually. In 2000 total installed capacities worldwide have surpassed 1000 MW, and in developing countries have overreached more than million house-holds which are using electrical energy generated by means of the photovoltaic systems. It is predicted that PV will deliver about 345 GW by 2020 and 1081 GW by 2030 (Ingmar, 2011). Over the last five years, the global PV industry has grown more than 40 % each year, (Radulovic, 2014). Overgrowing number of companies and organizations is taking active part in the promotion, development and the production of photovoltaic devices and systems.

Solar cells developed rapidly in the 1950s owing to space programs and used on satellites (crystalline Si, or c-Si, solar cells with efficiency of 6–10%). The energy crisis of the 1970s greatly stimulated research and development for PV. Research on semi-conductors (III–V and II–VI) based solar cells were studied since 1960 and at that time, new technology for poly-crystalline Si (pc-Si) and thin-film solar cell have been establish in order to lower the material cost and energy input but increase the production capacity (Razykov, 2011).

Silicon is still 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 (Razykov, 2011). Commercial PV materials commonly used for PV systems, besides silicium (Si), include solar cells of cadmium-telluride (CdTe), coper-indium-diselenide (CIS) and solar cells made of other thin layer materials.

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 (Kessler, 2004). 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 FLEXIBLE SOLAR CELLS

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 (Kessler, 2004).

2.1 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. Digital photograph of a-Si cell device deposited on patterned Al substrate is shown at Figure 1, (Xiaoa, 2015).

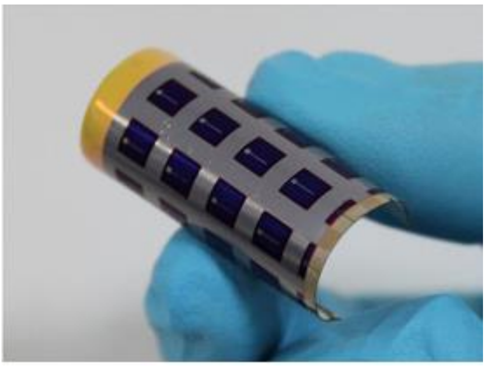

Figure 1. *Flexible a-Si solar module - photograph of a-Si cell device deposited on patterned Al substrate.*

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 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 (Razykov, 2011).

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 (Pagliaro, 2008).

2.2 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. It is achieved the lab efficiency on plastic foil of 11.4% (single-junction cell), and on metal foil 8% (single-junction cell) (Razykov, 2011).

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 (Zhu , 2012).

2.3 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. 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 polymide and on a variety of metals, e.g., stainless steel, Mo, and Ti (Kessler, 2004).

The flexible prototype mini-module developed on polymer foil is shown in Figure 2 (Zhu, 2012). These devices allow building integration in structures, which cannot take the additional load of heavy and rigid glass, laminated solar modules.

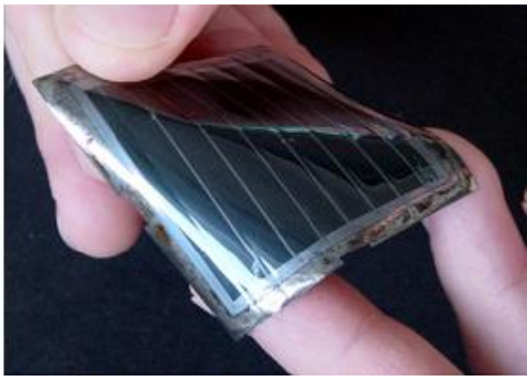

Figure 2. *Flexible CIGS solar module - photograph of flexible CdTe solar modules.*

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 (EMPA, 2015).

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 (Jelle, 2012a).

3 ADVANTAGES OF FLEXIBLE SOLAR CELLS FOR BUILDING INTEGRATION

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 (Radulovic, 2014).

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 (Pagliaro, 2008). 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 (Pagliaro, 2008).

There are some new material tehnologies, like organic PV (OPV) and dye-sensitized solar cells (DSC or DSSC), which are also applicable for building integration module (Radulovic, 2014). Since organic PV (OPV) relies on carbon based semiconductors, low cost high volume manufacturing of flexible solar modules without any raw-material concern appears feasible. In combination with the feature that devices can be fabricated in a number of colors and levels of transparency, this makes DSSC 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 Table 1 overview of different flexible solar cell technologies is given (Razykov, 2011).

Table 1. Overview of different flexible solar cell technologies.

	CIGS	CdTe	Amorphous silicon	Organic and titanium oxide
Lab efficiency on plastic foil	14.1% (single-junction cell)	11.4% (singlejunction cell)	8%*–12%* (multi-junction cell)	5–8%
Lab efficiency on metal foil	20.4% (single-junction cell)	8% (single-junction cell)	14.6% /13%* (multi-junction cell)	
Industrial efficiency (typical values)	6–11% (On steel foil, not yet available on plastic foil)	Not yet demonstrated	4–8% * (available on plastic and metal foils	Not yet demonstrated
Stability under light	Material stable	Material stable	Degrades	Stability not proven

*Initial values measured before light-induced degradation of solar cells.

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.

4 FLEXIBLE THIN FILM BIPV PRODUCTS

The BIPV foil products are lightweight and flexible, which is ideal for easy installation and the weight constraints most roofs have (Jelle, 2012b). They provide some specific features, which the rigid, conventional ones do not. Products from this group use newer and innovative materials platforms (such as thin-film and organic PV) and can be used in a variety of different applications, mainly flat and curved roofs.

Many of the flexible modules are designed to avoid conventional framework of rigid panels and can be adhesively bonded to roofing materials. They brings along many advantages like light weight, avoidance of heavy wind loads (because they do not allow wind beneath them) and avoidance of rack mounting system since they can be directly glued to the roofing material. Thanks to the above mentioned features, the mounting procedure of the panels on roofs as well as other building structures is different (easier) than the conventional, rigid ones (Montoro, 2013).

There are a number of manufacturers of flexible thin film PV products. The major technologies families are thin film amorphous silicon and thin film CIGS. In most cases the flexible product comes encapsulated and only has to be attached to the existing flat or curved roof. In few cases the PV manufacturer supplies a non-encapsulated functional PV laminate on a metal or plastic carrier foil. The manufacturer of the roofing product encapsulates the product in the building element (flexible or non-flexible) or applies encapsulation on the complete roof (Sinapis, 2013).

4.1 Flexible thin-film laminates - Centrosolar

So that solar plants can also be fitted to arched roofs, Centrosolar Italia is now offering flexible thin-film laminates alongside the frame-mounted standard modules, so that they can be optimally matched to the more complex curved roof shape. The flexible modules used, embedded in plastic, are particularly durable and light. They are therefore suitable for solar plants on lightweight-construction halls of the type commonly encountered in agriculture or industry (Centrosolar Group, 2015). The first Centrosolar Italia reference projects for such systems have already been connected to the grid (Figure 3).

Figure 3. *Centrosolar - Thin-film solar plant on the arched roof of a waste sorting station in Monte Crocetta, near Vicenza (40 kWp), constructed in collaboration with Rewatt, Vicenza.*

4.2 Flexible a-Si laminates - Alwitra

A system of technically and technologically integrated product groups, which have proven themselves in practice, for multifunctional roofing solutions including all flashings, capping and roof penetration details, which ensures permanent and reliable resistance to all impacts and loads on the roof sealing and serves for direct conversion of solar energy into electric power. The system ensures reliable and quick laying, application and installation by the roofer and the electrician. It provides maximum freedom of design for new build and refurbishment works and is extraordinary durable and economical.

Figure 4 represents the solution of flexible laminate (triple junction a-Si) installing on the rooftops, in Germany. The size of building blocks is 2848mm x 394mm (Alwitra Group, 2015).

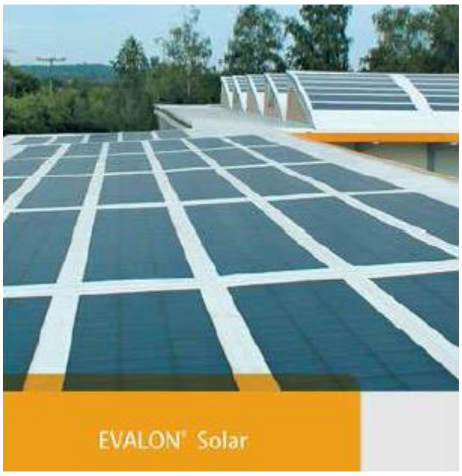

Figure 4. *Alwitra – Roof with flexible a-Si laminate*

4.3 Flexible CIGS laminates – Global Solar

Global Solar's high efficiency CIGS solar modules are designed for rooftops (Figure 5). The flexible module fits all roof shapes, is lightweight, and requires no roof perforations or mounting hardware.

Figure 5. *Global Solar – Roof with flexible CIGS laminate*

The Global Solar produces three types of flexible laminates. PowerFLEX® modules with 12.6 % efficiency (Figure 6), deliver the highest efficiency among flexible modules (Global Solar, 2015). It is also lightweight and can be applied directly to multiple surfaces without penetrations, and creates no additional wind load maintaining the integrity and aesthetics. The module has a large format (5.75 m x 0.5 m) and a high power density (300 W), enabling it to outperform other flexible solar solutions, including 50 percent more energy and power than the current amorphous silicon standard.

Figure 6. *Global Solar – PowerFLEX flexible CIGS module*

4.4 Flexible CIGS laminates – Ascent Solar

Ascent Solar's flexible, lightweight CIGS modules allow for seamless integration of solar power into a limitless number of applications without the restrictions of conventional glass panels. Ascent's high-efficiency modules provide the transformational ability to generate power anywhere, anytime. Ascent Solar WaveSol™ Light provides a new way to integrate lightweight, flexible CIGS solar modules into building materials to achieve cost-effective, high-performance solar power – Figure 7. WaveSol™ Light modules deliver the highest power density available on thin-film plastic substrates. WaveSol™ Light modules laminate onto roofing, shading and building surfaces to decrease energy costs and provide a clean, renewable source of energy (Ascent Solar, 2015).

Figure 7. *Ascent Solar – WaweSol flexible CIGS module*

4.5 Flexible thin-film laminates – Xunlight

Xunlight's offers a line of lightweight and mechanically flexible photovoltaic modules. The products are specifically designed for rooftop installations (Figure 8). These products all use the bandgap-tuned triple-junction thin-film silicon solar cells, manufactured by Xunlight at its Toledo, Ohio, USA factory. Xunlight also welcomes enquiries for custom sized product. Their flexible manufacturing process can allow to offer custom product at relative low minimum volumes. Xunlight's certified modules can be utilized for either on-grid or off-grid applications and they come backed by 25 year power-output warranty. Solar modules are produced using the company's innovative and patented manufacturing process and are designed to deliver high energy efficiency at a low cost for years to come.

Xunlight currently offers four widths of products, the XR (for TPO and EPDM membrane roofs), XRS (for 24" standing seam roofs), XRU (for 16" standing seam roofs) and XRN series (for 12" standing seam roofs) (Xunlight, 2015).

Figure 8. *Xunlight flexible module*

5 CONCLUSION

The present study has shown that there is great perspective for development flexible thin-film building integrated photovoltaic products. There is a progress in production of devices based on flexible thin-film technology, which are commercially available and present on market today. These products may have a great range of application due to the flexibility of the material and low cost. One of the main tasks of researchers is to develop products that can achieve a higher efficiency with better materials and better solutions. Advances in the development of PV materials will lead to advances for the BIPV systems.

REFERENCES:

Pavlovic T., Milosavljevic D., Radonjic I., Pantic L., Radivojevic A., Pavlovic M. 2013. Possibility of electricity generation using PV solar plants in Serbia, *Renewable and Sustainable Energy Reviews* 20:201–218

Ingmar W., Teske S. 2011. The solar photovoltaic electricity empowering the world 2011, EPIA report

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; Proc. Intern. Symp., Belgrade, 3-5 December 2014.*

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

Kessler, F., Rudmann, D., 2004 Technological aspects of flexible CIGS solar cells and modules, *Solar Energy*, 77: 685–695

Xiaoa H., Wanga H., Huang J., Lub H., Linc L., Zhiyong Q., Fanc Z., Chen, X., Jeongd C., Zhua, X., 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

Pagliaro M., Ciriminna R., Palmisano G., 2008. Flexible Solar Cells, *ChemSusChem* 1:880 – 891.

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.

EMPA laboratoty; http://www.empa.ch/plugin/template/empa/*/112136

Jelle, B.P., Breivik, C., 2012a. The path to the building integrated photovoltaics of tomorrow, *Energy Procedia* 20: 78-87.

Jelle, B.P., Breivik, C., Rokenes H. D., 2012b. Building integrated photovoltaic products: A state-of-the-art review and future research opportunities, *Solae energy Materials & Solar Cells* 100: 69-96.

Sinapis, K., Donker, M., 2013, BIPV Report -State of the art in Building Integrated Photovoltaics, SEAC

Montoro, D. F., Vanbuggenhout, P., Ciesielska, J., 2013, Building integrated photovoltaics: an overview of the existing products and their fields of application, EPIA (European Photovoltaic Industry Association)

Centrosolar Group,2015., http://www.centrosolar-group.com/

Alwitra Group, 2015, http://www.alwitra.de/

Global Solar, 2015, http://www.globalsolar.com/

Ascent Solar, 2015, http://www.ascentsolar.com/

Xunlight, 2015, http://www.xunlight.com/