Applied Energy 86 (2009) 1836–1844

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Thin film silicon photovoltaics: Architectural perspectives and technological issues

Lucia Vittoria Mercaldo *, Maria Luisa Addonizio, Marco Della Noce, Paola Delli Veneri, Alessandra Scognamiglio, Carlo Privato

ENEA, Portici Research Center, Piazzale E. Fermi, 80055 Portici (Napoli), Italy

ARTICLE INFO

Article history:
Received 21 December 2007
Received in revised form 24 November 2008
Accepted 25 November 2008
Available online 20 January 2009

Keywords:
Renewable energy
Thin film silicon photovoltaics
Building integrated photovoltaics
Micromorph solar cells

ABSTRACT

Thin film photovoltaics is a particularly attractive technology for building integration. In this paper, we present our analysis on architectural issues and technological developments of thin film silicon photovoltaics. In particular, we focus on our activities related to transparent and conductive oxide (TCO) and thin film amorphous and microcrystalline silicon solar cells. The research on TCO films is mainly dedicated to large-area deposition of zinc oxide (ZnO) by low pressure-metallorganic chemical vapor deposition. ZnO material, with a low sheet resistance (<8 Ω/sq) and with an excellent transmittance (>82%) in the whole wavelength range of photovoltaic interest, has been obtained. "Micromorph" tandem devices, consisting of an amorphous silicon top cell and a microcrystalline silicon bottom cell, are fabricated by using the very high frequency plasma enhanced chemical vapor deposition technique. An initial efficiency of 11.1% (>10% stabilized) has been obtained.

Contents

1. Introduction

It is well known that almost half (about 40%) of the power consumption in Europe originates from buildings, particularly for construction and maintenance, and most of all for operation. Therefore, a growing attention is nowadays paid to the building self-sufficiency, as demonstrated by the new European (and national) regulations about the energetic certification for buildings. The sustainability-oriented choices, that could be considered optional before, now are unavoidable. This means that the matter of energy nowadays is not only restricted to the field of research, but is really a "new material" of the design process for architects and engineers.

The utilization of energy generators into the building envelopes meets very well the "whole building approach", aimed to a simultaneous planning of the building and its services (for example heating and cooling systems). From this point of view the envelope is considered as not only the place where exchanges between inside and outside take place, but also the place where these systems are integrated. Generally, in order to maximize the contribution of sun-light to thermal and visual comfort of the inhabitants, reducing the energy consumption, bioclimatic design strategies are used (natural ventilation, solar heating and cooling, ground cooling, natural lighting and sun-shading devices). All this kind of systems are not separate from the envelope, as in the traditional case, but

* Corresponding author. Tel.: +39 081 7723217; fax: +39 081 7723344.
E-mail address: lucia.mercaldo@portici.enea.it (L.V. Mercaldo).

0306-2619/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apenergy.2008.11.034

coincide with the structure and the morphology of the building itself and sometimes can give the architecture a remarkable connotation (see natural ventilation chimneys and solar conservatories). Besides the adoption of passive strategies, the utilization of energy production elements is advisable.

Among the different energetic renewable sources, photovoltaics seems to be the best candidate for use into the building envelope. In fact photovoltaic components can substitute partially or totally some building elements (especially roofs and opaque/glazed façades) succeeding in a real integration in the design process. Photovoltaic energy generators can be used for existing buildings (valuable or poor/standard ones) and new buildings.

In this paper, we will point out the advantages of the thin film photovoltaic technology for building integration, for retrofit and in particular for innovative interventions, showing also examples of contemporary architectures requiring the use of very versatile photovoltaic modules. The core of the paper will focus on the technological aspects. In particular we will illustrate our activity on thin film silicon photovoltaics at laboratory scale.

2. Potentialities of thin film photovoltaics in architecture

Until the recent past, the attention of our culture to the renewables was due – chiefly – to the efforts and studies of researchers involved in the field of energy utilization. From the point of view of the researchers, the use of Photovoltaics into buildings was a good option, due to the possibility to use existing surfaces (facades, roof, etc.) to place photovoltaic systems, producing electric energy where an electric supply is required. Nevertheless, this use was not easy, for the great influence on the aesthetics of the building. The "acceptability" of photovoltaics in architecture can be considered one of the main barriers to the diffusion of building integrated photovoltaic systems.

As a consequence of the hostility of the public towards photovoltaics, much research in photovoltaics has been directed towards making photovoltaics more physically appealing, and technologically easy to use. This research can be synthesized by some valuable studies facing the requirements photovoltaic components must have if they are added to buildings (BAPV) or they are integrated into buildings (BIPV) [1,2].

Thanks to the research carried out in the recent past, photovoltaics has evolved from a functional element stuck on top of buildings to an increasingly aesthetic element of the building itself (Fig. 1). As a consequence of the improvements in the use of photovoltaics into buildings (technological and aesthetical), and also as a consequence of the new interest of the public into the energy problems, photovoltaics is now accepted by the public and architects. This change in perspective makes possible to use photovoltaics into buildings according to some hot architectural tendencies. This new status of photovoltaics generates new architectural and market demands [3].

Both in the case of retrofit and new buildings photovoltaic thin film technologies can ensure a good reply to these new demands. In fact, the industry markets many kinds of thin film components, that can be substantially divided into photovoltaic glasses, sheets and roof membranes. Glasses are produced with different dimensions and transparency, allowing the designer a good daylight and thermal control, whereas sheets and roof membranes can vary for dimensions and material (for example aluminum or steel for sheets) ensuring the compatibility with traditional roofing or proofing systems.

In perspective, thin film is the only technology suitable to satisfy the requirements of the most advanced architectural theories, like those looking at buildings as living organisms that should be able – during their life – to generate the energy needed to be in operation. This kind of approach is interesting also from a compositive point of view. In fact it suits well the new languages that translate the utilization of energy generators into morphological elements that can really connote the building appearance.

Fig. 1. Dutch Pavilion at the Expo 2000, Hannover, Germany, 2000 (façade integrated thin film PV sun-curtain).

An emblematic example is (Un)Plug, the concept building by R&Sie commissioned by the Research Department of the French Public Energy Society in Paris in 2001 (Fig. 2). It is conceived like a human body with hair (a series of thermal sensors) on a glassy skin with swelling blisters (photovoltaic devices). The envelope of the building can be defined as an environment responsive surface, which changes its shape with changing external conditions (temperature, humidity, light, etc.). Photovoltaics can be viewed as a special environment responsive material since it produces electric energy depending on the sun intensity, but present technologies are not yet sufficient to render a building environmentally sensitive in all the ways conceived by architects. Today, photovoltaics can only be integrated into the static surfaces of an environment responsive building, but not into its dynamic surfaces: new thin film photovoltaic technologies should be developed.

It is reasonable to imagine that in the near future 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 (see Figs. 3 and 4) and "media façades" communicating with people inside and outside the building (see Figs. 5 and 6). In this case thin film devices integrated into building surfaces, might supply the energy needed for functioning, and might integrate LEDs to transmit dynamic images outside the building, piquing the attention of the public.

Finally, contemporary architecture envelopes often look similar to natural landscapes. The difference between these buildings and the traditional ones is how the surfaces are conceived, land-formed or fractal, similar to geometries from the nature. The development of photovoltaic thin film modules, ensuring a satisfying flexibility