SOME RESULTS FROM RESEARCH AND DEVELOPMENT OF THIN-FILM PHOTOVOLTAIC CELLS

Hana Benešová, Jan Škorpil

ABSTRACT

The current predominate photovoltaic (abbr PV) technology is based on the crystalline silicon (c-Si). Unfortunately the PV cells created by the c-Si have few disadvantages. Therefore, the researchers worldwide are developing an alternative material in effort to improve the PV cells performances. The thin-film materials offer promising alternative to the c-Si technology. The thin films are base of the PV 2nd and 3rd generation. The properties of these cells are very largely determined by properties of the thin-film materials. For this reason, it is absolutely necessary to deal with their detection. This paper is concerned with some of the experimental methods used in the research and development of the thin-film generation and with some results of this research. The first part is very shortly introduction to problematic of the thin-film PV cells. The second part of paper discusses one of specific experimental methods, with which we can meet in research and development of PV cells 2nd and 3rd generation – X-Ray diffraction. The last part presents some results from this method.

Keywords

Thin-film photovoltaic cells, spectroscopy method, X-Ray diffraction, diffractogram

1. INTRODUCTION TO THIN-FILM PHOTOVOLTAIC

"Thin-film" is term used for material layer ranging of nanometers to several micrometers in thickness, which is applied on the substrates. The act of applying thin-film is so called deposition. The deposition methods are divided into two groups depending on whether processes are mainly – chemical vapor deposition or physical vapor deposition. In these ways prepared thin layer have special properties that destine these films for various utilizations – e.g. mechanical engineering, medicine or thin-film PV. Design of thin-film PV cells is completely different compared to the PV cells 1st generation. There are three basic configurations of thin-film cells – substrate and superstrate configuration (2nd generation) and tandem configuration (3rd generation).

Instead of the p-n junction used in c-Si PV cells, the thin-film cells use mainly the p-i-n junction. This junction consists of p-doped, un-doped and n-doped layers of semiconductor materials. Un-doped so called the intrinsic layer (i-layer) plays the most important role – this layer is single PV active layer. It means that it is able to absorb incident electromagnetic Sun energy and to generate electron-hole pairs, which enhance electric conductivity. Due to i-layer is often named the absorber layer or the photo generation layer. The PV cells 2nd generation have only one p-i-n junction. The tandem PV cells (sometimes named as multi spectral or multi junction cells) are based on using of the semiconductor materials with different band gaps. The base of these cells is formed by two (or more) p-i-n structures with different band gap sequenced into series. The solar radiation enters through semiconductor layer with the highest band gap at first, and then passes through other layer with monotonously decreasing band gaps. The top cell absorbs the high-energy photons – i.e. blue, green and yellow light, the bottom cell the low energy photons – i.e. red light.

The main materials, which created these junctions, is amorphous hydrogenated silicon (a-Si:H) and microcrystalline hydrogenated silicon (μc-Si:H). The basis of a-Si:H is created by amorphous silicon. It is non-crystalline silicon form, which possesses short-range atom structure. Unfortunately after discover of the semiconductor properties of this material very important fact was detect. Due to long-range disordered material structure the dangling bonds originate very simply in the band gap (e.g. by virtue of solar radiation). These bonds could cause unusual electrical properties of the material, because they act as recombination centers. For this reason, a-Si is unsuitable material for utilization in the PV cells. The researchers determined possibilities to minimize these defects – addition of 10 % hydrogen atoms into amorphous structure. These hydrogen atoms bond to the dangling bonds thereby reduce their density and improve electrical properties of the materials. The μc-Si is one of the silicon forms, which have local order. It is heterogonous material based on amorphous and crystalline phase, which is represented by c-Si grains sized about 20 nm.

2. EXPERIMENTAL METHODS

Although currently there is the relative large number of theoretic knowledge in the PV 2nd and 3rd generation, it is necessary to deal with the research and the development in this sphere to become fully integrated into electrical power engineering. There are some experimental methods, which are used in the research and the development of the thin-film cells. The methods are referred to collectively called spectroscopy methods and are based on interaction of the electromagnetic radiation with the research substance sample. They deal with the study of changes in the electromagnetic radiation spectrum. The changes can occur during passage of the electromagnetic radiation through some medium, during the radiation reflection at the interface of two mediums or the emission radiation from the medium. These methods can be based either on the energy exchanges between the radiation and the material sample (measurement and evaluation of electromagnetic radiation absorbed/emitted from/by substance) or no energy exchange interaction (measurement and evaluation of electromagnetic radiation diffraction).

These spectroscopy methods include X-Ray diffraction, UV/VIS spectroscopy and IR spectroscopy (spectroscopy in ultraviolet, visible and infrared radiation spectrum), FTIR spectroscopy (spectroscopy using Fourier transformation) or Raman spectroscopy. Next chapter deals with X-Ray diffraction.

2.1. X-Ray Diffraction

As the name says, this method is based on the diffraction (scattering) of the roentgen radiation. X-Ray diffraction can be defined as the physic-chemical method use to study of interaction crystalline substances with the roentgen radiation with no exchange energy. It is the technologically advanced non-destructive method used for analyzing of wide range of material, from liquids, through metals, polymers, plastics, ceramics, pharmaceuticals, semiconductors and to thin film structures.

If the electromagnetic solar radiation passes through the thin film structure (valid for generally some substance), atoms (molecules and ions) get in the variable electric field, which induces dipole moments in these particles. The dipole moments emit in all directions secondary electromagnetic radiation of the same frequency as in the case of the primary radiation. In the optically homogenous medium (i.e. the medium, in which all points have the same refractive index) the secondary radiation cancels interference in all directions outside direction of the initial primary radiation. It follows that the scattered radiation doesn't originate in the optically homogenous medium. Conversely, if medium isn't optically homogenous, the secondary radiation isn't chancel the interference (as in the previous case) and scattered radiation is created. This important physical phenomenon is called "diffraction". But the diffraction doesn't create in each optically inhomogeneous. It is created if the wavelength of the incident electromagnetic radiation approaches the size of the particles of substances, with the radiation interacts.

The X-Ray can be understood as flow of the photons with energy E or as the electromagnetic field defined the frequency ν and the wavelength λ. The wavelength ranges from 10^{-12} to 10^{-8} m, i.e. it is about 1000 times smaller than wavelength of visible radiation. The wavelength of X-Ray corresponds to the distance of atoms in the crystal lattice of the optically inhomogeneous substance. For this reason, the method X-Ray diffraction is able to provide information about the crystal structure of thin film and to help in research and development in the thin-film PV cells.

3. RESULTS

To measurement of the diffraction the device named the diffractometer is used. The Figure 1 shows PANalytical X'Pert PRO X-Ray Powder Diffractometer – one of these devices. This diffractometer is produced by PANalytical Company, which was established as part of Philips Company in 1948. Its then name was Philips Analytical. The mentioned device performs the powder diffraction analysis. Unlike the analysis on the single crystals, with which it is possible to encounter in the practice, in this case all variously oriented crystal lattice at the same time diffract.

Figure 1 – PANalytical X'Pert PRO X-Ray Powder Diffractometer

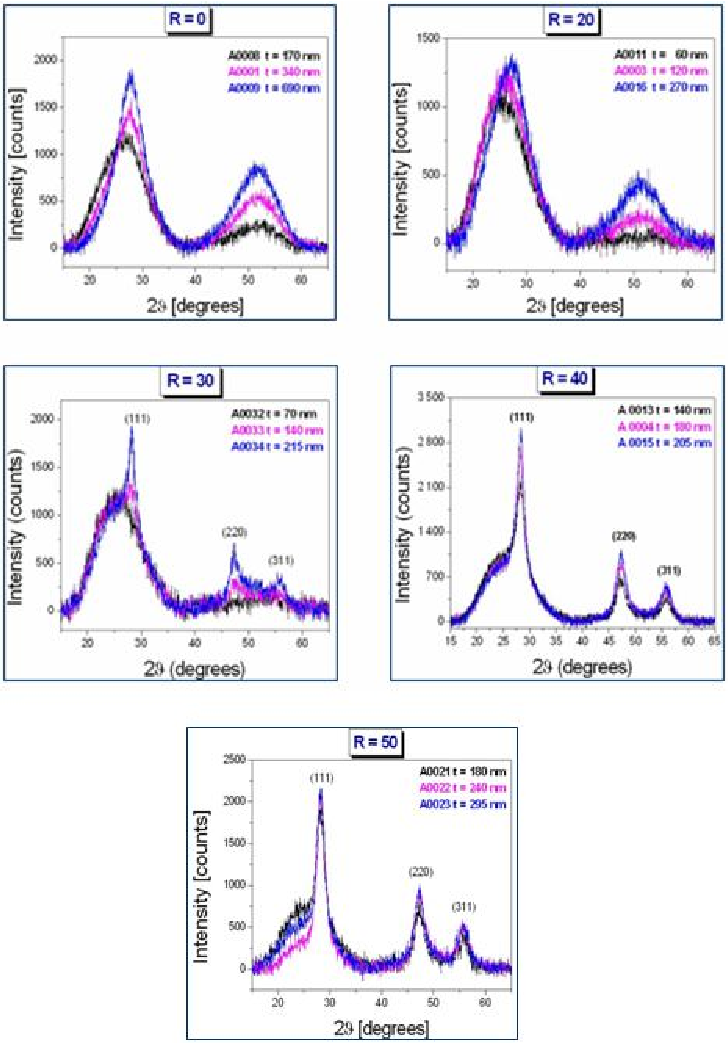

Figure 2 – Diffraction Patterns for Substance Sample Differing Thickness and Production

Thanks to diffractometers we are able to detect so-called diffraction patterns (diffractogram), see Fig. 2. These patterns can be detected for each substance. According to pattern can uniquely identify each substance. The pattern is defined as graphical representation of the dependence of intensity X-Ray radiation (expressed in number of the pulses per second or in absolute number of pulses) to two times the diffraction angle ϑ (i.e. angle between the incident beam and surface, on which this beam turns out). In the most cases, the intensity of radiation is low – it is so-called background. But in some cases, the diffraction pattern rises sharply, reaches maximum and then decreases sharply again. The maximums are called peaks (diffraction maximum) and correspond to the angle, at which intensity of the diffracted radiation increases sharply.

As mentioned earlier, the X-Ray diffraction is able to determine amorphous and crystalline phase of silicon in the research substance sample. If the electromagnetic radiation passes through some medium, depending on the type of the medium two basic situations may occur. If this medium is optically homogenous, any diffraction is originated. For this reason the diffraction pattern doesn't have the peaks for this type of medium, i.e. running of diffractogram is relative "smooth". Conversely, diffraction phenomenon originates in the optically inhomogeneous medium. In this case, diffraction pattern rises sharply, reaches the maximum value and then decreases.

4. CONCLUSIONS

Problems of the PV cells becomes more and more topical in the connection with increasing demand after energies, sharply rising cost of energies, resource energy scarcity and environment protection. For these reasons, new technologies of cells are developed. This paper is focused on one of the new trends in the PV sphere – on the thin-film PV cells.

The main aim of this paper is to short introduce to one of experimental method used in the research and development of the PV 2nd and 3rd generation – X-Ray diffraction. These cells are one of very attractive and perspective part of the electrical power engineering and constitute one of the most promising technology in the PV for following advantages – lower power and financial production intensity, lower cost, lower material consumption, higher efficiency, lower thickness, higher energy yield, lower energy pay back time, etc. (all compared with the PV 1st generation).

REFERENCES

[1] BENEŠOVÁ, Hana. *Nové trendy v oblasti solárních systémů*. Plzeň, 2011. 86 s. Písemná práce ke státní doktorské zkoušce. Západočeská univerzita v Plzni. Fakulta elektrotechnická. Katedra elektroenergetiky a ekologie. Školitel Jan ŠKORPIL.

[2] BENEŠOVÁ, Hana a ŠKORPIL, Jan. Configuration of Thin-Film Photovoltaic Cells. In: NOHÁČOVÁ, Lucie, aj. *Electric Power Engineering and Ecology – Selected Parts II*. Praha: BEN – technická literatura, 2011. s. 44-51. ISBN 978-80-7300-418-7.

[3] BENEŠOVÁ, Hana a ŠKORPIL, Jan. Experimental Methods in Research and Development of Photovoltaic 3rd Generation. In: *Proceedings of the 13th International Scientific Conference – Electric Power Engineering* 2012. Brno: Vysoké učení technické v Brně, 2012. s. 567-570. ISBN 978-80-214-4514-7.

ACKNOWLEDGEMENT

This paper was supported by project no. SGS-2012-047.

Authors:

Ing. Hana Benešová
University of West Bohemia
Department of Electrical Power Engineering
and Environmental Engineering
Univerzitní 8, 306 14 Plzeň, Czech Republic
E-mail: habe@kee.zcu.cz

prof. Ing. Jan Škorpil, CSc.
University of West Bohemia
Department of Electrical Power Engineering
and Environmental Engineering
Univerzitní 8, 306 14 Plzeň, Czech Republic
E-mail: skorpil@kee.zcu.cz