Thin film solar cells – promising technology – dr Piotr Panek

Solar cells can be divided into two main groups: wafer based and thin films. The major drawbacks of wafer solar cells are that the Czochralski or casting process consumes a large amount of electrical power and when the wafers are cutting, there is a considerable wastage of crystal of about 50 %. Unlike crystalline silicon solar module manufacturing, in which the cells are constructed first and later interconnected, the creation of thin-film modules in the process in reverse. First, the absorber and conductive layers are deposited on the substrate and than separated so that they are monolithically connected in series. The interconnection is necessary to convert the high current and low voltage output into a low current and high voltage. This minimizes ohmic power losses, which scale as the square of the current. The most prominent thin film solar cells are: CdTe, CIS and a-Si/μc-Si or a-Si/mc-Si [1]. Today thin film solar cells have a market share of about 12 %.
Cadmium telluride (CdTe) is a direct-bandgap material with energy of 1.45 eV and for this reason is favorable for conversion of the solar spectrum into electricity [2]. The layers are deposited onto the glass substrate used close-spaced sublimation (CSS) and chemical bath deposition (CBD) methods with the sequence presented in Fig.1.

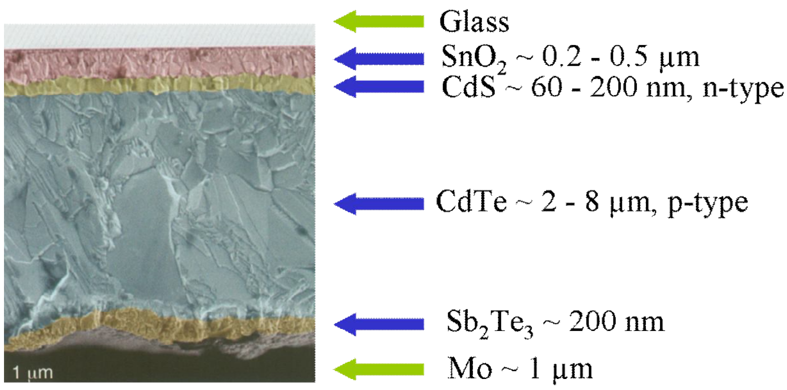

Fig. 1. The schematic cross-section of CdTe solar cell exhibiting the material components.

Figure 1 shows the construction layers of the CdTe solar cell. The SnO_2 layer, fluorine doped, is the transparent contact that provides current collection from the front side of the device. In thin film solar cells the TCO front contact needs a high transmission ~ 90 %, high bandgap ~ 3 eV, and high conductivity for use as a transparent contact in the top cell. The CdS layer serves as the window layer. The heart of the cell is CdTe layer, serves as the absorber for incident light. The Sb_2Te_3 layer produces an ohmic contact to the CdTe, and the Mo decreases the series resistivity of the back contact. The thickness of the CdS layer can strongly affect device performance. The cell with a CdS layer of 60 nm has lower open circuit voltage (V_{oc}). The cell with CdS thickness over 100 nm has reduced photocurrent due to absorption and lower V_{oc} due to inferior CdS from the latter stages of CBD growth [3]. The specific raw material quantity is about 100 g/kW$_p$ for the cadmium of the CdTe cell. CdTe photovoltaic panels are the cheapest of all types. At present, production costs amount 0.75 USD/W$_p$ as the result of the only nine production steps for a finished panel. The global market leader in CdTe solar cells is First Solar (USA). The company continued the expansion of its production capacities from 716 MW$_p$ in 2008 to 1,138 MW$_p$ at present.
Epitaxial thin film silicon solar cells have the potential to be a low-cost alternative to bulk silicon solar cells. The low cost substrate consists of highly doped crystalline silicon wafers from metallurgical grade silicon or mc-Si. In this method on top of the seed an a-Si layer is deposited first. This layer is than epitaxially crystallized by high temperature annealing at

about 600 °C. However, a major drawback of the current epitaxial semi-industrial screen-printed cells is that they only achieve a photoconversion efficiency of about 11 – 12 % due to the optically thin active layer ~ 20 μm [4].
CIS ($CuInSe_2$) is a one of the most light absorbent semiconductor and only 0.5 μm can absorb 90 % of the solar spectrum but on the other hand it is very complex material what makes it difficult to manufacture. Its bandgap of 1 eV is rather low and it is usually replaced by an alloy of indium and galium and it is found as CIGS ($Cu(In,Ga)Se_2$) cells. Its bandgap can be varied continuously between 1,0 – 1,68 eV, depending on the Ga/InGa ratio. Many applications require high specific power and CIGS cells on light weight and flexible substrates can yield more than 1,5 kW/kg specific power [5]. The industrial methods for CIGS synthesis employ: DC magnetron sputtering, Nd:YAG laser pattering, vacuum deposition and chemical bath deposition. The Indium is also used in flat screens, light emitting diodes and touchscreens and its exploited resources know today are approximately 11000 tons what has a negative effect on the future ability of the CIGS technology. Long life CIGS modules have only been possible when encased between glass. This is because the front contact made of zinc oxide is very susceptible to humidity. The main producer of CIGS modules is Wurth Solar (Germany).

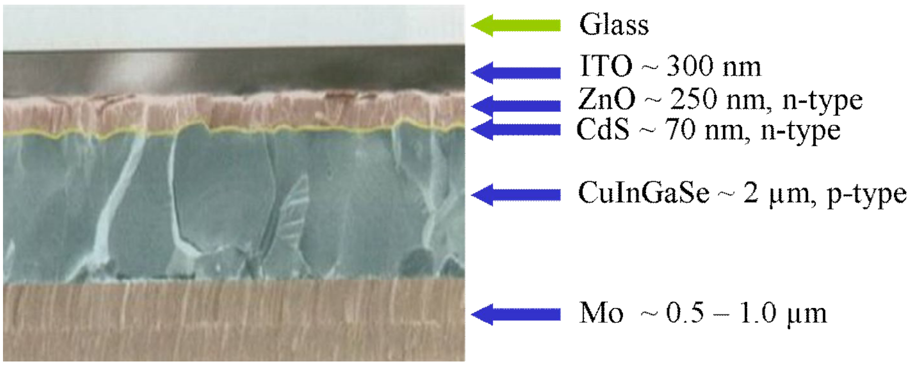

Fig. 2. The basic schematic cross sectional view of CIGS thin film solar cell [6]

Amorphous Si is produced from monosilane SiH_4 and the glow discharge method is the best for solar cell construction. The thickness of a-Si needed for absorption of the incoming solar energy is only 0,5 – 1 μm. On the other hand, the minority carrier diffusion length is very short, about 0,1 – 2 μm, what is caused by material defects such as dangling, strained and weak bonds that act as recombination centres. In order to increase efficiency, research are focused on tandem solar cells, with a top cell consisting of amorphous Si and a bottom cell made of microcrystalline Si. Amorphous Si can be formed on any substrate like metal, glass or polymer. The problem in the development of amorphous Si solar cells is the Staebler-Wroński effect. When the a-Si is illuminated with strong light of intensity about 100 mW/cm^2, the photoconductivity is lowered. The a-Si module performance changes to 77 % of the initial value in winter and recovers to 93 % in summer, and shows the periodic annual change every year. Mass production technologies of a-Si single junction and a-Si/mc-Si hybrid modules with stable 8 % and 10 % photoconversion efficiency were developed by Kaneka Corporation [7]. There are other possibilities. A layer of amorphous silicon is deposited on silicate glass and, using a laser, is selectively melted for a millisecond. The silicon immediately forms crystallites with grains of about 100 μm in size. Using plasma induced electron beam deposition, the next amorphous layer is deposited and repeatedly melted with short pulse laser. As the result, the multicrystalline silicon layer grows to a desired thickness of 2 to 4 μm at a speed of 1 μm/min. [8].

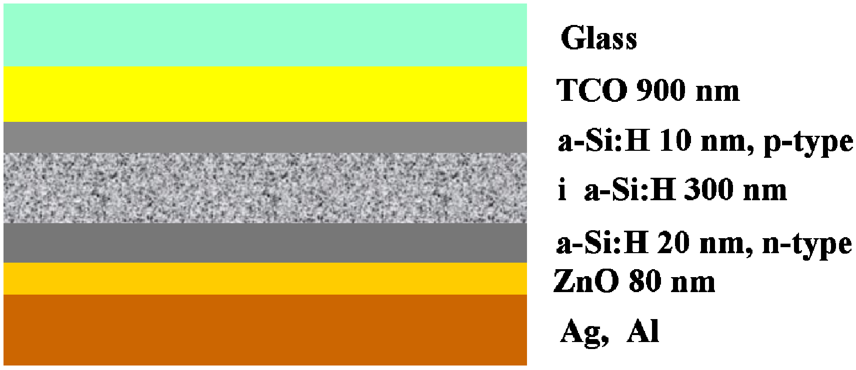

Fig. 3. Schematic illustration of single junction amorphous silicon solar cell.

The dye-sensitized (DSSC) and organic solar cells are considered as thin film cells. The DSSC uses nanoparticles of dye-sensitized TiO_2 to collect electrons from electron-hole pairs created by photons interaction at a day/TiO_2 interface. The holes are transported for collection at TCO electrode. The dye is regenerated by electron donation from electrolyte, usually an organic hole conductor or an ionic liquid containing most frequently the iodide/triiodide couple as a redox system [1]. The DSSC modules are mainly suitable for building integrated photovoltaics (BIPV).

A lot of combinations of donor and acceptor materials have been used to build organic solar cells. The advantages of these cells are low cost materials, cost processing and flexibility but the efficiencies are very low (see Tab. 1). One of the most promising combination of materials is a blend of a semiconducting polymer and fullerene C_{60} as acceptor between to electrodes. A key problem of the organic solar cells is the stability of organic materials [9].

Besides cost reduction, one of the major challenges for thin film solar cells is to increase their efficiency in order to reduce the balance of system cost. The European Photovoltaic Technology Platform foresees that by 2030 all thin film technologies will be above 15 % efficiency and this could go up to 25 % in the case of CIGS. Worldwide, 141 companies produce thin film PV modules of the various types [10]. Overview of solar cells and modules best efficiency by different materials is presented in Tab. 1.

Tab. 1. Best solar cells and modules efficiency [2], [10].

Classification	**Solar cell**	**$E_{ff\ cell}$ [%]**	**$E_{ff\ module}$ [%]**	**Module manufacturer**
Crystalline Si	Monocrystalline (Cz-Si)	24,7	22,7	SunPower – USA
	Polycrystalline (mc-Si)	20,3	18,6	Mitsubishi – Japonia
	Microcrystalline (μc-Si)	11,7	10,9	Sanyo - Japonia
	Ribbon (R-Si)	-	13,4	Evergreen - USA
	HIT	21,8	17,3	Sanyo – Japonia
III – V solar cells	GaAs	25,8	-	-
	InP	21,9	-	-
	$GaInP_2$/GaAs	39,3	-	-
Thin films	CdTe	16,5	10,1	First Solar – USA
	CIGS	19,5	12,2	Solibro - Miemcy
	Amorphous Si (a-Si)	10,1	7,5	NES - Chiny
Organic	Polymer	5,1	1,8	Konarka - USA
Photochemical	Grätzel	11,4	11,1	Sharp - Japonia

The environmental risk associated with thin films solar cells depends on the kind of the used materials. Silane is extremely explosive and flammable, Cd is a highly poisonous material, and H_2Se, used in the CIS production, is dangerous to health. This problem is investigated by many laboratories. The production of thin film solar cells is complex but can be adopted on an in-line and a large scale processes where the substrates size of 5.7 m^2 can be coated. This technology also opens the way to flexible photovoltaic modules [11]. The solar industry has undergone tremendous growth over the last several years. In a new market research report, global thin film production output reached level 3 GW_p in 2010 [12].

References:

[1] J. Poortmans, V. Arkhipov, "Thin Film Solar Cells – Fabrication, Characterization and Application", John Willey & Sons Ltd., Chichester, England, 2006.
[2] P. J. Reddy, "Science and Technology of Photovoltaics", BS Publication, India, 2010.
[3] D. H. Rose, F. S. Hasoon, R. G. Dhere, D. S. Albin, R. M. Ribelin, X. S. Li, Y. Mahathongdy, T. A. Gessert, P. Sheldon, "Fabrication Procedures and Process Sensitivities for CdS/CdTe Solar Cells", Progress in Photovoltaics: Research and Application, 7, (1999), p. 331-340.
[4] H. Degans, I. Kuzma, G. Beaucarne, J. Poortmans, ''Plasma Texturing and Porous Si Mirrors Boost Thin-film Si Solar Efficiency'', Photovoltaics Internationale, 3, (2008), p. 83-85.
[5] A. N. Tiwari, M. Krejci, F. J. Haug, H. Zoog, "12,8 % Efficiency $Cu(In,Ga)Se_2$ Solar Cell on Flexible Polymer Sheet", Progress in Photovoltaics: Research and Application, 7, (1999), p. 393-397.
[6] E. Fortunato, D. Ginley, H. Hosono, D. C. Paine, "Transparent Conducting Oxides for Photovoltaics", MRS Bulletin, 32, (2007), p. 242-247.
[7] Y. Tawada, H. Yamagishi, K. Yamamoto, "Mass Production of Thin Film Silicon PV Modules", Solar Energy Materials & Solar Cells, 78, (2003), p. 647-662.
[8] A. Müller, "Laser Processing: Promising Technologies?", Sun & Wind Energy, 5,(2008), p. 132-139.
[9] S. E. Shaheen, D. S. Ginley, G. E. Jabbour, "Organic Based Photovoltaics: Toward Low-Cost Power Generation", MRS Bulletin, 30, (2005), p. 10-19.
[10] J. Bernreuter, "Nano-columns and Other Tricks", Sun&Wind Energy, 1, (2010), p. 100-105.
[11] N. Anscombe, "Flexible Markets", Photovoltaics 2011, 1, (2011), p.8-14.
[12] News in: Photovoltaics International, 1, (2008), p. 134.