The development directions for PV sector based on a crystalline Si

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Photovoltaic is the most dynamically developing method for obtaining sources of renewable energy in the world. The solar energy revolution is not far away and the spark will come when solar electricity reaches grid parity. The crystalline silicon (c-Si) module price around the 0,72 USD/W_p and cumulative PV module volume of about 150 GW_p indicate a trend for PV industry. Achieving both cost savings and efficiency improvements is at present the main challenge in the mass production of c-Si solar cells which are manufactured with H pattern Ag metallization on the front side of n-type emitter of p-type wafers, and a full area Al contact with Al/Ag solder pads on the rear. The task for the future is to redesign this cell architecture. The efficiency of a solar cell depends on a variety of factors, including the material quality of the c-Si wafer, the solar cell design and its fabrication. Cost effectiveness of silicon solar cells production can be improved by using cheaper materials and by simplifying the manufacturing process for which the fundamental prerequisite is the use of continuous automatic methods. As part of steady efforts in the PV industry a lot of cost effective and high efficiency cells and modules concepts are in the process of being implemented in the manufacturing lines. The following are just a few of these innovations:

a) Passivated emitters and rear cells (PERCs).

Passivated emitters and rear cells are considered by many research institutes to be the next technology generation for industrial production. The PERC cells utilize AlO_x/SiN_x as the rear surface passivation layer in addition to laser contact opening to form local Al rear contacts. The record 21,2 % efficiency cell used a homogeneously diffused emitter with sheet resistance of 70 Ω/sq. Another attractive technology is to increase the number of front busbars. The 5 busbars front grid with the dual-print process reduces the total shadowing loss of the front grid to 4,0 %. The increased conversion efficiency is due to an increase of 0,9 mA/cm^2 in short-circuit current density. Additionally, the cells yield the highest open circuit voltage V_{oc} values of up to 662 mV because of the reduced metal contact area, as well as the highest fill factor FF of up to 0,809 because of lower resistance losses of the finger grid [1]. Because front-to-rear interconnection and soldering of interconnects induce too much stress on thin wafers, the International Technology Roadmap for Photovoltaics (ITRPV) roadmap expects 35% of all cells to be rear contact by 2020. There are three main approaches to rear-contact cells: metal wrap-through (MWT), emitter wrap-through (EWT), and back-junction (BJ). In the first two approaches, the emitter is still at the front of the device, but holes are laser drilled through the wafer that transports carriers to the rear, either through the metal contacts (MWT) or the emitter (EWT). In a BJ cell, the emitter is located at the rear surface, typically in an interdigitated fashion with the back surface field (BSF). The efficiencies of 24,2% have been reached on BJ solar cells and over 20% on MWT cells. An interdigitated back contact silicon (IBC) HIT cell (IBC-HIT) has been reported at an efficiency of 20,2%, but simulations show that 26% conversion efficiency is achievable [2].

b) Pastes.

Metallization pastes containing silver and aluminium are the most costly non-Si materials in solar cells processing. The Ag price of 690 USD/kg results in a cost of around 0,023 USD/W_p [3]. The total cost of ownership of the metallization process today still accounts for around 50 % of the total cell process cost [4]. The silver pastes used in screen printing technique are composition of silver powder - conductive phase, where grain size varied between 1 and 3 μm, and glaze - auxiliary phase, helps in the sintering process. The characteristic temperature of sintering silver layers is 850 ^{o}C. Silver nanopowder paste represents a new generation of thick-layer materials dedicated to screen printing. The conductive phase is silver powder where grains size range from a few to over a dozen nanometers and methyl polimethacrylate is the matrix of nanocomposite. In consequence melting point of nanoparticles can be much lower than microcrystalline solid. Preliminary research in the field of silver nanopowder paste contact preparation for silicon solar cells has brought to well-conducting layer forming through firing at much lower temperatures 300 – 600 ^{o}C in comparison to so far used pastes [5]. These new characteristics arise from the quantum effects and high share of surface atoms causing high reactivity [6]. The future trend of Ag reduction is combined with the implementation of plating technologies of copper but the introduction of such technologies into mass production is not expected to take place before 2018 [3].

c) Coextrusion printing technology.

The coextrusion technology is a contact and mask-free fine line metallization technology for direct printing of narrow grid lines with strongly enhanced aspect ratio in a dual print mode. The silver and sacrificial paste that merge inside the nozzle are simultaneously extruded onto the wafer and form a silver paste structure smaller than every design feature inside the nozzle. After contact firing the grid lines become as narrow as 35 μm with an aspect ratio up to 0,7 [7]. The coextrusion printing technology offers an alternative or even replacement to screen-printing, stencil- and fine line dual printing and inkjet based printing for grid line metallization.

d) N-type Si.

It is well known that n-type silicon provides several advantages over p-type, including better tolerance to common impurities, high bulk lifetime, and no light-induced degradation due to the boron-oxygen complex formation. The n-type silicon solar cells currently achieves an average conversion efficiency of 20,2 % using a relatively simple process flow. This bifacial cell concept is based on homogeneously doped p^+ front and n^+ back surfaces [8]. Ion-implanted n-type silicon (Si) solar cells are attracting considerable interest in photovoltaics because of their potential for stabilized high efficiency and low cost. In addition, ion implantation can produce advanced high-efficiency cell structures with fewer processing steps.. They have been demonstrated the high quality of boron and phosphorus implantation by fabricating a 22.3% small area efficient n-type passivated emitter, rear totally diffused cell on a float-zone Si wafer [9].

e) Zinc oxide (ZnO).

Indium tin oxide (ITO) and fluorine tin oxide (FTO) have been common materials as window electrodes in optoelectronic devices, but they have some disadvantages e.g. high price, chemical instability and low mechanical strength. Zinc oxide (ZnO) is nowadays worldwide extensively studied for optoelectronics and photovoltaics application as transparent electrodes in solar cells and will soon replace ITO. It may be used as the *n*-type partner for the organic materials but for Si too. There is a bright future in front of the PV cells based on such a hybrid structures for their flexibility and a very low cost of production. The use of ZnO in the novel electronic and PV devices demands low or extremely low processing temperature [10]. There are many different technologies used to obtain ZnO layers. These are chemical vapor deposition (CVD), molecular beam epitaxy (MBE), sputtering, electron-beam evaporation, pulse laser deposition (PLD) and hydrothermal method. In this context the Low Temperature Atomic Layer Deposition method (LT ALD) technique has proven to be the most promising. Moreover, the technique is fairly cheap and allows ZnO growth with atomic resolution.

f) Graphene.

In last years a significant increase in interest about graphene can be observed because of great properties of this carbon one atom thick material. Some extraordinary properties like low resistance, high elasticity, mechanical stability, and high transparency of light in visible lenghts have been described in the literature locating graphene in the main point of interest of researchers working on transparent electrodes. They have been made some approaches in obtaining transparent graphene films by chemical vapor deposition, dip coating in hot Graphene Oxide (GO) aqueous dispersion, ink-jet printing [11] [12].

g) New assembling PV module technology.

The technology which can be used for the assembling process depends on the cell architecture. There are several new and advanced interconnection concepts available, such as the gluing of standard ribbons using electrical conductive adhesives, multiwire technologies or the NICE module developed by Apollon Solar company. In the case of multiwire technologies, instead of interconnecting the cell busbars by means of two or more copper ribbons per cell, the busbar-less cells are interconnected by many thin wires [13]. The key elements of the NICE are: the connection between the solar cell contacts and the metal interconnectors is soldering free and a contact is obtained by creating and maintaining a lower pressure inside the PV module, filled additionally with a neutral gas to protect the components from oxidation. This construction simplifies the recycling of modules, because they can be easily disassembled and separated into their basic components: glass, cooper and cells. The Tab. 1. presents the technological development that are expected to be implemented by a near future. The photovoltaic (PV) market has experienced double digit growth in the past decade and has now reached a global capacity of approximately 67 GW [2]. Such fast growth in photovoltaic industry is connected with intensive research on increasing the efficiency of photovoltaic conversion in solar cells. It is expected that various forms of crystalline silicon solar cells will dominate the market for the foreseeable future but it will require simultaneous optimization of the many components that constitute a complete solar cells.

Tab. 1. The main PV industry expectations compared with the present status [14].

Technology	Current status 2014	Expected for 2018
Avarage cell thickness	180 μm	150 μm
N-type Si market share	5 %	20 %
Back-contact market share	5 %	12 %
Module glass thickness	3,2 mm	2 mm
Glass-glass market share	5 %	20 %

The higher efficiency will help to produce energy cheaper, and create new applications for photovoltaics. The research covering the PV materials recycling are also a key issue for PV elements to minimizing their environmental effect during entire period of life [15].

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