SILICON HETEROJUNCTION CELLS R&D IN EUROPE

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ABSTRACT: Europe has a leading position in the production of crystalline ingots and wafers for PV applications. The development of a cheaper, medium-thick polycrystalline ribbon silicon or similar silicon materials is an important topic of photovoltaic R&D. The chemical-physical properties of the predicted material involves the risk of degradation of minority-carrier lifetimes associated with high-temperature processes and imposes a new approach to realize the junction. The decrease in active-layer thickness requires novel concepts for light trapping, correspondingly and the roughness of the surface requires specific and more efficient surface treatment for passivation. The amorphous silicon (a-Si)/monocrystalline silicon (c-Si) Heterojunction with Intrinsic Thin-layer (HIT^{TM}) solar cell developed by Sanyo Electric was applied successfully to c-Si and offers many excellent features for the solution of the indicated issues, but the potential of Silicon Heterojunction (SHJ) technology on thin silicon is not totally explored. This paper gives an overview about the current R&D activities in Europe dealing with the SHJ technology as well as the perspective for short mid term application on thin silicon.

Keywords: Silicon-1: Thin Solar cells-2: Heterojunction-3.

1 INTRODUCTION AND BACKGROUND

By the end of the 21st century, PV will probably be based on materials different from what we know at today, but the current photovoltaic market is by far dominated by silicon. About 84% of the solar-cell world PV production for terrestrial applications has its origin in monocrystalline- (c-Si) and multicrystalline-silicon (mc-Si) wafer technology [1]. Most of the remaining 16 % market is dominated by thin-silicon (amorphous, microcrystalline, nanocrystalline, etc.) and by hybrid amorphous-crystalline solar cells (microcrystalline Si on low-cost substrates, a-Si on CZ slides). In the short term (until 2010) PV technology has to rely on the development of silicon technology in order to sustain the rapid market growth, the continuous decrease of PV module prices and on the efforts for closing the gap between existing and predicted performance for thin film options[2]. For a long time, silicon wafer and thin-film silicon technologies have evolved as competing options, i.e. as if the solutions to the technical problems could have come out from only one of these two research lines.

In wafer silicon production technology the key point concerns the reduction of wafer thickness and the economy of scale triggered by the rapid growth of wafer silicon production capacities. The prime goal to lower costs leads to multicrystalline instead of monocrystalline silicon, thinner active layers (~10^1 instead of ~10^2 μm) and a more efficient use of raw materials.

Thin silicon is forced in the same direction from the opposite side by improving the optoelectronic properties and stability of the material, its growth rate and consistently of making the cell active-layer thicker. This leading force result in requests for an increased crystallinity, a thicker active layer (~10^1 instead of ~1 μm), and higher growth rates.

A rough view at the guidelines of both tendencies leads to conclude that the key properties of silicon material in next-generation photovoltaics would be:

- Medium crystallinity (Multi-or polycrystalline silicon).
- Medium active-layer thickness (>3μm; <50 μm).
- High fabrication throughput, either by epitaxy, fast solidification of melted silicon, fast film growth from gaseous silicon sources or similar processes.

Several efforts are in progress based on techniques such as molecular-beam graphoepitaxial growth (MBGE), solid-phase crystallisation (SPC), zone-melting recrystallisation (ZMR), plasma-spray silicon growth (PSSG), liquid-phase epitaxy (LPE) molecular-beam epitaxy (MBE) [3,4] hot-wire CVD, VHF-PECVD or other suitable techniques [5,6]. Whereas it is unclear whether this kind of material will be obtained from the evolution of wafer technology, or from thin-film technology the mutual convergence of these two research lines is more and more obvious. Thin film technology is intrinsically compatible with the predicted material. On the other side, the conventional crystalline technology, based on high temperature processes (700°C-900°C) imposes a new approach to avoid degradation of minority-carrier lifetimes and thermal damage of substrate and thin silicon layers. These requirements, added to other factors such as the search for automatic module-assembly techniques , the need to lower costs by simplifying the technology and spending less energy, or the tendency to produce large-area devices, have led to the development of new approaches that could merge together both technologies.

Some promising results could come from Rapid thermal processing (RTP) [7] where heating and cooling rates can de dramatically increased up to 100 K/s instead of 15-20 K/min, but silicon-heterojunction solar cells (SHJ) basically made of a crystalline-silicon (mono- or multi-crystalline) wafer or ribbon absorber and one or two thin-film-silicon layer(s) grown through Plasma-Enhanced Chemical Vapour deposition (PECVD) or similar techniques represents a realistic relatively simple technology to fabricate solar cells with very high efficiency. Also it is an excellent example of technological convergence for both – thin-film and wafer -technologies. Key features of the silicon-heterojunction technology are:

- A very simple low-temperature fabrication process. It eliminates the degradation of bulk properties (diffusion of impurities, defect formation). No wrapping problems

on thin c-Si or multi-Si wafers and no damages to the semiconductor/glass structures
- An important cost-reduction potential and enhanced throughput due to reduced process time (only for in line application in production, due to the vacuum process)
- High efficiencies (~21%) with a high potential for significant improvements

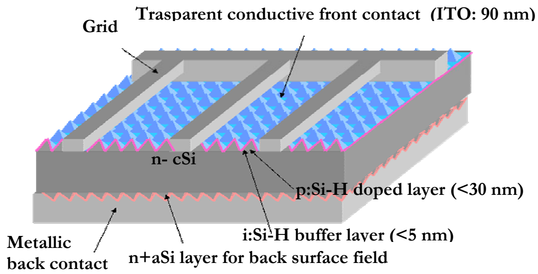

Fig.1. Typical architecture for amorphous-Crystalline Heterojunctionsolar (SHJ) cells [5,10]

Furthermore:

- The depth of junction can be easily and accurately controlled (~1nm- up to 100 nm or more)
- Large gap emitter 1,6 eV-2,3 eV to enhance the response in the blue area of solar spectra (window effect).
- Passivation of bulk material and wafer surface. Excellent back surface field
- Opportunities for Tandem structures

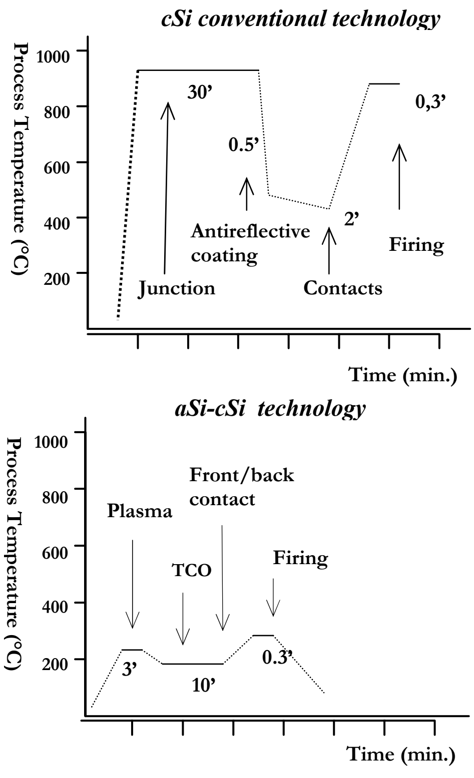

Fig.2 Estimated thermal budget and process time for the conventional cSi technology and SHJ technology

Starting from pioneering work of early 80's on amorphous Si/crystalline silicon stacked solar cells, Prof. Y. Hamakawa and his co-workers predicted the relevance of this kind of devices on thin silicon applications [8]. The application was extended to the so called "Honeymoon" four terminal solar cells concept (η=21% [9].

Following the first studies of Prof. Hamakawa, Sanyo started in the early 1990s on the growth of low temperature junction on c-Si and multi-Si, and the application of the so-called Artificial Constructed Junction- heterojunction with intrinsic thin layer ACJ-HIT® solar cells (η=18.1%). Sanyo improved their world's highest efficiency up to 21.0% (2003) [12] confirmed by the Japan Quality Assurance organization (JQA) by optimizing the cell designs on low-cost solar grade CZ-Si wafer (100cm^2) and have consequently attracted much attention from the international scientific community. Especially, the high open circuit voltage (Voc) of 714mV was remarkably well obtained on textured substrates due to a specifically developed surface conditioning process. Some of the developed technologies have been introduced to mass production and as a result, 200W HIT solar cell modules have been commercialized with a cell conversion efficiency of 19.5% and module efficiency of 17% [12]. In 2002 Sanyo reached a market share of around 6% of all PV sales in the world by using this technology [1].

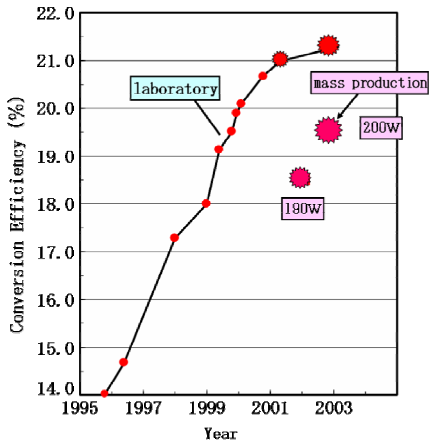

Fig.3 Evolution of Sanyo ACJ-HIT^{TM} solar cells efficiency on area of typical interest for commercial applications (~100 cm^2) *(Sanyo courtesy [12])*

2 BASIC PROPERTIES OF SHJ TECHNOLOGY

The solar cells based on SHJ can be considered as interfacial devices. The chemistry and kinetics of the gas surface interaction during Plasma Enhanced Chemical Vapour Deposition (PECVD), and in general, during plasma treatment is not totally explored. A wide potential is available for further investigation of different process schemes that affect, not only the structural quality of the deposited films, but also surface morphology, roughness, surface reactivity and surface composition. The effects produced by impingement of radicals on the surface involve several process steps such as:

1. Adsorption and insertion of radicals onto the crystalline silicon deposition surface
2. Diffusion of the etching species in the substrate
3. Surface dimerization of adsorbed SiH_2 groups, or of the other impinging radicals;

4. Formation chains and islands of radicals on the surface, through the formation of higher surface hydrides and exchange of hydrogen or other chemical species,
5. Dangling-bond-mediated dissociation of surface hydrides [19,44,45].

As effect of deposition condition, can be changed dramatically:

1 the electrical and optical properties of the emitter including optical gap, activation energy, band offset, band bending, gap state density;
2. interface state density, Dit(E)
3. surface roughness

The development of different Plasma process schemes (RF, VHF, MW-PECVD, cat-CVD) based on conventional (SiH_4, NH_3, H_2, N_2,) and new classes of precursor gasses (SiF_4, NF_3, other gases) leads to the development of new plasma regime experiments . These options should help to better understand the route by which the kinetics and the effects of impinging radicals on the front and back interface could be changed. As a way of fact, Sanyo was able to increase the conversion efficiency of their devices based on n-type c-Si only after the development of a specific plasma surface conditioning process therefore never indicated in literature.

Notwithstanding this, it is definitive the beneficial role of surface treatment in hydrogen of n-type based devices, but some authors experimented detrimental effects of hydrogen radicals in plasma , always present in this kind of process, on p-type based SHJ solar cells, due to interfacial acceptor passivation and consequently an increase of interface state density defect was noted [29,32]. Furthermore, to the knowledge of the authors in all p-type based SHJ solar cells having a conversion efficiency of interest for PV application (>15%) always a conventional high temperature contact was used on the back. No opportunities for a low temperature back surface field are offered to p:Si-H deposition on the back respect n-type based SHJ, where it can be recognized through the use of specific simulation programmes [26] that a very low recombination rate is expected on the back contact due to valence band offset between i-n-type amorphous layer and n-cSi. All indicated considerations explain why the main results on p-type c-Si based SHJ show always lower conversion efficiency respect high efficiency demonstrated by Sanyo on n-type cSi. As opposite route, full innovation in SHJ technology can be produced by application to multicrystalline silicon and to the new class of predicted thin silicon materials As effect of the wide extension of knowledge, a number of research groups and R&D braches of companies are actively working on SHJ cells in Europe. Their individual results are promising and reveal an excellent scientific level, but only during late years interesting applications were seen on devices having a significant conversion efficiency and further efforts need to be address in direction of common objectives.

3 SHJ R&D LINES AND APPLICATION IN EUROPE

Some projects are now running under the European Community Framework Programme FP5 with promising results and additional ones are in progress under the current Framework programme FP6 (e.g. CrystalClear project) but the potential of SHJ isn't totally explored. Owing to the difficulty to synthesise so much information in a short paper, we just indicated some non-exhaustive highlights of the ongoing activities. No information were available on the R&D activities of European PV companies, however, RWE-Schott Solar (D) and Eurosolare, now Eni Tecnologie (I), are participating in the 5FP MOPHET project specific for application of SHJ [35] on PV technology (see following paragraph)

Fig.4 Distribution of R&D groups operative on SHJ RTD. Data elaborated on received information.

Belgium:

• IMEC-Interuniversitair Micro-Elektronica Centrum: HIT emitters on bulk silicon and heterostructures for rear surface passivation, Heterojunctions on porous intermediate layer on p-type Cz material (textured surface) 1 cm^2 15.3 %. HIT on multicrystallline material $0.98cm^2$ 14.6 % [38,41]. Applications of SHJ to thin-silicon solar cells foreseen.

France:

Research is conducted under the national funded programme SINERGIES (2004-2009). LPICM Ecole Polytechnique: study of plasma processes and interface characterization through the use of in-house in situ diagnostic techniques such as UV-visible ellipsometry; Kelvin probe and Time Resolved Microwave Conductivity (TRMC); growth of thin films and dry surface etching/conditioning process for native oxide removal and passivation prior to amorphous silicon deposition. Studies on ITO contacts. Collaboration among CNRS PHASE, CEA-Grenoble, Ecole Superieure d'Electricité-Gif-sur-Yvette concerning the chose about substrate and the aSi/cSi interface plasma treatment. Foreseen activities: improved efficiency on p and n-type crystalline silicon substrates. Shift to polycrystalline silicon [18,44].

Germany:

Germany has a national project on SHJ co-ordinated by Hahn-Meitner Institute (HMI) and funded by BMBF (Federal Ministry of Science, contract No. FKZ 01SF00-19- 5 yr project). The general aim of the project is the control and understanding of the physic of the device in such extent that the cell efficiency will only be limited by the crystalline wafer properties (diff. length of minorities). The goal in 2004/2005 is to realize a-Si:H(p) emitter and apply this on low cost Si as mc-Si and EFG-Si. The main organization participating to project and their R&D main activities on SHJ are indicated below:

- HMI: Deposition of amorphous and thin-film crystalline-silicon solar cells by PECVD and ECR-CVD; Solar cells using heterostructures such as a-Si:H / c-Si. Results: η=17.1% for a-Si:H(n)/c-Si (p) cells using FZ-cSi wafer and rear diffused BSF. UV exited photoelectron spectroscopy for a-Si:H Fermi level and a-Si:H/c-Si band offset determination. Study of excess charge carrier kinetics in the space charge region of HIT cells[24,25]. Development of AFORS-HET, a numerical computer simulation program for modelling (thin film) heterojunction solar cells [39]. Development of contactless observation of electronic transport in the a-Si:H layer[17,40].; seed-layer approach for a poly-Si thin solar cells on glass; epitaxial growth a T<600°C by ion-assisted deposition techniques, low-temperature emitter technology
- Universität Stuttgart, IPE : Preparation of complete HIT cells (pi/n/in+, ni/p/ip+) focus on back contacts, electrical characterization. Analysis of recombination mechanisms, band diagram for p-asi/n-csi and n-asi/p-csi.. Highest confirmed Voc values on p-c-Si [22]. Flexible solar cells, transfer of monocrystalline-silicon thin films (thickness 10-50 μm) to arbitrary substrates; direct deposition of a-Si:H on polymers at 70^{o}C; transfer cells η=16.6% (45 μm thick on glass), flexible a-Si:H cells on plastics η=5%.aSi/cSi heterojunction cells.
- FhI-ISE, Gelsenkirchen: HIT cells on p-type mono- and multicrystalline silicon in an in line PECVD system, with excellent surface passivation properties (S<10cm/s) η=13.5% on 100cm^2 on CZ-silicon, η=12.0% on 100cm2 mc-silicon [37]. c-Si thin-film solar cells (high-temperature approach) on low-cost silicon and ceramics by Si-APCVD (using SiHCl3 at ~1200°C), zone melting recrystallisation (Si thickness ~45μm) η=19.2% , direct epi (37μm) on p+-Cz: 17.6%,: Activity foreseen for the future: Transfer of results on reference cells to "realistic" substrates, scaling of the substrates / cells to 10x10cm^2. Bringing c-Si thin-film to a pilot production can begin by establishing a low temperature BSF Efficiency >15% on 100cm^2 (CZ-silicon).
- Forschungszentrum-Jülich, IPV: light trapping using (textured) ZnO, low temperature defect passivation for HIT structure on multicrystalline Si wafers, 11% on 10×10cm^2 multicrystalline Si wafer in collaboration with RWTH Aachen and FhG-ISE Gelsenkirchen.[36,37]. Activities foreseen: highly conductive ZnO on large area applicable to SHJ, role of hydrogen in multicrystalline Si wafers, simulation of light trapping in 3D
- Universität Oldenburg,IP-: Exploitation of quantitative photoluminescence to determine quasi-Fermi level splitting in c-Si absorber layers, interface defect density and diffusion length and predict open-circuit voltage for subsequently processed cells through photoluminescence measurements (on devices). Development of versatile numerical simulation tool for stationary and time-dependent experiments [47].
- RWTH Aachen: Screen printed: 11.3% on Cz-Si and 11,1% on mc-Si evaporated 8μm Ag-contact: Screen printing on larger substrates EFG on multi-c-Si 10*10 cm2 η= 13.5 %, ; η= 12.5 % on EFG [37]
- Fern Universität- Hagen: Si/c-Si Heterojunction Solar Cell on Low Cost Si Substrates Investigation in a-Si:H(n)/c-Si(p) Heterojunction Solar Cell (η= 17,0 %, in collaboration with HMI,D) Comparison of multicrystalline silicon surfaces after wet chemical etching and hydrogen plasma treatment. application. Stability of a-Si:H/c-Si heterojunctions under high energy particle irradiation in collaboration with Salerno University ,I.

Outside the German SHJ national project the Bavarian Center for Applied Energy Research, developed a low temperature formation of contacts to a-Si:H passivated Si wafers and passivation of boron-doped, low-resistivity crystalline silicon wafers.[48]. A recombination as lower then 48 cm/s was obtained

Italy :

- CNR-Inst. Metodologie Inorganiche e dei Plasmi : Fundamental studies on the interaction of hydrogen and fluorine atoms with c-Si for cleaning and passivation. Interface characterization. Study of the growth mechanism of ultra-thin silicon and its alloys, nucleation, kinetics and morphology. Deposition of amorphous and microcrystalline emitter layers from SiF_4H_2 plasmas. Growth of fully microcrystalline thin layers. Modelling of TCO layers and their modifications upon device processing and optical/structural modifications of interfaces in c-Si/a-Si:H/TCO stacked structures by ellipsometry[29,30]. Optimisation of c-Si/μc-Si heterojunction solar cells (η=15%). Fully μc-Si thin films with very low H-content even at low temperatures; growth of μc-Si on plastic substrates.
- CNR-Inst. per la Microelettronica ed i Microsistemi: p/n HIT with nanocrystalline emitter using VHF PECVD Texturing using TMAH, Study on interface passivation and application of p-type nanocrystalline and/or epitaxial silicon shallow emitter. TEM determination of the epitaxial or amorphous structure of the intrinsic buffer layer. Optical determination set-up of very thin thickness by using effective medium approximation Efficiency on n-type CZ (η>14%). Starting activity on textured c-Si.[33,34].
- ENEA CR Portici: development of processes suitable for industrial applications (screen printing, TCO) [31] Leaning and passivation procedures on wet/dry conditioning for (p)c-S in SHJ technology [32] (η=16.2 % on texturized p-type CZ 1.26 cm^2, η=17,1% by using a specific interfacial treatment on the emitter in collaboration with Univ.Rome [27]), Studies about the thermal modification of stacked ITO/aSi/cSi structures [30] and plasma treatment of n+:Si-H/p c-Si interface in collaboration with CNR-IMIP[29]. Development of diagnostic tools for the morphology characterization of thin layer of a-Si on c-Si [19]. Deposition of emitters using a wide range of technological options (Si, SiN, SiC, SiGe, Hot-Wire CVD and VHF-PECVD). Seed layer by standard LPCVD-epitaxial growth of thick polysilicon films, Solid-Phase Crystallisation (SPC), and Laser-Induced Crystallisation (LIC). Optical and electrical modelling on the device and CVfT characterization in collaboration with Univ. Rome La Sapienza [25]. Effect of high energy nuclear particles on SHJ in collaboration with Salerno Univ,I

Application, in collaboration with CR ENEA Casaccia, of Laser doping, screen printed contacts.

- Univ. Rome: Development of optical and electrical modelling of SHJ [28] through finite elements modelling (DIFFIN) and by using CVfT measurements for the characterization of the electrical and optical properties of the emitter including optical gap, activation energy, band offset, band bending, gap state density; interface state density. Achievement, in collaboration with ENEA, of one of highest conversion efficiency (η=17,1%) on p-type CZ cSi, by using a specific interfacial treatment of the emitter [27])

Netherlands:

- ECN-Energieonderzoek Centrum Nederland: development of methods to grow silicon films by plasma sprayed silicon on ceramics. Advanced surface and bulk passivation and silicon nitride anti-reflection. Development of special ceramic substrates for film silicon applications and "adapted" solar cell concepts. Possible co-operation with HIT research groups
- Univ. Utrecht - Debye Institute: development of SHJ physic and transport knowledge properties and application of Hot-wire CVD for the interface passivation and emitter growth and role of intrinsic layer 20,21]. HIT emitter in collaboration with Ljubljana University to realize solar cells up to >16% on low quality <220 µm multi-Si p-type wafers [38]

Spain:

- CIEMAT DER: applications of deposited silicon (amorphous, microcrystalline and hybrid silicon). PECVD of amorphous silicon at high growth rates. Wide-bandgap, highly conductive emitters [42]. Development of tools for the accurate optical analysis of silicon thin films. Modelling of interface recombination in heterojunction cells [43]. Study and modelling of parasitic diodes in silicon heterojunction devices. Dry etching and passivation of c-Si surfaces. Application of microcrystalline- and hybrid-silicon emitters to silicon heterojunction solar cells
- Univ. Barcelona and Universitat Politecnica de Catalunya (UPC): a-SiCx thin-film (PECVD) and HWCVD Si for surface passivation [44,45]. HWCVD microcrystalline p-type emitters at low temperature (<200ºC). Development of HIT structures with HWCVD-deposited emitters (Voc=577 mV, Jsc=24.2 mA/cm2, FF=0.65, η~9%)

Slovenia:

- Univ. Ljubljana. Optical and optoelectrical numerical simulation and characterisation. Growth of a-Si and µc-Si for emitter and/or (local) back surface field layers; fixed charge dielectrics for LBSF. Collaboration with Utrecht Univ. (see foregoing paragraph) on p a-Si, p µc-Si Solar cell on mc wafer with/without BSF: Cell size 1cm^2 on 10×10cm^2 mc-Si wafer η_{eff}: 14.01 % ; average efficiency 12.4 %. Foreseen activities: upscaling to 5"×5" cells mc wafer with 16% efficiency.

Switzerland:

- IMT: Pioneering work on SHJ developed in early '90 for the development of BAP-Both side Amorphous passivated solar cell under USA patent [16] Voc as higher then 635 mV was obtained on p-type cSi. [15]. Renewed interest manifested by IMT to start again activities on SHJ

4 EU-FUNDED PROJECTS

The main projects involving hybrid technologies in the 5th EU Framework Programme (1998-2002) are:

- MOPHET (ENK5-CT2001-00552) PV-Module Processing Based on Silicon Heterostructures. Partners: (c) Eurosolare, Scanwafer, RWE Solar, ENEA. CIEMAT and UNSW (Dec. 2001 / Nov. 2004 (~2.6 M€) The project deals with the development of a new process for the automatic assembling of photovoltaic modules. The expectations are to achieve heterostructure cells with η>15% average efficiency with printed process and η=17% in pilot line with buried contact process [35]. A sequence of conductive and insulating pastes is applied in order to create the electrical interconnections amongst the cells as well as string interconnections. Pastes, inks, and adhesion media, deposited on the substrate on the whole module area, complete the process. This process guarantees the possibility to work with large solar cells and lower temperatures and reduced stress for the cells as compared to standard soldering. These cell structures also give the chance to replace the traditional p-type with n-type silicon substrates in order to eliminate degradation effects due to B-O pairs, recognised to be responsible for the initial degradation of commercial PV modules. Results up to date include the realisation of lab scale high efficiency cells, the realisation of mini-modules using heterostructure cells and the all-screen printed approach, and the realisation of small quantities of high quality n-type multicrystalline and EFG silicon substrates
- ADVOCATE (ENK6-CT2001-00562) Advanced dry Process for low-cost, thin Multicrystalline-Silicon Solar-cell Technology (Dec. 2001/ Dec. 2004 (~ 2.7 M€). partner: (c) IMEC, Photowatt, Utrecht Univ, MFA, FAP, Secon, Univ.Ljubljana, CL SENES. The project focuses on the cost reduction of c-Si solar cells by using screen printing and plasma to remove all wet chemical and water rinsing processing on back and front side such as saw damage removal, phosphorous silicate or emitter etch, isotropic dry plasma texturing process applicable to all type of silicon substrates, plasma immersion diffusion suitable for solar cell emitter formation by using environmentally friendly multi-Si cell fabrication processes on all types of low-cost crystalline-silicon substrates (standard multi-Si, EMC multi-Si, silicon ribbons). Industrial type 'dry' cells on multi-Si substrates with efficiencies >16% on large (4 to 5") multicriystalline silicon wafers of less than 200µm thickness.

Several projects concern the development of thin silicon devices where the use of SHJ is considered of specific interest:

- METEOR (ERK5-CT2001-00543) Metal-Induced Crystallisation and Epitaxial Deposition of thin Efficient and low-cost crystalline Solar cells. (Jan. 2002 / Dec. 2004; 2.5 M€). Partners: (c) HMI, Katholieke Univ. Leuven, Vienna Univ. of Tech., British Photovoltaics Ltd and IMEC The project proposed a novel two-step process: preparation of large-grained Si-seed layers on glass (HMI) and ceramics (IMEC) by metal-induced crystallisation (MIC) on which subsequently Si is epitaxially grown by ECR-CVD (low temperature path) and CVD (high-temperature path). Targeting at an efficiency of 12% and it is planned to present a mini-module with η=10% by the end of the project with a cost potential below 1 €/Wp.

• SUBARO (ERK6-CT1999-00014) Substrate- and Barrier-layer Optimisation for CVD-grown thin-film crystalline Si Solar cells (Apr. 2000 / Mar. 2004; ~4.0 M€). Partners (c) IMEC, Bayer AG; FhI-ISE, TU-Delft; RWE-Schott Solar AG; ECN; ENEA; CNRS, N.C. Starck GmbH; Shell Solar Energy B.U; Everest Coating. The project deals with the numerous possible options for thin-film crystalline-silicon solar cells (for substrate and barrier layer), the selection of a suitable low-cost substrate, compatible with Si-deposition by means of thermally-assisted CVD (and possibly a liquid-phase recrystallisation and the development of suitable barrier layers to prevent impurity diffusion from the low-cost substrate into the active layer and to optimise internal reflection. A 12% efficient large area solar module (>900 cm^2) obtained by a two-side contacting technology is expected.

Other EC projects can be noted related to possible applications of SHJ. are:

• SPURT (ENK6-CT-2001-30006) Silicon Purification Technology For Solar Cells at Low Costs and Medium Scale; (Jan. 2002 / Dic. 2003; 2.0 M€).

• SOLSILC (ERK6-CT-1999-00005) a direct route to produce solar grade silicon at low cost; (March 2000 / Feb. 2003; 2.2 M€).

• RGSELLS (ENK6-CT2001-00574)- Cost Effective, High Throughput Ribbon-Growth-On-Substrate Solar Cell Technology: (Jan. 2002 / Dec. 2003; 2.3 M€).

• FANTASI (ENK6-CT2001-00561) Fast and Novel Manufacturing Technologies for Thin Multicrystalline silicon Solar cells; (Jan. 2002 / Dec. 2004; 3.7 M€).

• FAST (ERK6-CT2001-00529) Fast low thermal budget area system for high throughput solar cell production; (Dec. 2001 / Dec. 2004; 3.0 M€).

Further details on other project under 6^{th} EC Framework programme can be found in web site: http://www.cordis.lu

5 CONCLUSIONS

Europe has a leading position in the production of crystalline ingots and wafers for PV applications. The efforts towards thin silicon are generating new approaches involving the combination of wafer and thin-film technologies. The characteristics of new materials impose new limitations, thus requiring innovative solutions. A number of research groups are working on SHJ cells in Europe with excellent scientific level and promising and interesting individual results but needs to address the fragmentation of European R&D must however be recognised by creating a permanent structure ensuring the harmonisation of the whole R&D on SHJ cells. An Expression of Interest was presented in 6^{th} EC Framework programme (EUROHIT). The initiative has the added value that it proposes to co-ordinate the efforts of the top European groups working on the field in order to obtain the fastest and most efficient development of SHJ technology in Europe through a solid and permanent structure aimed to coordinate the European research and development on silicon-heterojunction cells in Europe, by defining strategies on technologies based on silicon wafer, ribbon and thin-film technologies. These objectives should be pursued by means of the achievement of a number of Integration Objectives:

- creation of a co-ordination board of silicon-heterojunction photovoltaics and generation of a Consortium Agreement in which all intellectual-property-right issues are regulated,
- elaboration of a catalogue of resources aimed at making available to any member the use in common of selected facilities and results as agreed.
- Generation of specific Targeted-Research Project proposals within the field
- Analysis of the market to propose policies for the penetration of silicon-heterojunction photovoltaics in the electricity sector

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