Materials for Next-Generation Photovoltaics – 2014–2021

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NanoMarkets, LC
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TABLE OF CONTENTS

OBJECTIVES AND SCOPE OF THIS REPORT

The main objective of this report is to provide a comprehensive overview of the next-generation solar photovoltaics (PV) market, assessing the future potential and providing detailed eight-year forecasts for the photovoltaics business. In this report we analyze the market under different segments (in terms of technology and potential applications) with separate revenue and volume estimations.

In compiling our forecasts, we examine the product development and marketing strategies of the leading influential players, both large and small, in the emerging solar PV field.

We also take into consideration announcements by current and prospective players regarding pricing, new product introduction, capacity expansion, technology evolution, and production timetables. These announcements are reviewed critically—because in some cases the expectations and projections seem highly unrealistic to us.

Photovoltaic technologies covered in this report include:

- Novel crystalline silicon photovoltaics
- Organic photovoltaics
- Dye-sensitized solar cells
- Perovskite-based photovoltaics
- Quantum dot-based photovoltaics
- Silver nanowire based photovoltaics
- Carbon nanotube-based photovoltaics
- Graphene-based photovoltaics

METHODOLOGY AND INFORMATION SOURCES

This report is the latest from NanoMarkets that looks closely at the trends in solar photovoltaics.

The forecasting approach is to identify and quantify the photovoltaic markets for next-generation photovoltaics over the next eight years, and then assess and quantify their potential to actually penetrate these markets via substitution for conventional silicon-based photovoltaics. This is a key factor, because next-gen photovoltaics represent a completely new form of solar energy harvesting.

As part of the analysis, we assess the likely level of competition from other technologies in the different addressable markets. We also consider how technical developments can accelerate, slow, and in some cases halt the ability of different photovoltaic technologies to gain widespread commercialization.

To determine where the opportunities lie, we have based this report both on primary and secondary research:

- Primary information is gathered through analysis of relevant applications and market trends based on discussions with key players in the photovoltaics segment, including entrepreneurs, business development and marketing managers, and technologists.

- Secondary research is based on technical literature, company websites, trade journals and press articles, trade shows, and conferences. This also includes the complete library of our own reports in this field, which is now quite extensive. Where data is based on another report, it has been reinvestigated, reanalyzed, and reconsidered in the light of current information, and updated accordingly.

This report is international in scope. The forecasts here are worldwide and we have not been geographically selective in the firms covered or interviewed.

PLAN OF THIS REPORT

In Chapter Two, we review the potential of emerging photovoltaics in terms of feasibility of the technology, timeline to transfer from research labs to volume production lines, and the ability to attain economies of scale. We look at how the performance specifications and standards are evolving for crystalline silicon technology while keeping track of how emerging thin-film and dye-sensitized solar cell (DSC) technologies are able to improve commercial production potential. Special emphasis has been put on the need for cost-effective manufacturing techniques that can eventually reduce retail prices.

In Chapter Three, we review the market opportunities for next-gen thin-film photovoltaics by assessing the potential of improved and novel materials. We look at how different technologies can enable the conventional thin-film market to ride over the cost pressures imposed by the standard silicon photovoltaics.

In Chapter Four, we analyze the pros and cons of organic and dye-sensitized solar cell (OPV and DSC) technologies, and how new materials and process optimization can play a significant role in improving their market acceptance.

Finally, in Chapter Five we review the markets that can be catered by nanomaterial based photovoltaic technologies. We take a deeper look at the evolving requirements of the solar industry and how these nanomaterial-based technologies can play a crucial role in bridging the technology gaps that are left open by the currently available photovoltaic technologies.

At every stage, we have emphasized the commercialization efforts behind each technology, to provide a fair assessment of the business potential of the specific technology along with the practical applications.

At the same time, we provide the core forecasts for emerging photovoltaics on an application-by-application basis. We describe assumptions about pricing, market trends, and other factors that may influence the forecasts. The forecasts are broken out by the type of applications and the type of photovoltaic technology powering those applications.

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REPORT TABLE OF CONTENTS

REPORT TABLE OF CONTENTS

REPORT TABLE OF CONTENTS

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REPORT TABLE OF CONTENTS

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REPORT TABLE OF CONTENTS

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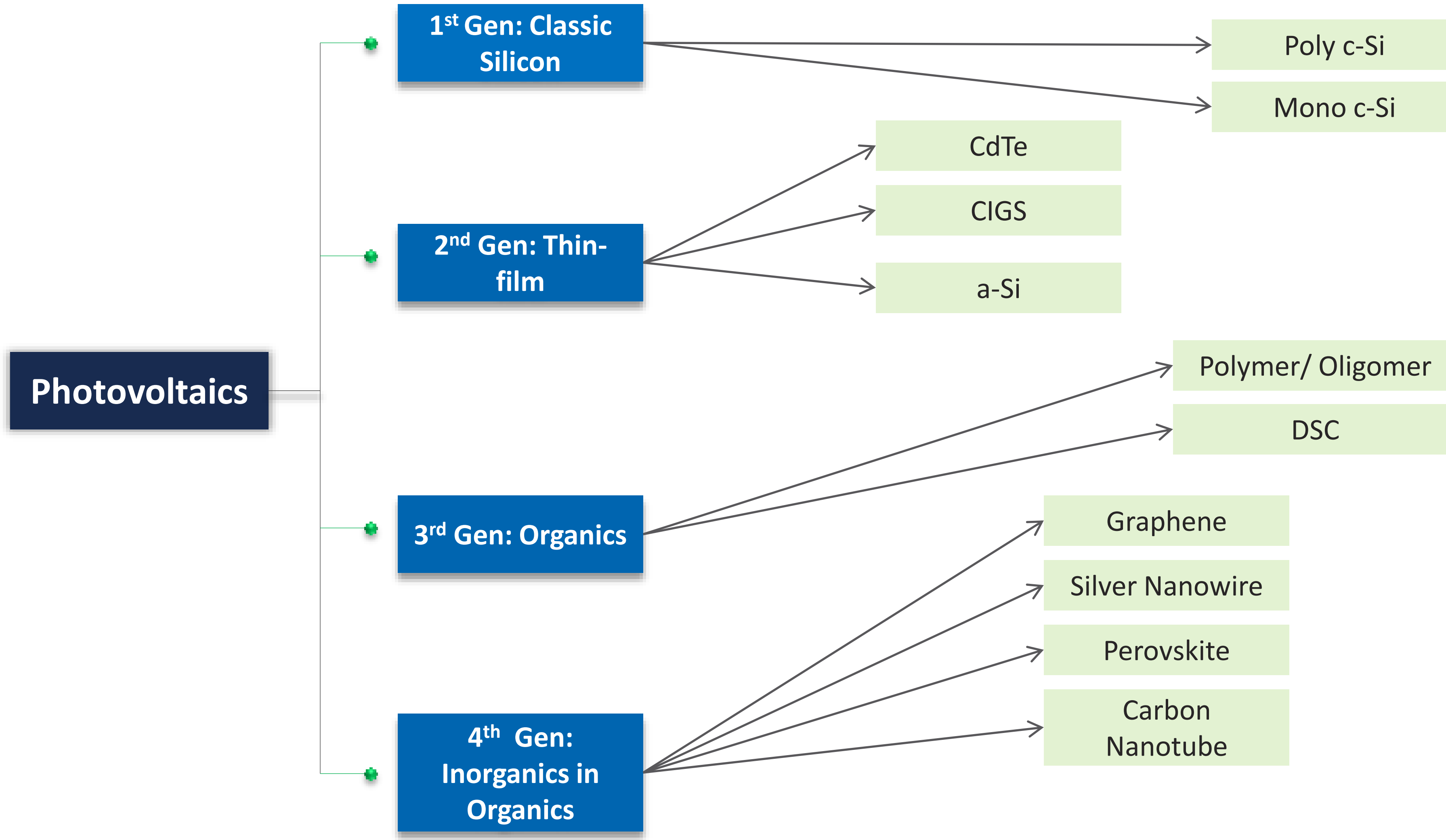
RELATED REPORTS

- CIGS Photovoltaics Markets-2014 and Beyond
- BIPV Glass Markets-2014 & Beyond
- BIPV Markets Analysis and Forecasts 2014-2021
- Dye Sensitized Cell Markets - 2014-2021

Chapter One: Introduction

CLASSIFICATION OF PV TECHNOLOGIES



While of late various existing PV technologies have been affected by the build-up of overcapacity, the fates of the emerging ones are to be determined by investment attractiveness, value addition, and cost-effectiveness.

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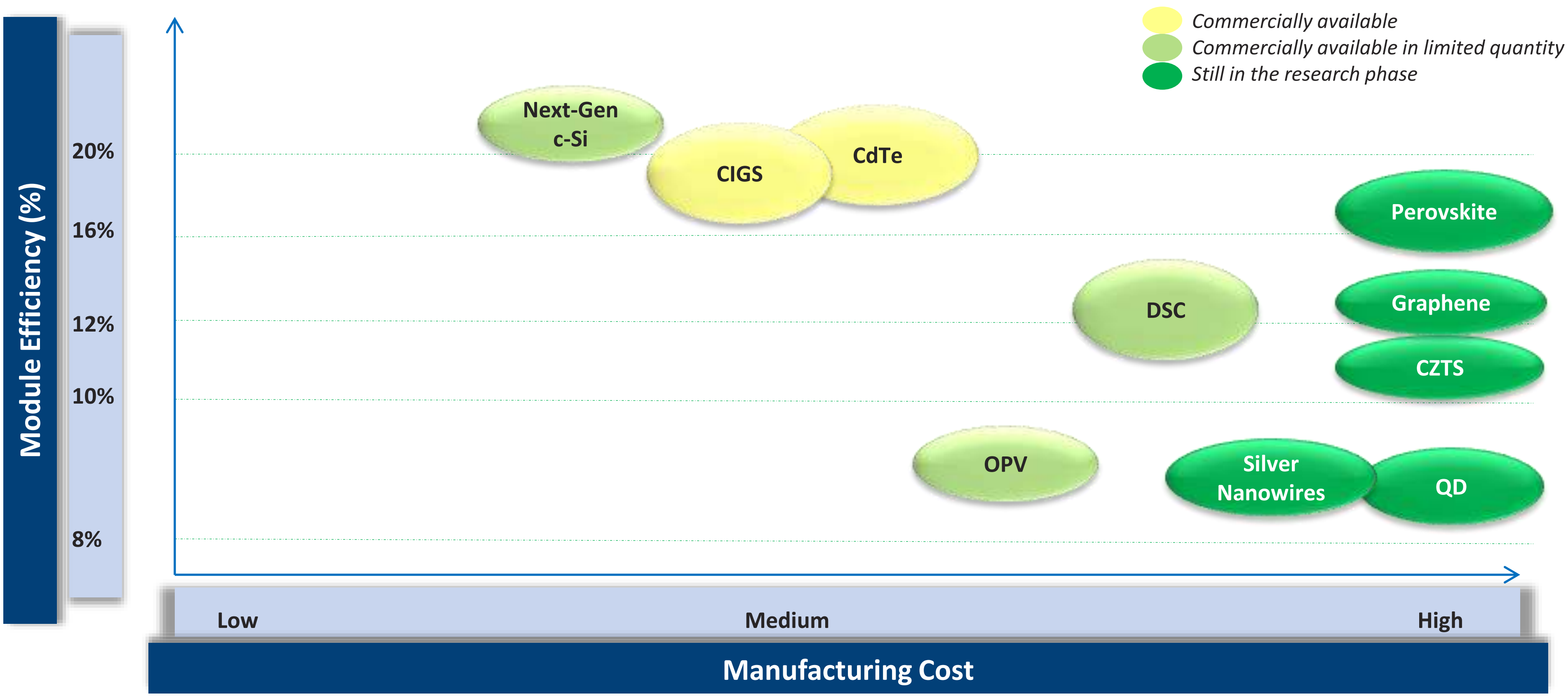
EFFICIENCY AND COST COMPARISON OF NEXT-GENERATION PV TECHNOLOGIES



The standard thin-film PV players have found it hard to compete with Chinese makers of conventional c-Si solar panels who have steadily cut costs. This competitive pricing pressure from c-Si players, along with efficiency improvement records such as those set by Japan based Panasonic and Sharp, have been pushing thin-film PV manufacturers to deliver value-added PV solutions at even more competitive prices.

While DSC regained investor confidence in building up volume production capacities, the scientific community has been upbeat about the pace of efficiency improvement with perovskite-based PV cells at the lab scale.

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EVOLUTION OF THE STANDARD c-Si PV TECHNOLOGY

The need for better c-Si technology has urged a more aggressive roadmap based on advanced c-Si technologies. The prominent ones include n-type cells, selective emitter options, wrap-through variants, and cells with rear side passivation technique that have started gaining traction. Within a span of three years (2010 to 2013), these technologies have almost doubled (~10%) their market share, indicating a shift in the roadmap for the next generation of c-Si technology.

However, 2014 is unlikely to be the year of change as the industry is expected to implement upgrades in their existing facilities. Further, there has been no revolutionary change in PV technology to enable large scale commercialization. As a result, large volume production is more likely in 2015, when investments are expected to pick up.

The Need to Improve Standard c-Si Techniques	Adopted Pathways to Improve Standard c-Si Technology	
	Material Related	**Manufacturing Process Related**
Relatively weak optical properties of standard c-Si technology (requiring thicker and expensive substrates), and difficulty in processing thin solar cells, have prompted the need for advanced c-Si approaches.	• Use of smaller size diamond saw wiring approach for wafering • Reduction in the consumption of Ag/Al metallization pastes • Optimization of anti-reflective coatings to improve transmission of the front cover glass of solar modules • Development of new encapsulants with shorter processing time and novel interconnection technology can enable higher throughput for module manufacturing equipment while occupying lesser floor space.	• A conscious shift to higher-generation furnaces (from the current industry standard of G6 furnaces) for casted Si materials can lead to higher throughput. • For Cz technology, reusable crucibles and a conscious shift to n-type crystalline Si technology can improve productivity. New crucible materials can be an added advantage. • Reduction in solar cell recombination losses on the front and rear side of c-Si bulk material can ensure high cell-level efficiency.

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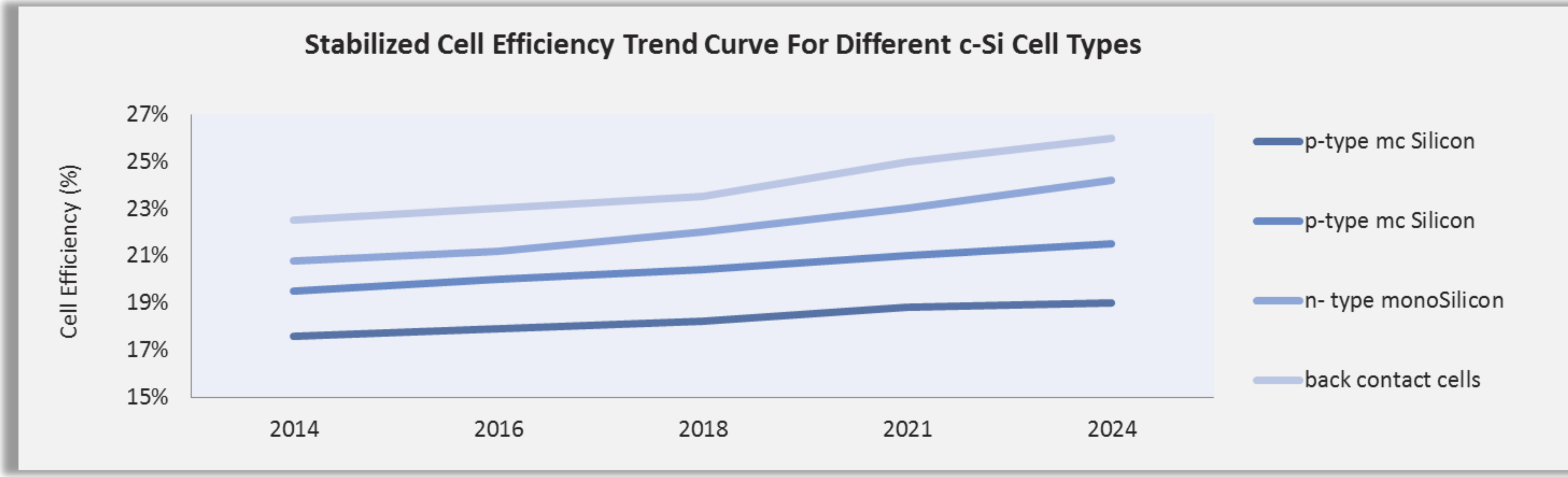
EVOLUTION OF THE STANDARD c-Si PV TECHNOLOGY

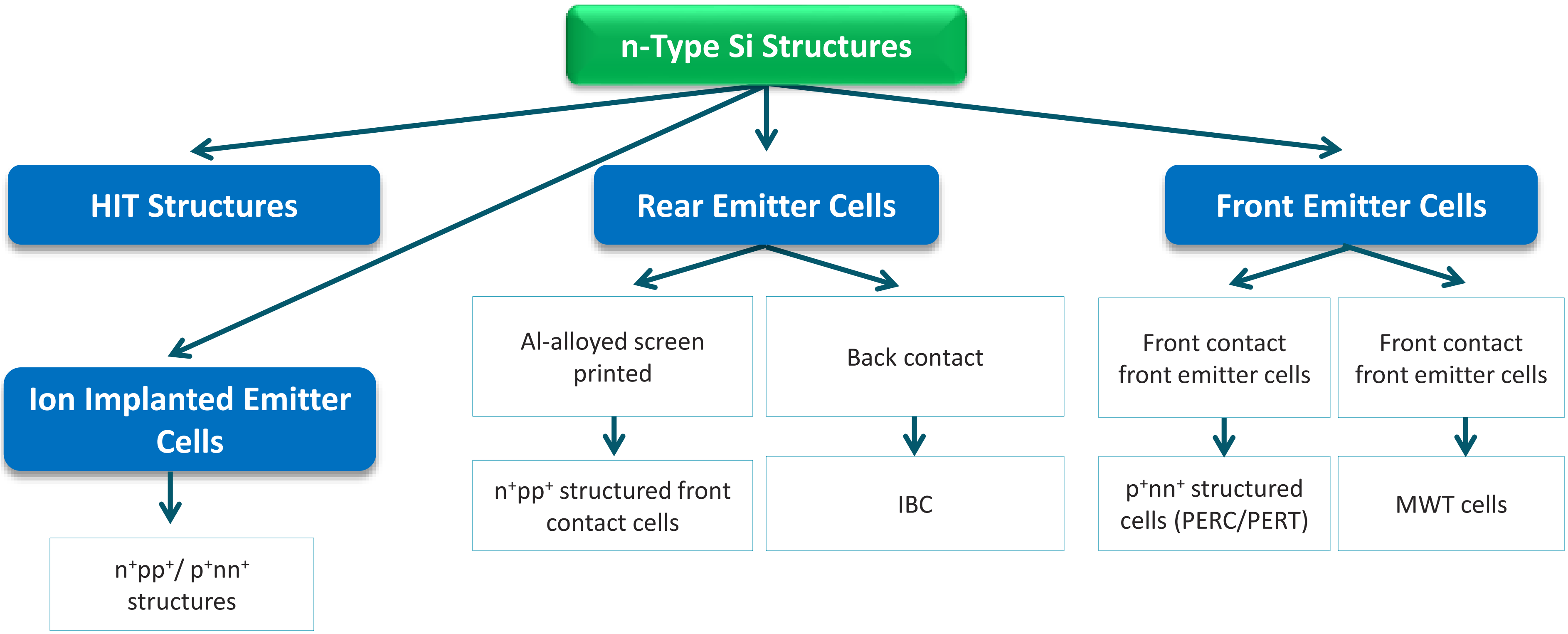
c-Si PV Technology Efficiency Future Roadmap



In state-of-the-art mass production facilities, there is potential to improve the average efficiencies of PV cells based on different wafer materials. Among all the potential candidates, back-contact cells predominantly based on n-type wafers have the biggest potential to achieve higher efficiency levels within the next decade. In another 10 years, an improvement in cell efficiency of around 3%-4% can be expected from n-type cells.

GROWING PREFERENCE FOR n-TYPE Si PV TECHNOLOGY

The ability of n-type Si to offer better tolerance to common impurities, higher device lifetime, and lesser light-induced degradation has prompted suppliers of standard p-type c-Si PV to consider n-type Si wafers. However, further research is desired to eliminate non-uniform electrical resistivity and to come up with more effective passivation techniques for charting out a sizable, and cost-effective, production route for n-type Si cells.



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GROWING PREFERENCE FOR n-TYPE Si PV TECHNOLOGY

Key Players Actively Pursuing Advanced n-type Si Technologies

Among the established players who could introduce new variants of n-type Si PV technology are Yingli (China), SunPower (U.S.), and Panasonic (Japan)—all of which currently offer n-type Si cells and are actively involved in improving the performance of n-type Si cells. To date, Panasonic and SunPower have offered highest efficiencies with n-type cells at the industrial level, but process complexity and a substantial number of processing steps have restricted their wide-scale commercial production. This mandates the development of industrial compatible techniques and new ways (such as emitter formation technique) to enhance energy conversion efficiency.

n-type MWT Solutions

The Energy Research Centre of the Netherlands (ECN) has been instrumental in developing a n-type front and rear contact Pasha technology, which is used in Yingli's Panda brand of cells. ECN's n-type MWT (n-MWT) technology has experimentally demonstrated a power gain of up to 5% at the module level over the n-Pasha approach. To date, n-MWT technology has resulted in 20.2% cell efficiency on ECN's pilot production line utilizing high-quality n-Cz material.

n-type Bifacial Solutions

Yingli and LG (South Korea) are already producing n-type bifacial PV cells under the brands of Panda and Neon respectively. Others like Suniva (U.S.) and Fraunhofer (Germany) have active research programs to device advanced cell processing techniques from n-type substrates.

RECENT DEVELOPMENTS IN THE NEXT-GEN c-Si SEGMENT

The standard and matured p-type c-Si technology is expected to pave the way for the adoption of the more efficient n-type Si technology. Although suppliers in Taiwan, the U.S., and Europe have shown signs of adopting higher efficiency c-Si technology, greater adoption in Japan and bigger involvement of Chinese players will be significant to facilitate the migration of standard c-Si technologies to the advanced forms.

Noteworthy Research/Manufacturing Trends

JA Solar (China) is the first company to use black silicon technology (RIECIUM module) with which a cell efficiency of 18.3% has been achieved, representing a noticeable improvement over the standard mono-crystalline silicon modules. Meanwhile, the company's p-type mono-crystalline silicon solar cells (PERCIUM) surpassed 20% conversion efficiency. Mass production of both these modules is expected to commence in 2014.

Crystal Solar's (US) technology allows for solar cells and modules to be manufactured at total PV module costs approaching $0.50/Wp, in alignment with the target set by the US Department of Energy's (DOE) Sunshot Program. With this technology, Si thickness down to the level of 50 um can be achieved compared to currently used (180-200 um) Si layers.

Steel wires, which are used to slice large ingots into wafers, will be increasingly replaced by more cost-effective diamond-tipped wires. Meyer Burger (Switzerland) currently offers its diamond wire-saw system specifically designed for monocrystalline Si PV cells. The company is also expected to start manufacturing its smart wire interconnection technology in Poland this year in partnership with Polish companies Freevolt and Hanplast.

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RECENT DEVELOPMENTS IN THE NEXT-GEN c-Si SEGMENT

Encouraging Developments in the n-type Si Space

Research Centre IMEC's (Belgium) departure from the conventional PERC (Passivated emitter rear cell) architecture to adopt PERT (passivated emitter, rear totally diffused) approach using n-type mono wafers resulted in 21.5% efficient cells in July 2014.

SolarCity's (U.S.) plans to build a 1-GW solar PV module factory based on recently-aquired Silevo's technology (June 2014) will give a substantial push to n-type monocrystalline Si wafers.

CdTe supplier First Solar (U.S.) acquired TetraSun, giving it a potential foray into the Si PV domain and compete with the likes of Panasonic and SunPower while also migrating from utility-scale segment to more lucrative distributed generation.

GT Advanced Technologies (U.S.) has agreed to supply HiCz ingot pullers to Qatar Solar Energy (June 2014) for the production of n-type wafers.

A recent start-up, MegaCell Srl (Italy) plans to start production of its BiSon brand of n-type monocrystalline Si (in bifacial architecture) by the end 2014. By 2015, the company claims it will reach annual production capacity of 80 MW.

The selective emitter (SE) approach is seen as a reliable and cost-effective route to improve the performance of n-type Si cells. Already several SE development routes are being investigated that can further improve power generation capacity of advanced Si cells while keeping recombination losses and contact resistance at the minimal level. In this regard, ion implantation by Intevac (U.S.), inline selective emitter technique by Schmid (Germany), and Si ink doping by DuPont (U.S.) are promising approaches.

FATE OF THIN-FILM TECHNOLOGY

Favorable Features of Thin-film Photovoltaics

The costs of BOS components (such as mounting hardware, wiring, and inverters) in the thin-film approach are lower than other PV devices due to lightweight form factor. Typically, thin-film solar cells utilize only around 1-4 µm thick layer of semiconducting material to produce electricity, thus requiring less processing and fewer materials.

Status of Thin-film Si Technology

Despite several advantages of a matured PV technology, thin-film Si has been losing out to crystalline and other non-Si emerging thin-film technologies because of low efficiency. In order to achieve efficiencies beyond 15% at the cell level, it is important to effectively utilize the maximum portion of the available solar spectrum. In this context, multi-junction PV cells hold promise as a high-efficiency thin-film Si candidate.

Meanwhile, thin-film Si solution providers could benefit by addressing newer markets where outdoor PV installations dominate. The absence of any toxic additives and its compatibility with semi-transparent glass and other building-integrated PV (BIPV) applications provide an opportunity to move beyond low-end applications in electronic products.

Ambitious Roadmaps of Emerging Non-Si Thin-film PV Technologies

In certain conditions (such as low light and hot environments) thin-film PV modules can have a lower levelized cost of energy (LCOE, i.e. the cost to produce 1 KW of solar power) compared to c-Si modules. Because of this advantage, as the solar industry shifts toward remote and unsubsidized markets, emerging thin-film technologies have a chance to significantly increase their acceptance rates.

Going by the ambitious roadmaps set by thin-film leaders including First Solar and Solar Frontier (Japan), 2015 could witness active commercial developments. As the cost difference between the standard C-Si and existing thin-film technologies narrows, focus will shift to comparison of efficiencies between thin-film and advanced c-Si technologies.

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FATE OF THIN-FILM TECHNOLOGY

CdTe – Currently Leading the Thin-film Race; Might Lose Out to CIGS

CdTe PV cells currently pose a strong challenge to multi-Si cells in terms of efficiency. This market is currently dominated by First Solar which has achieved a record efficiency with 21.0% for cells (August 2014) and 17% for modules. CdTe is expected to find acceptance in constrained spaces and other related industrial applications, given First Solar's aggressive technology roadmap over the next 3-5 years.

OPV – Struggling Despite a Good Potential

Organic PV (OPV) manufacturers have found it difficult to come up with optimal material sets and chemical synthesis processes that could result in efficiencies above 10% at the commercial level. Although Heliatek's (Germany) February 2013 attempt yielded a 12% efficient OPV cell that featured a unique high-temperature and low-light operating profile, commercialization of such OPV cells has not materialized. The roll-to-roll production technique, as envisaged by Heliatek, is yet to take shape. Thus, OPV developers have an uphill task of bringing the technology on par with c-Si and thin-film technologies, in terms of both efficiency and cost-effectiveness.

Perovskite – A Promising Candidate

Although only about five years old, perovskite PV cells' efficiency has skyrocketed from 3.8% in 2009 to 19.3% (as reported in May 2014). Researchers are attempting to develop cost-effective perovskite devices compatible with existing PV manufacturing processes. Further, as Si and perovskite absorb different portions of the electromagnetic spectrum, efforts are underway to use these two materials together in so-called tandem cells.

CZTS – Not Yet There

Copper zinc tin sulfide (CZTS) cells are a variant of CIGS PV cells with a different absorber material. They have caught attention amidst a possible future high pricing scenario with the In and Ga absorbers used in CIGS cells. However, R&D efforts must improve efficiency levels and chart out a commercial production route. Among the recent developments in this space (December 2013), Solar Frontier achieved 12.6% efficiency in a joint research project with IBM and Tokyo Ohka Kogyo.

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DSC – Holding Near-term Commercialization Potential

With research-level cell efficiency reaching to 15% in 2013, dye sensitized solar cell (DSC) space has received a fresh lease on life from the investment community after recent rounds of financial troubles cited by the established players, including Dyesol (Australia) and G24 Power Ltd (UK). Further, the scheduled commencement of operations at the largest DSC plants (by Exeger, Sweden) by 2014 and mass production by 2016 can provide an outlook for commercial applications in the next three years.

Currently Under Research

Silver nanowires are yet to find use in commercial PV cells as efficient transparent electrodes that can boost energy conversion efficiency to realistic levels. To date, most of the research around the use of silver nanowires in PV cells has demonstrated efficiency below 10%.

Carbon nanotubes (CNT) have been demonstrated to result in PV cell energy conversion efficiency of up to 80% via an efficient charge transport mechanism inside the cell. However, CNTs are unlikely to be commercialized for PV applications anytime soon. MIT (US) has been a frontrunner in CNT research for PV applications and might play a crucial role in its commercialization in the future.

Research has shown that quantum dots (QDs) made with inexpensive low-temperature solution processing techniques can reach a theoretical energy conversion efficiency of up to 45%—although actual efficiency still lies below 10%. A simple processing technique and room for performance boost keep QDs in the race to become a promising PV candidate.

Research initiatives around the use of graphene in PV applications have been shifting from treating graphene as a substitute for ITO (in transparent electrodes) to viewing it as a potential conduction layer candidate in the next generation of PV cells.

Although graphene has remained confined to the labs till date, there is a possibility of using it in combination with titanium dioxide as a charge collector, keeping perovskite material as the sunlight absorber in PV cells. Under such an arrangement, cell efficiency of 15.6% was achieved in January 2014 by a European research team.

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RECENT DEVELOPMENTS IN NEXT-GEN THIN-FILM PV

After the decline in investment in new thin-film equipment in 2013, it is expected to pick up in 2014 and 2015 with the addition and expansion of capacities.

Stion (U.S.), a thin-film PV manufacturer, claimed to have achieved 23.2% efficiency in its thin-film CIGS cells using a proprietary tandem-junction technology.

A major development was seen recently in organic solar cells when research institute Interuniversity Microelectronics Centre (IMEC) achieved a record-breaking 8.4% efficiency (March 2014) with its new organic solar cell made without fullerenes.

Researchers at the University of California (U.S.) have made 19.3% efficient perovskite cells that are expected to match the output of silicon cells at a price claimed to be lower than that of thin-film CIGS cells. The ingredients are cheap bulk chemicals, and the cells can be built using simple, low-cost processing techniques. Perovskite has already made its debut in DSCs, though not on a large scale.

Researchers at the Hong Kong University of Science and Technology (HKUST) have developed a novel coating made of silicone with tiny nano-cones on its surface, which can directly be applied onto a silicon wafer, thus promising around 7% improvement in efficiency.

Solexel (U.S.) announced in July 2014 that it plans to commercialize 20% efficient thin-film Si PV modules in 2015. The PV monocrystalline Si cells will only be about 35 microns thick and will use much less silicon than most PV cells. Along with this ultra-thin factor, the company intends to use aluminium rather than silver as the back contact in a bid to reduce costs.

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