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NANO-PHASED MATERIALS AND THIN FILM HETEROSTRUCTURES: A PATHWAY TO HIGH-EFFICIENCY SOLAR ENERGY CONVERSION TECHNOLOGIES

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ABSTRACT
The sun fuel conversion, solar photovoltaics, bio-catalysis, and solar water splitting are all things that are covered in this road map. Perovskites, organic photovoltaics, and dye-sensitized solar cells (DSSCs) are several components of this category. The distribution and bridging of storage via the use of direct and indirect storage systems is the cornerstone of energy management for this electricity. This will exhibit energy efficiency ahead of several criteria, including mobility and light weight, high energy storage capacity, cheap manufacturing cost, low temperature performance, and quick energy transfer. Consequently, this will demonstrate energy efficiency. When an announcement is made on an increase in capacity, it is common practice to just include the installation of the equipment. Although it may seem like the manufacturing line is functioning well, this does not always mean that it is. It is possible that the installation of the manufacturing line and the actual sale of solar cells will be delayed for a period of time due to the introduction of new technologies. A semiconductor is the fundamental component of dye-sensitized solar cells. This semiconductor is produced by a photoelectrochemical system that consists of an electrolyte and a dye-sensitized anode.

Keywords: Nano-Phased Materials, Thin Film, Heterostructures, High-Efficiency, Solar Energy, Technologies

INTRODUCTION
In recent times, the rapid development of nanotechnology in the realm of energy, in addition to its potential applications in mobile and smart gadgets, has captured the attention of many who are interested in the subject. Therefore, it is of the utmost importance that this energy technology exhibits efficiency, flexibility, and durability over an extended period of time. Numerous applications that are associated with energy, such as those that are thermal, electric, kinetic, acoustic, or optical, are searching for solutions that may improve performance at the nanoscale, which is a very small size. In addition, the present study, which employs a variety of techniques for the conversion of energy, such as thermal, thermochemical, biochemical, chemical, electrochemical, mechanical, nuclear, and gravitational, has the potential to communicate the most powerful power.

The basic objective of energy management is to connect and distribute storage via the use of direct and indirect power storage solutions. When compared to a number of other factors, such as mobility, high energy storage capacity, low temperature performance, cheap manufacturing cost, and fast energy transfer, it is likely to get a higher ranking in energy efficiency assessments. This is because it is more likely to be able to transmit energy quickly. In order to achieve total equilibrium in the energy triangle, which is comprised of the production, consumption, and storage of energy, improvements should focus on the utilisation of nanoscale technology rather than macroscopic tactics.

Energy Sector Trends Related to Nanotechnology
It is necessary to have a basic understanding of the characteristics of fundamental energy carriers, which may be summarised by the length and time scales in solids, gases, and liquids, in order to have a successful understanding of nanotechnology in the energy business. This information is important in order to comprehend the aforementioned perspective. In order to enhance the performance of the energy system, it is required to provide a detailed description of the material scales involved during the time range that is most significantly influenced by the processes of energy carrier transit, conversion, and storage.

Nano and Micro Technologies to Traditional Photovoltaic Systems

It is necessary to develop photovoltaic technologies of Generation III in order to achieve new levels of efficiency while maintaining an affordable price, given the solar efficiency-cost environment shown in Figure 1. It is possible to merge existing solar technologies from Generations I and II with upcoming technologies such as nanotechnology. This is a possibility regardless of the circumstances. Considering the significant amount of material that is still accessible (about 80–85 percent in 2011), it is very improbable that silicon will be completely replaced in the near future. On the other hand, in 2011, CdTe thin films accounted for around 15–20 percent of the market.

The remaining component of the market was comprised of CIGS modules that are still in the process of being developed and amorphous silicon (a-Si) thin films that are used in certain applications. It is possible to make use of micro- and nanotechnologies for a number of reasons, the most important of which are to improve the power conversion efficiency (PCE) of the technology or to improve the processing of conventional solar modules in order to reduce costs, yield, and other production goals linked with the technology.

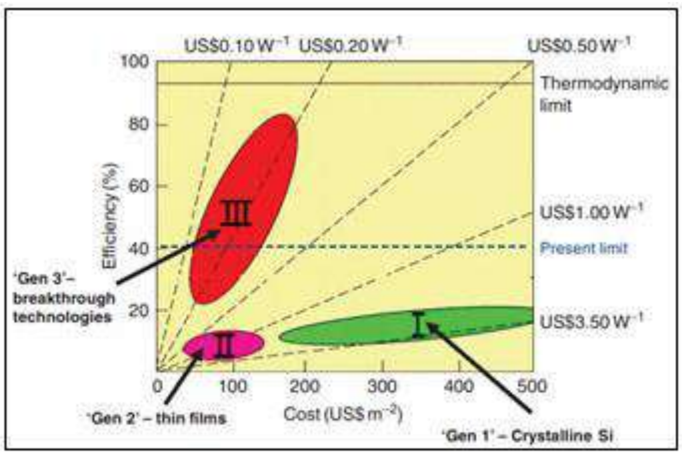

Figure 1: The solar cell landscape, as described by M. Green, demonstrates the aim to create low-cost, high-efficiency Generation III technologies in contrast to Generation II (thin films) and Generation I (silicon).

OBJECTIVES OF THE STUDY

1. To study on Trends in nanotechnology in the energy sector.
2. To study on Utilizing Micro and Nanotechnologies in Conventional Photovoltaic Systems.

RESEARCH METHOD

This chapter aims to provide an overview of the technologies mentioned. Specifically, it will list the many technologies that are being investigated and produced, providing basic descriptions instead of techno-scientific specifics, which are best left to the expertise of the relevant professionals. This chapter discusses the many research projects pertaining to thin-film solar cells and attempts to analyze the reasons why funding agencies have varying degrees of interest in this technology.

Japanese NEDO PV Program's Thin Film Activities

In Japan, the management of research on renewable energy is the responsibility of the New Energy Development body (NEDO), which is an independent government body. Under the context of the Energy and Environment Technologies Development efforts, the present photovoltaic projects are built on the basis of three primary ideas:

- Development of New Energy Technologies
- Introducing and Spreading Energy Conservation and New Energy
- Global Initiatives

Bringing down the price of photovoltaic (PV) systems and solar cells is unquestionably one of the most important aims, in addition to the anticipated expansion of the PV manufacturing industry. A document titled "PV Roadmap towards 2030" (Fig. 3) was developed by NEDO, METI, PVTEC, and JPEA. This document displays the goals that are planned to be achieved.

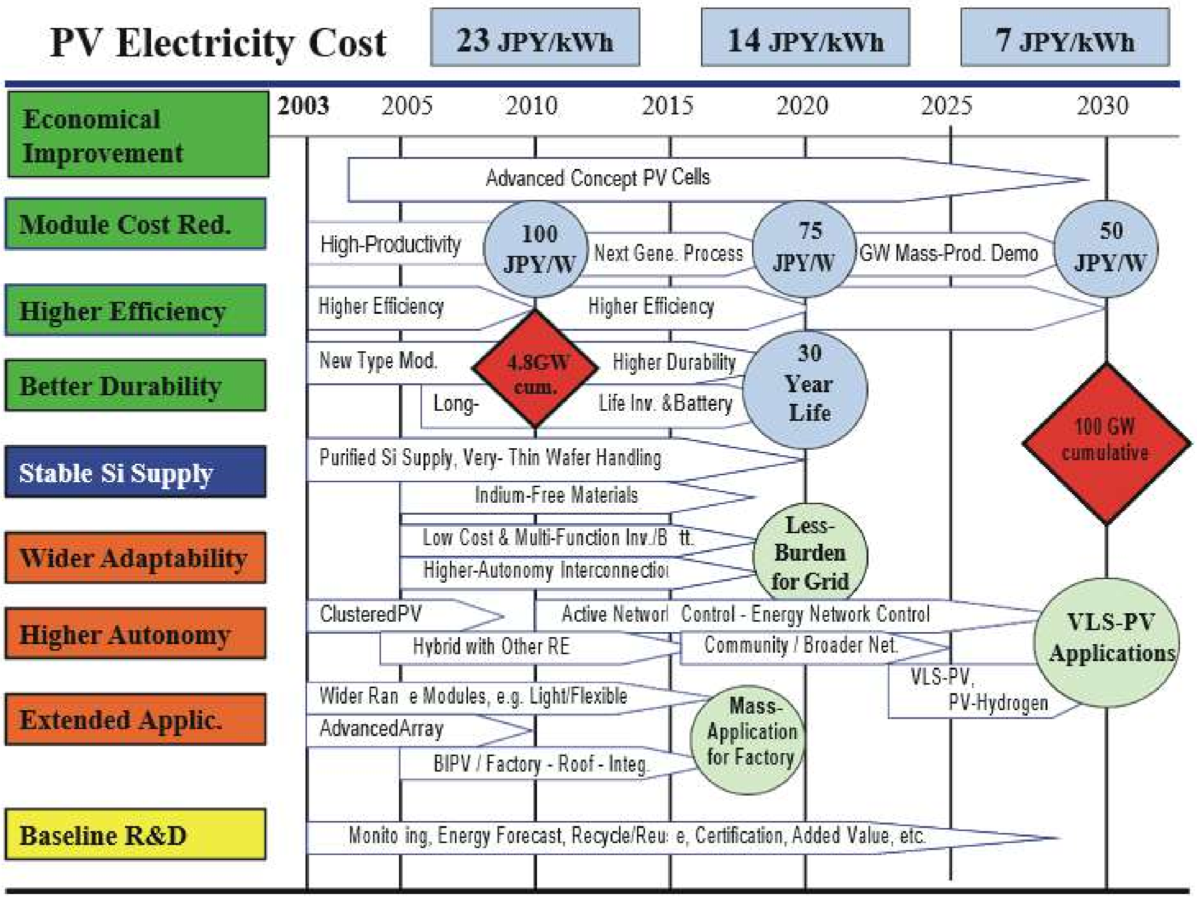

Figure 2: Japanese research and commercialization plan for solar photovoltaics

The New Energy Technology Development Programme encompasses a wide range of projects, including those that address grid-connected system difficulties, concerns that are particular to photovoltaic technology, and public solicitations. Only projects that are associated with thin film are discussed in this article.

1. Investigation and Creation of Next-Generation Photovoltaic System Technologies

It is going to be very important in the future of energy production to have solar systems that are not just efficient but also practical, economical, and simple to operate. It is required to make significant improvements in each of these components in order to stimulate the expansion and utilisation of solar power generation. As a result, efforts are being made in the medium to long term to develop new technologies that go beyond just upgrading those that are already in existence. These technological advancements are anticipated to be developed in the future.

2. Investigating and Developing Novel Solar Cells

By using novel and inventive concepts, the purpose of this study is to discover methods that will make the conversion of solar cells much more effective. Tokyo University and the Advanced Institute of Science and Technology in Tsukuba were both designated as Centres of Excellence (CoE) by the Tokyo Institute of Technology in July of 2008. This honour was bestowed upon both of these institutions.

3. Investigating and Creating Standard Core Technologies for Solar Energy Systems

For the purpose of facilitating the future implementation of photovoltaic producing systems, it is of the utmost importance to create and include fundamental technologies that are extensively used, as well as to reduce the cost of solar cells.

United States Thin Film Research

With a long history of commitment to the "Solar Energy Technologies Programme," the National Renewable Energy Laboratory (NREL) is now pleased to extend its unwavering support to the commendable initiatives that are being led by the Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE). The United States Department of Energy has the commendable objective of reducing the average cost of all grid-connected solar systems from $6.25 per watt to $3.30 per watt. This will make these systems more accessible to end customers who are interested in purchasing them.

In the National Centre for Photovoltaics (NCPV), which is a prestigious facility within the National Renewable Energy Laboratory (NREL), diligent researchers are working on intelligent research projects to support this goal. It is crucial to keep in mind that the Department of Energy's (DOE) famous "Solar Energy Technologies Programme" will run from 2008 to 2012 and will encompass the intriguing sectors of concentrated solar thermal power and photovoltaic electricity generation. One of the most motivating aspects of the Solar Energy Technologies Programme is its ideology, which contains a strong desire for:

- Solar power will be available to every single American at a price that is reasonable.
- Solar technology will be used by millions of residential and commercial structures throughout the country in order to fulfil all or the majority of their energy utilisation requirements.
- Solar power will be responsible for the generation of a significant portion of the nation's electricity.

Roadmaps for Solar Technology

In 2007, a group of scholars from the National Renewable Energy Laboratory (NREL), Sandia National Laboratories, the Department of Energy (DOE), universities, and business collaborated to produce ten different solar technology roadmaps. The Solar America Initiative provided a portion of the funding for the studies conducted. The purposes of these technological roadmaps are to present a basic view of the current status of each technology as well as its future trajectory. A number of photovoltaic (PV) roadmaps, including those for multiple-excitation-generation PV, intermediate-band PV, and nano-architecture PV, are now in the preliminary stages of development.

DATA ANALYSIS

It was the first time in history that the yearly manufacturing of thin-film solar modules surpassed 100 megawatts (MW) in the year 2005. Since then, the average compound annual growth rate (CAGR) for thin-film solar module manufacturing has surpassed 6%, which has resulted in an increase in the market share of thin-film products from 6% in 2005 to 10% in 2007 and from 12% to 14% in 2008. The utilisation of thin-film capabilities is at a rate of sixty percent, which is somewhat higher than the average utilisation rate of fifty-four percent in the solar sector. During the year of 2007 to 2008, thin-film exports had a 129% growth.

There are about 150 distinct firms that are engaged in the manufacture of thin film solar cells. These companies range from large manufacturing facilities to research and development departments. Immediately after the first 100 MW Thin Film facilities were put into operation in 2007, there was a flurry of statements about increasing production capacity in the year 2008. In the event that all of the development plans are carried out as intended, the manufacturing capacity of thin films might potentially reach 11.9 gigawatts. If we compare this to the 4.5 GW that was forecast in 2007 during the 22nd EUPVSEC in Milano, we see that this is a growth. This represents thirty percent of the overall output, which was forty-eight and a half gigawatts in 2012 and thirty-seven and a half gigawatts in 2010 (Fig. 4). For a variety of thin film technologies, the first plants that are capable of producing GW have already begun to put their finishing touches on their construction.

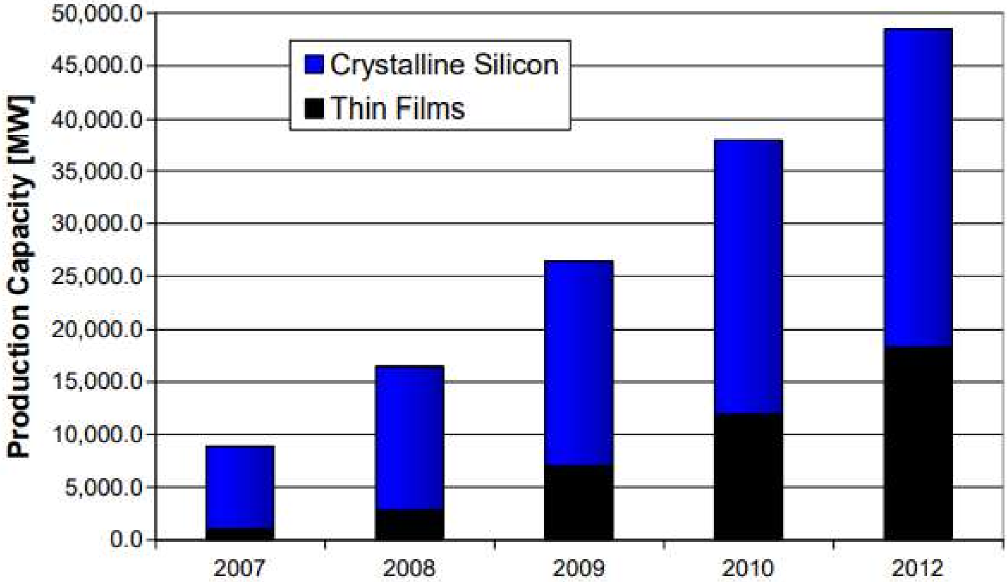

Figure 3: PV, both actual and anticipated Capabilities for producing solar modules based on crystalline silicon and thin film.

In the year 2006, there were only 21 companies that were able to produce thin film solar modules that were available on the market in numbers greater than one megawatt. This data was uncovered in August of 2007, when the first investigation was carried out in preparation for a presentation that was to be given at the 22nd European Union PVSEC in Milan. During the years 2007 and 2008, at least fifteen new companies started the ramp-up phase of their operations and delivered their first modules. In contrast, it is interesting to note that in August of 2007, about 82 businesses had announced their intentions to expand or increase their manufacturing capacity. However, by the beginning of 2009, this number had increased to over 150 businesses. This suggests that a large number of thin-film businesses are beginning the process of creating production lines; nevertheless, it is necessary to determine whether or not the ambitious timeframes can be met.

Table 1: Performance achieved by thin-film technology based on A-si

Measurement	Current Situation	Next Aim
Manufacturing amount	Hundred megawatts per year	>5 GW/yr
Purchase price of new machinery	one and two dollars per watt at the facility's capability	0.7 $/W @ plant capacity
Foundation price	12–20 per square meter	4 $/m2
Cost of producing an a-Si module	125–200 $/m2	0.45–0.70 $/W or 70 $/m2 @ 10%–15% efficiency
Increased productivity, optimal a-Si lab cells	13%	15%
Increased stability and commercialization a-Si module	5%–8%	10%–13%
Trustworthiness of a-Si screens	~1%/yr degradation	1%/yr degradation

Table 2: The performance of the C-Si film technology

Measurement	Current Situation	Next Aim
Manufacturing amount	< 1MW/yr	1 GW/yr
Purchase price of new machinery	2–3 $/W @ plant capacity	0.7 $/W @ plant capacity

Foundation price	26 $/m2	10 $/m2
Cost of producing silicon wafer-less modules	Not available	0.50 $/W or 65 $/m2 @ 13% efficiency
Efficiency, film c-Si lab cells with the finest support	10%	16%–18%
Effectiveness, optimally backed film c-Si modules	5%–6%	13%–16%
Panels made of silicon dioxide are reliable	? ? %/yr degradation	1%/yr degradation

In the last several years, it was not possible to acquire whole Thin Film production lines that had guaranteed deposition and manufacturing techniques. This was the case prior to the aforementioned time period. Up until very recently, this was the situation that prevailed. To put this into perspective, as compared to solar cell lines that were built on wafer silicon, the initial investment costs and risks were much higher as a result of this. This was due to the fact that each potential manufacturer was required to independently design the proper production equipment and ramp it up, with just minimum assistance from the vendors of equipment. As a result of this, this was the situation that occurred.

Some of the companies that have started offering whole manufacturing lines for thin-film solar cells are Applied Materials, Oerlikon, and ULVAC, to name just a few examples. These businesses are among the most well-known businesses in the world that make semiconductor equipment. Furthermore, as a result of this, the conduct of prospective manufacturers and investors towards investments was impacted as a consequence of this, in addition to the high demand for solar cells and the scarcity of silicon that was occurring at the time.

One may get the conclusion that the majority of supply companies who provide entire "turn-key" manufacturing lines do so for amorphous silicon. This is a conclusion that can be drawn. As a result of the fact that the bulk of production capacity expansions are included in this technology (Fig. 4), it is possible to arrive at this conclusion. It is the decision of the great majority of companies to seek help from their equipment provider in order to go forward with the development of their amorphous silicon technology in order to include micro morph tandems.

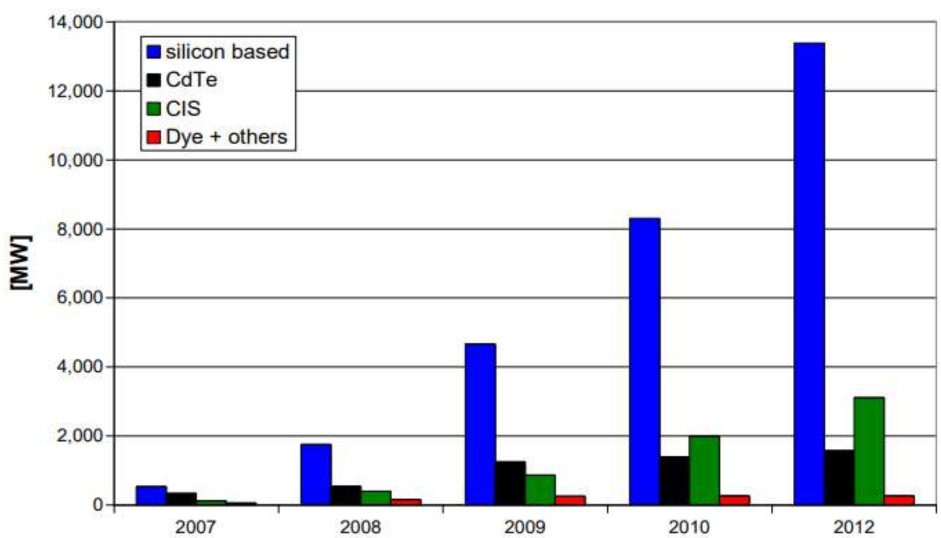

Figure 4: The various technologies' current and projected thin-film photovoltaic production capacity.

The increase of manufacturing capacity in thin film technologies that are not based on silicon is being driven by a number of large firms. These corporations are making this expansion possible. These firms are the ones that possess the necessary technical know-how and collaborate with certain businesses that provide the goods or services. Regardless of this, things are going through a shift that is both continuous and constant. It is predicted that other businesses will follow in the footsteps of the pioneering equipment providers, such as Centrotherm, at some point in the not-too-distant future. These pioneering equipment suppliers are already offering whole production lines for sale. As a consequence of this occurrence, it will be less difficult for potential customers who have less experience with technology to develop in their careers that they are already employed in.

Table 3: Overall Performance of OPV Technology

Measurement	Current Situation	Next Aim
The effectiveness of the Champions gadget	5.2%	12%
Degradation of the cell	< 5% per 1000 h, research-scale	< 2% per 1000 h, module
Efficiency in material figure of merit. Finding potential materials whose basic characteristics—like band structure, carrier mobility, and optical absorption—allow for high theoretical efficiency.	There are some material sets that have better figure-of-merit efficiency.	Finding and creating many donor-acceptor materials that satisfy every essential condition needed to reach the Shockley-Queisser limit.

Table 4: Multiple-Generation Photovoltaic

Measurement	Current Situation	Next Aim
MEG quantum yield at hν = 2.5 x Eg	105% – 110%	180%
IPCE at hν > 2Eg	45%	>100%
Champion NC solar cell efficiency	1%–3%	25%
AM1.5 photocurrent density at Voc = 1.0 eV	~1 mA/cm2	36 mA/cm2
Carrier mobility (DC value for coupled NC array)	~1 cm2 /(V·s)	100 cm2 /(V·s)

CONCLUSION

Due to the fact that the cost of conventional energy is increasing, there has been a significant increase in interest in renewable energy, particularly photovoltaics. Since 2006, investments and research in thin film photovoltaics have exceeded the already robust growth rates of the whole photovoltaics business. This is due to the fact that thin film technologies have promised to reduce costs more quickly, and there were already limitations in the availability of silicon at the time. Due to the developing wafer-based production technology and proven learning curves, new companies are required to compete at exceptionally high levels. This is despite the fact that thin film solar cells have the potential to dramatically reduce the costs of manufacturing. Moreover, as the market grows, the "entry ticket," or plant size, that thin film manufacturers need to have in order to enter the business gets increasingly complicated and expensive. Research is still required for thin film technologies on a wide range of subjects, including but not limited to the enhancement of our understanding of basic material features, the development of cutting-edge production techniques, and the exploration of new commercial prospects. We need to do research over a long period of time and have a long-term vision for photovoltaics in order to overcome these difficulties. In order to address these challenges, the European Photovoltaic Technology Platform is now in the process of finalising the Strategic Research Agenda for Photovoltaics Implementation Plan. The importance of this cannot be overstated when it comes to thin-film solar cell materials, since their assistance in the development of production methods is notably missing from other industries, such as the microelectronics industry. As an additional point of interest, there are a number of research issues that need to be handled that are pertinent to all thin film technologies. There is not a single solar cell technology that is capable of satisfying the requirements of consumers all over the globe or satisfying all of their expectations about the aesthetics or functioning of photovoltaic (PV) systems.

REFERENCES

1. International Energy Agency, World Energy Outlook 2008, International Energy Agency, Paris, 2008, ISBN 978 92 64 04560-6
2. Shah A, Torres P, Tscharner R, et al. (1999) Photovoltaic technology: The case for thin-film solar cells. Science 285: 692
3. Green MA, Emery K, Hishikawa Y, and Warta W (2011) Solar cell efficiency tables (version 37). Progress in Photovoltaics: Research and Applications 19: 84–92
4. Green MA (2003) Third Generation Photovoltaics: Advanced Solar Energy Conversion. Berlin, Germany: Springer Science+Business Media.
5. Queisser W and Shockley HJ (1961) Detailed balance limit of efficiency of p-n junction solar cells. Journal of Applied Physics 32: 510.
6. Henry CH (1980) Limiting efficiencies of ideal single and multiple energy gap terrestrial solar cells. Journal of Applied Physics 51: 4494–4500
7. Kayes BM, Nie H, Twist R, et al. (2011) 27.6% conversion efficiency, a new record for single-junction solar cells under 1 sun illumination. Proceedings of the 37th IEEE Photovoltaics Specialist Conference. Seattle, WA: IEEE.
8. Basol BM (1990) Thin film CdTe solar cells: A review. 21st IEEE Photovoltaic Specialists Conference 1: 588
9. van Sark WGJHM, Meijerink A, Schropp REI, et al. (2005) Enhancing solar cell efficiency by using spectral converters. Solar Energy Materials and Solar Cells 87: 395
10. Shalav A, Richards BS, and Green MA (2005) Application of NaYF4:Er3+ up-converting phosphors for enhanced near-infrared silicon solar cell response. Applied Physics Letters 86: 013505.
11. Strumpel C, McCann M, and Beaucarne G (2007) Modifying the solar spectrum to enhance silicon solar cell efficiency: An overview of available materials. Solar Energy Materials and Solar Cells 91: 238.
12. Trupke T, Green M, and Würfel P (2002) Improving solar cell efficiencies by up-conversion of sub-band-gap light. Journal of Applied Physics 92: 4117
13. Wang F, Han Yu, Lim CS, et al. (2010) Simultaneous phase and size control of upconversion nanocrystals through lanthanide doping. Nature 463: 1061–1065
14. De Wild J, Rath JK, Meijerink A, et al. (2010) Enhanced near-infrared response of a-Si:H solar cells with β-NaYF4:Yb3+ (18%), Er3+ (2%) upconversion phosphors. Solar Energy Materials and Solar Cells 94: 2395–2398.
15. Fischer S, et al. (2010) Journal of Applied Physics 108(4): 044912–044912-11