Solar module installation in India: concerns, options and roadmap*

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This article discusses the concerns, choices and tentative avenues towards the success of module installation for solar power production in India. Renewable energies, especially solar modules, have played a vital role in India's recent success in the generation of electricity. Several initiatives have accordingly been taken to implement a sustainable model of development. To achieve those targets, it is necessary to deploy the time-tested and dependable crystalline silicon solar modules initially. To attain self-reliance and economic sustainability ($/W), India should also look beyond silicon solar cell modules by setting up foundries favourable for thin-film technologies as well. With already established thin-film materials like copper indium gallium selenide and cadmium telluride, development of advanced solar energy material, such as copper zinc tin sulphide and hybrid halide perovskites is therefore of unquestionable importance. On a short-term frame, contribution from these thin-film modules may not look very significant. These non-silicon modules should now supplement silicon technology to accomplish the present requirement and gradually phase out silicon modules in the long run.

Keywords: Module manufacturing, road map in the Indian context, thin-film technology, solar cell materials.

Energy requirement: year-wise

INDIA is proud to have become the world's third largest producer of electricity[1]. With a global share of 4.8%, electricity generation in India has now surpassed Japan and Russia[2]. At the moment, the electricity sector of India has an installed capacity of 329.20 GW (as of 30 April 2017)[3]. In recent times, we are in a position to export electricity to our neighbouring countries ('energy diplomacy'). The escalation in demand in fact manifests the industrial growth that we experience along with improvement in the quality of life in villages, cities and metropolises across the country. According to the industrial growth forecast, one can expect further escalation in the demand for energy. With the present growth rate, we should be ready to achieve an installed capacity of 450 + GW by the end of 2022 (Figure 1). The growth, as seen in Figure 1, is indeed exponential compared to near-linear rise in the initial decades. The overall plot manifests the condition of our nation that we reclaimed from our ruler and also the sluggish development achieved in the initial decades after independence.

*This article is dedicated to the memory of Dr Baldev Raj, who encouraged the author to pen down his thoughts on solar module installation in India.

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One may argue that newer energy-efficient appliances may lower the rate of growth in energy consumption to some extent. However, in projecting the energy requirement, we need to keep in mind that the per capita electricity consumption in India has been low so far compared to other nations despite cheaper electricity tariff in our country. Additionally, we have to consider the 'power for all' scheme in the country launched by the Government of India to address the lack of availability of adequate electricity to all its citizens by March 2019 (ref. 4). Hence the projected requirement of electricity may not reduce at all. We must, therefore, be prepared to have an installed capacity of 450 + GW by the end of 2022 to envisage a truly developed India.

Renewable energy

Renewable power plants constituted 30.8% of the total installed energy sector in India[3]. This high percentage of renewable power compared to many so-called developed nations simply manifests our government's commitment to the environment and a sustainable model of development. To make the 'power for all' scheme in the country a success without compromising on environment-issues, India has taken several initiatives under the scheme of National Action Plan on Climate Change (NAPCC)[5]. The Jawaharlal Nehru National Solar Mission (JNNSM), also known as National Solar Mission, is one of the eight key national missions comprising India's NAPCC; its sole aim is to promote renewable energy, especially solar power, in India[6]. The objective of JNNSM is primarily to envision a pollution-free world and to establish India as a global leader in solar energy as rapidly as possible.

The immediate aim of this mission is to focus on setting up a healthy environment for solar technology in the country at both centralized and decentralized levels, besides serving crucial purposes like long-term energy security and ecological protection. Till 2013, the first phase has already focused on options like solar thermal and grid connected large scale ground-mounted solar PV plants to empower citizens at a grass-root level. In the subsequent phases, especially after taking into account the experience of the initial years, it has been planned to ramp up the capacity with an ultimate aim to deploy 100 GW of grid-connected solar power in the nation by 2022. Such follow-up phases recommended decentralized applications like grid-connected and net-metered roof-top system under the smart city programme named as kilowatt programme in megawatt scale. In Figure 2, we present the growth of the renewable energy sector in India showing energies from different renewable sources along with projected energies to be obtained from solar cell modules till 2022.

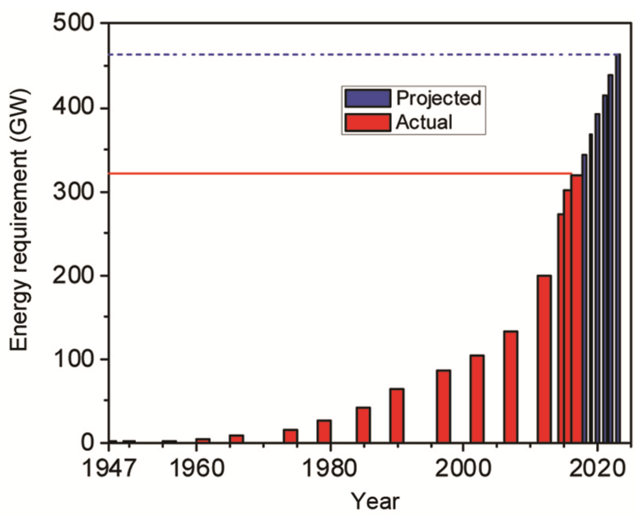

Figure 1. Growth of electricity sector in India showing the installed capacity and the projection till 2022 based on last years' values[35].

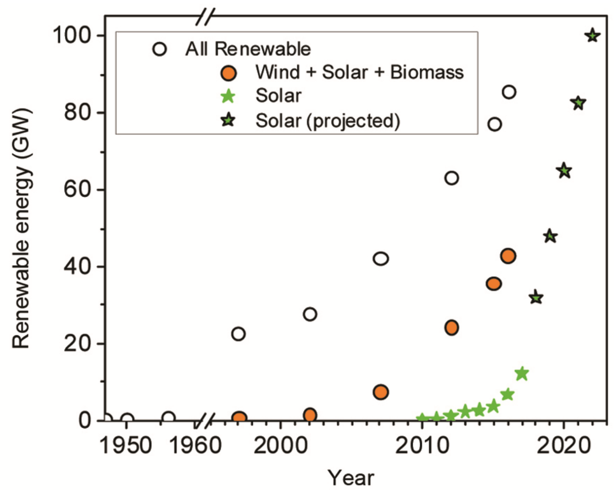

Figure 2. Growth of renewable energy sector in India showing the energies from different renewable-sources along with projected energies to be obtained from solar cell modules till 2022 (ref. 36).

Till date, energy obtained from solar cells is a minor percentage of renewable energy produced in the country, to the tune of 14%. With the year-wise projected values of solar modules (Figure 3) and deployment of 100 GW solar power, solar cells will be a major contributor to renewable energy. While retaining the present growth rate of different renewable energy resources such as wind, biomass, etc., we may expect that in 2022 about half of our required energy will have a green-form in spite of providing electricity to every village across India. This high percentage of renewable energy in a densely populated country like ours will indeed be a laudable achievement.

Present status of photovoltaic module manufacturing

The status of photovoltaic (PV) module manufacturing can be addressed from two aspects: efficiency and cost per watt. The majority of modern-day solar modules contains crystalline silicon (*c*-Si) solar cells made of multi-crystalline and monocrystalline silicon. As a result, by 2013, more than 90% of worldwide PV production has been shared by crystalline silicon, while thin-film technologies using cadmium telluride (CdTe), copper indium gallium (di)selenide (CIGS) and amorphous silicon

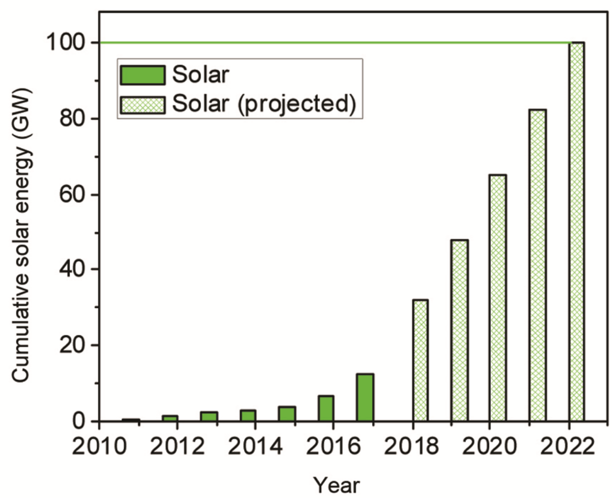

Figure 3. Year-wise installed solar energy along with the projection to achieve 100 GW by 2022 (ref. 37).

contributed to the rest of the overall market share[7]. CIGS is a I-III-VI_2 semiconductor material in the form of a solid solution of copper indium selenide ($CuInSe_2$) and copper gallium selenide ($CuGaSe_2$). It has a chemical formula of $CuIn_xGa_{(1-x)}Se_2$ where the value of x can vary between 0 and 1, resulting in a monotonical change in band gap from 1.0 eV in $CuInSe_2$ to about 1.7 eV in $CuGaSe_2$ (ref. 8). The efficiency of solar cells could be found to be optimized at a composition of $CuIn_{0.7}Ga_{0.3}Se_2$, whose band gap interestingly matched well with the peak of Shockley-Queisser (SQ) efficiency limit versus band gap plot (Figure 4).

When we look at cell efficiencies, the value did not reach the SQ limit of 33.5% leaving room for newer materials to make inroads[9]. Progress with certain materials is indeed astonishing keeping their scope in solar-module manufacturing wide open. The commercial module efficiencies, which were expectedly lesser than that of a cell, hovered between 12% and 20%. Both cell and module efficiencies depended on PV materials; the efficiencies did not necessarily follow the SQ efficiency limit versus band gap plot, since factors such as recombination and carrier mobility played important roles in solar cells. When cell and module efficiencies are compared, the efficiency of cells and modules differs with the latter being at the wrong end. As a thumb rule, commercial modules will be 20–30% less efficient than laboratory-made PV cells based on the same material (Figure 5).

The second important issue in module manufacturing is price, i.e. cost per watt. Interestingly, the price of cells and modules has shown a clear sign of systematic reduction over the long term scenario. For example, the cost per watt has gone down around 500 times from a value of USD 150 in 1970 to about USD 0.30 in 2015. A study conducted in 2015 showed that the price/watt dropped by 10% per year since 1980 (ref. 10). The price of a module has two major components: materials cost and manufacturing cost. The material cost depends on abundance of elements/compounds in the earth's crust and purity requirement. Use of earth-abundant elements in the raw material for solar cells has hence been a cost-effective approach. The module manufacturing cost on the other hand depends on the process including temperature of processability.

Efficiency of silicon, CdTe and CIGS solar modules

Generally, semiconductor grade silicon is the prime material for commercially available solar modules, whereas thin film technology shares the rest of the global solar market. These two technologies have their own pros and cons. Considering the modern scenario in energy-requirement, every solar cell should not only excel in terms of efficiency but should also have a decent operating life to compete with other sources of energy. Therefore, while designing an acceptable solar cell, it is a prerequisite to select materials in such a manner that the cell remains efficient for a significant period of time, so that the energy produced by the cell becomes appreciably greater than energy required for the production of the cell. Silicon's superiority as a practical photovoltaic material lies in this regard. Along with the high abundance of the raw materials in the earth's crust, silicon solar cells are not only more efficient than other thin-film solar cells, but also possess significantly longer operation lifetime. But the high expense of pure silicon makes up about 20–25% of the cost of the crystalline panels. The high percentage of material cost is due to the indirect band gap of the semiconductor that necessitated 200 µm thick silicon wafers to absorb sufficient solar light.

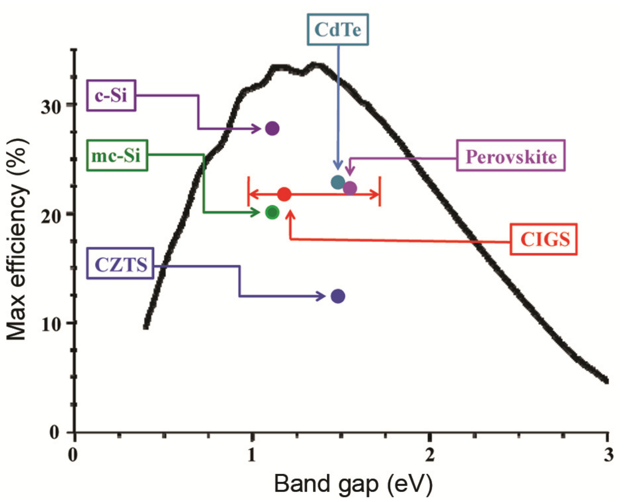

Figure 4. Shockley-Queisser efficiency limit versus band gap plot showing the efficiencies achieved in different materials[9].

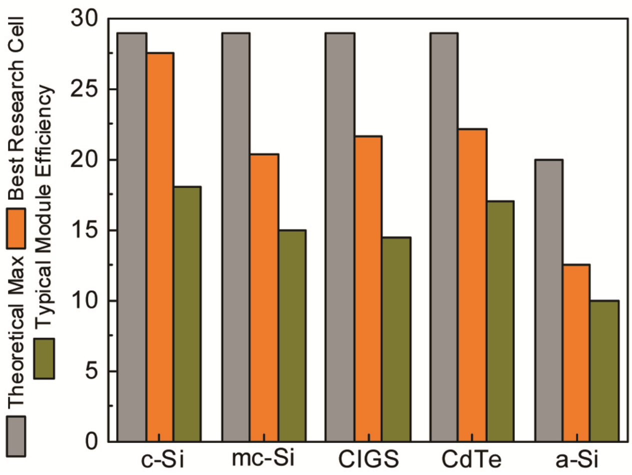

Figure 5. Solar cell and solar module efficiencies along with theoretical limits from Shockley-Queisser equation of different materials used in commercial production process[38].

Several attempts have been considered to reduce the cost of this silicon feedstock and one of the interesting ones in this direction is the development of metallurgical grade silicon for solar application. Metallurgical grade silicon contains a tolerable amount of metal impurities, viz. iron and aluminum, that do not affect the device performance largely but effectively lower the manufacturing cost and therefore the energy payback time is also lessened. Actually, use of this low-quality metallurgical-grade silicon by the present manufacturing companies as opposed to the ultrapure electronic grade counterparts employed in earlier silicon solar cell modules has lowered the price per watt drastically; this unfair price war has led to closure of many silicon module manufacturers in the USA and Germany which were leaders of the manufacturing market in the initial decades of this business.

Thin film technology, on the other hand, has advantages as far as module production cost is concerned. Chiefly based on materials like CdTe and CIGS, this grade of solar modules can be manufactured by simple evaporation process and non-vacuum avenues are also available for the latter. Such a favourable route of material processability lowers the manufacturing cost. Also, in thin-film panels, thickness of these direct bandgap semiconductors can be even less than 1 μm. Hence the cost of materials is only about 2% of the panels. With low manufacturing and materials costs established, the biggest prospect of these materials lies in the improvement of device efficiency. Currently, the maximum efficiency of commercial modules is around 17% for CdTe (ref. 11) and 14.5% for CIGS (ref. 12) which are surely not up to the mark. Module-installation is, however, a market-driven process. A comparison of CdTe-based panel installation vis-à-vis those of silicon is best reflected in the market share of different companies and technologies. Market share of First Solar, USA, a prime manufacturer of CdTe panels, declined over the years.

In the Indian context, thin-film technology could still be the possible way out, since we are in a position to manufacture CdTe and CIGS-based modules in India. As stated earlier, thin-film of these materials can be formed by cost-effective approaches so that the overall module production cost is less than modules based on imported silicon. Moreover, since thin-film technology is associated with the deposition of a large number of materials, it is worthy to set up a favourable infrastructure considering the longer time-frame.

There are some cautions and apprehensions that one should mention at this point. Materials such as CdTe and CIGS are always associated with a concern of availability. Abundance of tellurium in the earth's crust has always been inadequate and indium is also scarce. Moreover, use of indium is preferred in higher-valued opto-electronic products than solar modules. So, there is a probability that the rising demand for these materials will increase their prices and this can quickly nullify the cost advantage of these semiconductors. However, the low amount of materials needed for these solar cells (cost of the materials being about 2% of the panels at the moment) may counterbalance the availability issue[13].

Efficiency of CZTS and perovskite solar cells

As a solution to this challenge, absorber materials with earth-abundant elements such as copper zinc tin chalcogenide (Cu_2ZnSnS_4, CZTS) and hybrid perovskites have evolved with promising energy conversion efficiency[14,15]. CZTS shares similarities with CIGS including device architecture and fabrication technology; knowledge from CIGS has moreover accelerated the improvement of CZTS-based solar cell technology. In the lab scale, CZTS has yielded an efficiency of 12.6% (ref. 16); it is believed that the efficiency can go up by a large extent due to a much lower open-circuit voltage (V_{OC}) achieved so far, compared to the theoretical prediction.

On the other hand, the breakthrough discovery of organometal halide perovskite materials as a superior converter has completely changed the research arena of photovoltaics. The attraction toward this class of materials for solar cells has arisen for a multitude of reasons. First, they possess appropriate optoelectronic properties, such as direct optical band gap, long carrier diffusion lengths (in μm range), and low exciton binding energies, resulting in a remarkable power conversion efficiency of over 22% in lab-based optimized photovoltaic devices[15]. In addition, ease of processing via low-temperature solution or vapour phase techniques, less-expensive materials required for processing, abundance of constituent elements/materials, flexibility in terms of substrates, and sequential formation of multiple layers have made perovskite solar cells a strong contender in module-manufacturing[17]. Till date, more scientists and engineers are initiating research on perovskite solar cells. This has prompted improvement of device efficiency as well as the understanding of this new star material for solar energy conversion with working scalable devices. A significant amount of effort has also been made to improve the material properties leading to both high efficiency and stability in such devices, along with development of effective strategies for perovskite deposition on larger areas. Despite being a relatively young field, the immense potential for module manufacturing based on perovskite materials can be foreseen. A successful conventional TiO_2-based architecture module with an aperture area of more than 150 sq. cm has been demonstrated[15]. This effort rightfully reflected the potential of using perovskite solar cells in high-performance stand-alone applications. Another area of application can be considered as a stack of perovskite modules on top of existing thin-film technology, such as CIGS or crystalline silicon having both optical and electrical compatibility[18]. Aiming for the industrialization of perovskite solar cells, a tandem architecture between perovskites and conventional inorganic semiconductors can be seen as a major deployment area. Besides, fabrication of large-area modules with new semiconductors such as graphene or other 2D materials can also engineer the interfaces, improving both efficiency and stability of perovskite cells and modules[19].

With a theoretical understanding of solar cells based on these materials, further improvement can also be contemplated. In Figure 6, we present theoretically predicted and experimentally measured solar cell parameters of different thin-film technologies. In the same plot, we have added actual cell efficiencies which show that materials except CZTS have already yielded efficiencies exceeding that of silicon. The plots show room for further improvement and scope to reach SQ limit of efficiency[20–22].

Critics of perovskite solar cells often argue on the degradation issues of the material. It is true that without any solution to this roadblock, this exciting achievement cannot be transferred from laboratory scale to industry and finally to outdoor applications. The instability of perovskite solar cells actually refers to a series of chemical reactions of the material at different atmospheres and under harsh conditions affecting the performance. Typically, perovskite solar cells are susceptible to the following four factors: oxygen and moisture, UV light, the solution process (solvents, solutes, additives) and temperature[23]. Moisture sensitivity has been a long-standing issue in fabrication and long-term device use of perovskites. As a result, during the assembling and testing process, it reacts with water and degrades rapidly (hydrolyses) to PbI_2. Such an irreversible degradation is often accelerated in the presence of oxygen. Several precautions have been proposed and exemplified in this direction, such as fabrication of the cells under controlled atmosphere, modification by Al_2O_3 protective layer[24], incorporating aprotic organic ions, such as tetramethylammonium, $(CH_3)_4N^+$, chemical tuning by partial substitution of iodine by bromine[25], etc. Another way to impart moisture-resistance is by using two-dimensional (2D) perovskites having hydrophobic organic layers. Moreover, some effective encapsulation methods for CIGS cells, for example, double glass protective layers, could be employed to improve the stability of perovskite solar cells.

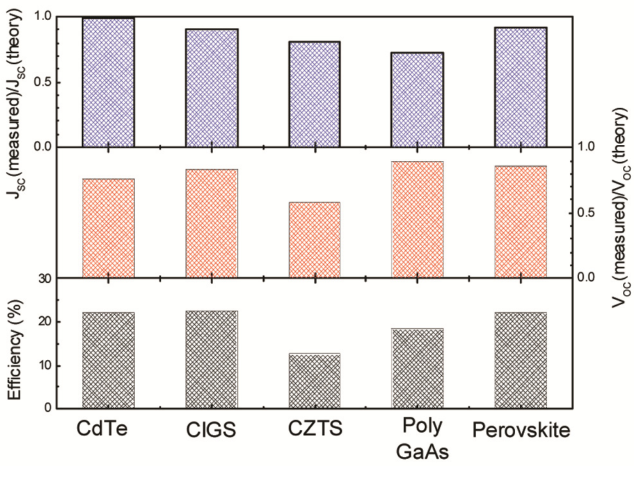

Figure 6. Theoretically predicted and experimentally measured parameters of solar cells based on different materials used in thin-film PV technologies.

Thermal decomposition of the perovskite solar cells occurs as the temperature of the solar cells working under sunlight seems to be greater than the transition temperature for $CH_3NH_3PbI_3$. This perovskite has a very low thermal conductivity in both single crystal and polycrystalline forms. Therefore the heat inside the perovskite due to photo-illumination cannot dissipate quickly enough, causing mechanical stress and limited lifetime of the photovoltaic devices[26]. Polymer-functionalized single-walled carbon nanotubes (SWNTs) embedded in an insulating polymer matrix have successfully retarded such thermal degradation when used in place of the traditional organic hole-transport layer[27].

Considering stability as a roadblock to commercialization, it is worthwhile mentioning here the success of organic light-emitting diodes (OLED) and quantum dot light-emitting diodes (QLED) in the television industry. Both these LEDs, which suffered degradation issues in the initial years of inception, have been successfully introduced in printable and flexible displays of all sizes, including large screen TVs. These materials have made the displays thinner, lighter and brighter with much improved resolution while consuming lesser power than conventional backlighted displays like LCDs. AMOLED (active matrix organic light emitting diode) is another display technology that has overcome the drawbacks of organic substances and has been commercialized successfully in smart-watches, mobile devices, laptops and televisions. With the success of OLEDs and QLEDs, we expect that the organometal halide perovskites with unusual optoelectronic material properties will similarly be commercialized as solar cell modules.

Degradation of silicon solar-cell modules (year-wise)

Although several advances have been made in the characterization and mitigation of silicon solar cell modules, they still suffer from different types of efficiency losses. A detailed study on various kinds of modules has shown that modules lose their efficiency primarily due to material degradation. Degradation upon exposure to sunlight is an inherent drawback of modules based on crystalline or thin-film solar cells. In case of silicon solar cells, such light-induced degradation, which is termed as the Staebler–Wronski effect, is a prevalent one for both crystalline and thin-film structures[28]. For thin-film structures,

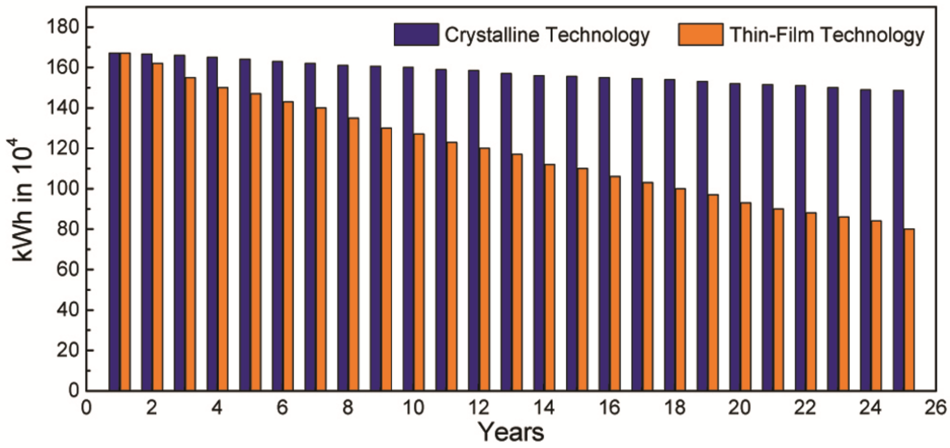

Figure 7. Year-wise degradation of solar modules based on crystalline and thin-film technology[39].

there is an initial fall in power output due to light soaking; the efficiency stabilizes thereafter for long term applications. Therefore, in case of thin-film solar cells, the term 'stabilized output' is more important than 'initial output'. Although microcrystalline silicon solar cells are protected from light-induced degradation, we still need to keep in mind that the term 'microcrystalline' covers a large diversity of different materials having prominent differences in microstructure, crystallite orientation, etc. It should not be ruled out that certain types of microcrystalline silicon layers may rigorously suffer from light-induced degradation. Apart from such degradation, post-oxidation is another potential source of instability for silicon solar cell modules if the cells are not sealed properly[29]. Such modules, when exposed to air over a long period of time, do suffer from an increased contamination by oxygen. This so-called post-oxidation effect induces a change in the Fermi energy (E_F) which in turn affects the output of the modules. Considering all these issues, the manufacturers' claim of 25 years of lifetime (Figure 7) may not actually hold, leaving the possibility of a large volume of electronic waste.

Effect of the use of metallurgical grade silicon on degradation

Metallurgical grade silicon (MG-Si) is industrially prepared by reacting high-purity silica with wood, charcoal and coal in an electric arc furnace using carbon electrodes at temperatures over 1900°C. The production rate is millions of tons/year at a low economic cost of few $/kg and an energy cost of 14–16 kWh/kg. As such, it is 98–99% pure, with a major contamination of carbon, alkali-earth and transition metals, and a large content of boron and phosphorus (Figure 8)[30]. These impurities can easily supersaturate during the cooling of the melt and form precipitates that reduce the lifetime of the product. Carbon usually enters the silicon product through feedstock, graphite furnace parts, or the atmosphere and acts as a substitutional element forming various precipitates. Oxygen contamination appears in the product from the crucible used during the melting of polysilicon causing a range of defects and precipitates. Finally, nitrogen causes SiN precipitates that appear from the crucible coating. SiN contamination is most common in cast-ingots.

Donors and acceptors are often addressed as sources of point-defects and substitutional impurities in MG-Si. Arising out of feedstock or internal doping, the donor elements, such as B, Al and Ga, and acceptor elements such as P, As and Sb form deep level defects close to the band edges; a high recombination activity of these dopants interferes with the efficiency of the cell, making MG-Si unsuitable for use in electronics.

Studies on light-induced degradation (LID) of *c*-Si solar cells made of electronic grade (EG-Si) wafers have revealed that either reduction of oxygen contamination or lessening of boron doping below a level of $\sim 10^{16}/cm^3$ could lead to less LID of such wafers. Since the impurity level in MG-Si is higher than that in EG-Si, such LID is a prevailing issue of degradation. Directional solidification of molten silicon can effectively remove many impurities in MG-Si except boron (B) and phosphorus (P), as the distribution coefficients of these elements are relatively large. Nevertheless, through such purification, solar grade silicon (SoG-Si) is produced with impurity levels in between that of metallurgical silicon and semiconductor grade silicon[31]. Though the purity of SoG-Si is generally three orders of magnitude poorer than the purity of EG-Si, several leading solar cell manufacturers claimed that solar cells made of SoG-Si have yielded conversion efficiency comparable to EG-Si and thus a faster energy payback time.

We therefore reiterate that the use of this low-quality metallurgical-grade silicon (or the solar grade one) by the present manufacturing companies has lowered the price per watt of the solar cell modules considerably. The long-term efficiency and degradation parameters of these modules may not match the earlier silicon solar cell modules based on ultrapure electronic grade silicon. While importing modules, we need to check the quality of silicon being used, instead of simple cost per watt at the time of delivery.

Potential-induced degradation (PID) occurs when a solar module's voltage potential and leakage current drive ion mobility between the semiconductor and other elements of the module (e.g. glass, mount, and frame), resulting in a decrement of the module's power conversion efficiency (PCE). Basically, PID occurs mostly at negative voltage with respect to the ground potential and decreases the shunt resistance (R_{sh}) of a solar module. A decline in R_{sh} in turn reduces the open-circuit voltage (V_{OC}) and accordingly the PCE[32]. The occurrence of PID also depends on conditions including both environmental and system-based factors, such as humidity, temperature, and voltage potential. Since it is difficult to control the environment of modules, PID preventive measures are best addressed in terms of designing the module itself. Avenues such as application of polyvinyl butyral (PVB) laminated encapsulations[33], SiO_2-based sodium diffusion barrier, quartz-based protective glass[34], etc. have shown high-susceptibility to PID. However, designing of such PID resistant modules with possible preventative efforts within the limitations of each individual system is an expensive approach to consider inclusion in modules.

While installing solar modules, one must not hence forget their recycling possibility. In the Indian perspective at the moment, the parameter for recyclability is yet to be considered, since there is a lack of demand for recycled silicon wafers in India due to our manufacturers' inability to make solar cells in the country. Overseas, the silicon solar cell recycling technologies involve breaking the silicon wafers upon removal from the panel; the wafers are typically stripped of their impurities using

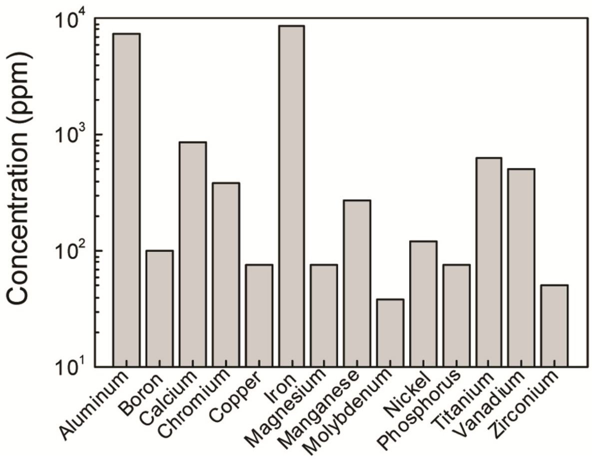

Figure 8. The impurity content in metallurgical grade silicon[35].

hydrofluoric acid, which is again harmful to environment and human health. Researchers are now working on an alternate process like controlled heating of the panel so that wafers do not break during the heating process. Removal of electrodes still involves chemicals like nitric acid and potassium hydroxide. Another point that one may add is that as per European standards, non-silicon-based solar panels have a better recovery rate than silicon panels.

Roadmap ahead and concluding remarks

With the unquestionable need for solar energy, India must become a manufacturing hub of solar modules. The manufacturing process will not only provide energy at an affordable cost, but also generate tremendous employment. With the present trend of installing solar modules based on silicon, the scope of manufacturing in our country is not very bright. In India, where production of semiconductor grade silicon has not flourished (it is said that we missed the 'silicon bus'), the deployment cost per watt (or \$/W) of these solar cells would become significantly high if the all-important raw materials have to be imported. Establishment of silicon solar cell plants in India is unlikely to flourish due to lack of feedstock and also the presence of well-established overseas solar industries. A glance at the possible options (countries) for importing crystalline silicon reveals China's outright dominance in the crystalline silicon solar PV production chain. So, importing a large amount of raw material and manufacturing of solar module will be a colossal undertaking and does not seem to be a feasible option. On the other hand, purchase of a huge amount of commercial solar modules for nationwide installation, again, is not a rational approach. In doing so, we will indirectly become energy-reliant on other countries, which may not be a pleasing circumstance considering the ever-shifting economic and political equations among power-centres of the world. Moreover, with our over-dependence on silicon solar-modules, we may become inclined to neglect the development of other renewable energy resources, such as wind, biomass, and so forth, and may also act in a sluggish manner in installing more nuclear power plants.

In the same breath, the targeted installation of solar modules cannot wait for the manufacturing process to initiate in India. To achieve a balance, we shall have to address the issue in a phased manner. The present roadmap of solar cell modules may continue with silicon as the base material for the next couple of years. We can even 'reserve' some percentage of planned installation from materials other than silicon, so that companies already manufacturing CdTe and CIGS modules may take active interest in our ever-growing market. As the percentage of installable capacity based on non-silicon materials goes up, the companies would find the necessity to invest for manufacturing in India. Some joint-ventures between overseas and Indian companies can also be predicted. India can thus become the manufacturer of all solar modules installed in the country implying the success of the 'Make in India' programme. The ambience of module manufacturing in India will make India ready to take up other materials, such as CZTS, perovskites, etc. to the solar cell modules.

So the vision for India's 2022 target should be to initially deploy majorly, the time-tested and dependable crystalline silicon solar modules. In a short-term frame, such installation will promote solar power generation in the country. But to achieve economic viability, it is essential to build solar cell fabrication plants within India. Since establishment of silicon solar cell plants in India is unlikely to flourish due to lack of feedstock and the well-established overseas solar industries, plants based on thin-film technologies are a better choice due to the flexibility of the technique and the possibility of materials engineering. Therefore along with the initial installation of commercial silicon solar modules, India should look to set up foundries favourable for thin film technology. On a short-term frame, contribution from these thin film modules may not look very significant, but gradually in conjunction with silicon technology these modules will also serve to accomplish the target and be expected to phase out silicon solar cells in the succeeding years.

Recommendations

- India is currently the world's third largest producer of electricity with 30.8% of its total installed energy sector being renewable power plants.
- With the unquestionable need of solar energy, India must become a manufacturing hub of solar modules.
- The scope of manufacturing silicon-based solar modules in our country is not very bright due to India's inability to produce semiconductor grade silicon.
- Thin-film technology based on CdTe and CIGS materials, on the other hand, has advantages considering the possibility of module-manufacturing in India.
- The vision for India's 2022 target should be to continue with the installation of silicon solar modules and also to set up foundries favourable for thin-film technology.
- In the initial years, contribution from these thin-film modules may not be very significant, but gradually, in succeeding years, they should phase out silicon solar cells modules.
- The success of thin-film module manufacturing process will make us ready to transfer new upcoming materials into modules.

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