

Photovoltaics in India—Thrust on Research and Education

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Abstract— Photovoltaics has registered an impressive growth despite the vicissitudes of the sixty years since the first solar cell was developed at the BELL LABS in 1954. It is a defining moment for the PV Industry today as costs are coming down with economies of scale and the need for clean and green energy is gathering momentum. This paper reviews some of the recent trends in photovoltaic technology, the research initiatives in India and also how the academia in our country is gearing up to meet the objectives enunciated in the Jawaharlal Nehru Solar Mission document in terms of training, curriculum development and research in collaboration with the Industry. The ultimate aim is to ensure energy sufficiency, energy security and reliability.

Keywords—Photovoltaic(PV); energy; reliability; Jawaharlal Nehru Solar Mission;

I. INTRODUCTION

Photovoltaic (PV) growth has had a long and chequered history since 1954 when the first solar cell was developed at the BELL LABS. In the formative years, PV found extensive application in Space, albeit at an exorbitant cost. The oil shock of the early seventies gave the impetus for terrestrial applications but the impediment of high costs made government support mandatory to promote this technology. PV development has been through a cycle of government subsidies, funding by bilateral/multi-lateral agencies, extensive R & D, implementation of favorable FIT (Feed in Tariff), boom time, silicon shortage, cap on FIT, withdrawal by big names (Siemens, BP Solar etc) from PV production, bankruptcy of well established companies, supply-demand imbalance leading to build-up of inventories, Chinese dominance, plummeting of prices and so on.

PV Industry is at the crossroads today with prospects of revival being very bright. PV growth in India has been bolstered by the JNNSM (Jawaharlal Nehru National Solar

Mission) that encourages grid connected and off grid applications, research/ development and training in various institutions particularly academic and so on. Our Government's initiatives to drive research, with the focus on reducing costs and increasing efficiency and reliability, range from setting up of a National Institute of Solar Energy to joint PV research by U.S. and India (SERIUS – Solar Energy Research in India and the U.S.) , with participation from both the Academia and the Industry [1].

II. RECENT TRENDS IN PV TECHNOLOGY

Today's research efforts are directed at improving efficiencies and reducing costs. Broadly they could be categorized as:

Cost-driven that looks at using cost effective material such as use of polyurethane in place of Ethylene Vinyl Acetate (EVA), fiber reinforced polymer as frame material and Poly methyl methacrylate (PMMA) in place of glass as front material [2]. Progress has been reported in New Industrial Cell Encapsulation (NICE) that does away with cell inter-connection soldering, EVA and even lamination. It relies on the application of pressure to the front and back sheet sandwich. It is claimed that module costs will come down 50%. Process automation can further bring down costs [3]. Cost reduction in the context of the balance of Systems is also important.

Technology driven that aim at increasing cell/module efficiencies and use of materials that are environment friendly

Environment driven such as lead free solder and use of materials that are environment friendly.

Reliability driven: Increasing the life of PV modules to 25 and 30 years. Research could also be **market driven**.

Some of the important trends towards increasing the efficiency of already existing PV cells/modules are highlighted below:

Selective Emitter (SE) in crystalline silicon cells: A SE approach is characterized by a highly (N++) doped area underneath the contacts and a lightly (N) doped otherwise. The highly doped ensures low contact resistance and reduced contact recombination while the lightly doped area in between contacts reduces both surface and augur recombination. This leads to increase in the open circuit voltage and short circuit current [4].

Laser grooved buried contact cell (LGBC): Inside a laser formed groove, a plated metal contact is placed. This technique scores over the screen printed contacts in that there is a 25% performance increase as more front area is exposed to the sun. . The emitter resistance is reduced. The large volume of metal in the groove results in low metal grid and finger resistance. This has a lower resistivity than the metal paste used in screen printing [5].

Inter-digitated Back Contact Cell: The contacts are put on the rear of the cell thereby eliminating shading-losses. By using a high-quality thin solar cell, electron-hole pairs generated in the front surface can still be collected in the rear of the cell. Cells with both contacts in the rear are easy to interconnect [6].

Passivated emitter rear locally diffused cell (PERL): The top surface of the solar cell is textured (inverted pyramid structure) and covered by double layered anti-reflection coating (ARC) to reduce considerably the top surface reflection. The top contacts (metal finger grids) are realized using the photolithography technique to make it very thin to reduce metal shading losses. Optical losses are reduced to increase currents. Contact area recombination and contact resistance can be minimized by a selective emitter approach that also improves the blue response. Point contact rear surface (local boron diffusion) with thermal oxide passivation, in the non-contacted rear surface covered with aluminium, further reduces recombination [7].

‘Smart Plus Module’ A new PV module has been developed by Innotech Solar (ITS), which embeds three chips (ICs) in the laminate replacing both the bypass diode and junction box. Each chip serves to optimize the output of 20 solar cells connected in series. The Smart Plus modules exploit the full potential of a PV installation even when individual cells are shaded/soiled [8].

Research continues, keeping in focus increase of efficiency, reliability and life, in the context of Organic PV cells, quantum dots, dye-sensitized solar cells, silicon film, Copper Zinc Tin Sulphide (CZTS) and so on. **CZTS**, a quaternary semiconducting compound, is being researched for application in solar cells. It offers favorable optical and electronic properties as in CIGS (Copper indium gallium diselenide) making it suitable as an absorber layer. CZTS is non-toxic and abundantly available. Availability and toxicity issues related to CIGS and CdTe (Cadmium telluride) have been the key driver to look at alternative thin film materials such as CZTS. Recent material improvements for CZTS have pushed the efficiency to about 12.0% in laboratory cells. But much more work is required [9].

III. EFFORTS OF THE RESEARCH AND EDUCATIONAL INSTITUTIONS IN INDIA

In order to give a further impetus to the research activities in India, consistent with the objectives delineated in the JNNSM (Jawaharlal Nehru National Solar Mission) document, a National Institute of Solar Energy (NISE) has been established, under the administrative control of the Ministry of New & Renewable Energy (MNRE), by upgrading the existing Solar Energy Centre (SEC).

Educational Institutions are making every endeavor to be in sync with developments in solar energy, particularly PV, in terms of training, curriculum development, expert lectures, installation of solar PV systems (grid connected and off grid standalone), evaluation (both short term and long term), setting up of laboratories for PV/RES and carrying out research. The initiatives taken by some of the Institutions [10] deserve mention viz Maharishi Solar (Solar PV manufacturer who are developing poly silicon material), IIT Bombay (20 -22% efficiency single crystal silicon cells), Indian Association for the cultivation of Science (development of 10 to 12% efficient nano-crystalline thin film modules), Amrita Nano Centre, Coimbatore & IIT Kanpur (10 to 12% efficient Dye Sensitized Solar Cells), IIT Delhi (6% efficient organic-inorganic hetero junction cells) and so on.

Research Endeavour's by **IIT Bombay** in and outside the NCPRE (National Centre for Photovoltaic Research and Education) are well documented [11]. As many as fifty investigators from thirteen Departments, including, inter alia, Energy Science and Engineering, Electrical Engineering, Material Science, Physics and Chemistry are involved to give a stimulus to inter-disciplinary “cross cutting technologies” (Photo 1. shows Silicon Solar Cell

Process facility at NCPRE) . The primary objective of the centre is to be one of the leading photovoltaic (PV) research and education centers in the world within the next decade. The centre is located at IIT Bombay which has a strong tradition for inter-disciplinary activity and is thereby well positioned to take up this challenge. Apart from carrying out research, various short term/full time courses are being offered by NCPRE through the Office of Continuing Education Program (CEP). These courses cover the entire gamut of PV technology, trends, system integration, installation, testing and evaluation apart from giving an insight into storage systems for PV, new materials, and novel PV structures, balance of systems, power electronics and PV application. The training courses target academicians, engineering students, working professionals, entrepreneurs and researchers.

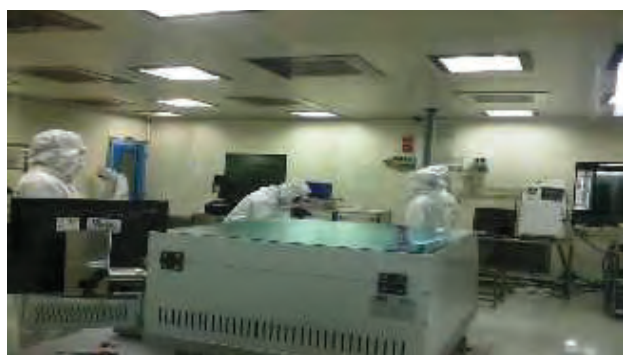


Photo 1: Silicon Solar Cell Process facility at NCPRE

The Energy Research Unit of the **IACS (Indian Association for the cultivation of Science), Jadavpur, Kolkata**, has pioneered frontier research in the areas of development of materials and fabrication technology for thin film silicon and amorphous silicon solar cells.

B.V. Raju Institute Of Technology (BVRIT): An Autonomous Institution for engineering education, located at Medak district, TELANGANA, INDIA and affiliated to the Jawaharlal Nehru Technological University (JNTUH), Hyderabad, BVRIT had evinced interest in solar energy (particularly PV) as early as 2004 when they set up an Energy Park with funding from the erstwhile MNES. The express aim of the Energy Park was to educate the students and also spread awareness among people about renewable energy technologies, particularly PV. The Institution with the help of third and final year students undertook the long term (2004 to 2007) evaluation of different silicon (Si) PV technologies viz PV arrays of mono-crystalline Si, poly-crystalline Si, Edge defined film fed growth (EFG) Si and amorphous silicon [12]. More recently in 2012, BVRIT had

forged a three way tie up with Elkem Solar, Norway (research partner), Titan Energy Systems Ltd, Hyderabad (Industry partner) and BVRIT (Academic partner) to carry out long term evaluation of solar grade silicon cells developed by Elkem Solar. Solar grade silicon (ESS) process starts with the production of raw silicon from quartz by a standard metallurgical process. This is further purified by processes like slag treatment, leaching and directional solidification. The emission of greenhouse gasses during manufacturing is also reduced by 75% compared to the best Siemens process case [13].

A Test Station has been jointly set up at BVRIT. The Test station was commissioned in Feb 2012. The cells developed by Elkem Solar were converted into 240 Watt, 30 V modules. 28 PV modules are under testing/evaluation, 14 Elkem Solar Silicon (ESS) modules and 14 poly-crystalline reference modules have been installed in 4 strings, each carrying 7 numbers of series connected modules (Photo 2 shows the Test bed System of 6.72kW capacity). The ESS strings are connected to an inverter and the Poly Silicon strings are connected to another inverter, which are connected to the grid.



Photo 2: Test bed System (6.72kW PV plant on BVRIT rooftop)

DC and AC Energy meters are wired and the readings are continuously monitored and stored in the computer server (at one minute intervals). The ambient temperature, the module temperature, wind speed/direction and irradiance readings (horizontal and plane of array) are sensed and sent to a data logger and transmitted to the server in the control room (Photo 3 shows the sensors and CR3000 data logger). The energy production data can be viewed from anywhere in the world thanks to the web based software installed in the server. Two years of testing has established the superior performance of the Elkem solar cells/modules especially at high temperatures [14, 15, 16]. The entire Project has been

funded by the Research Council of Norway. State of the art instruments are used in the BVRIT Test Station.



Photo 3: Weather station and CS Campbell Scientific Data-logger

The instruments and sensor equipment available at BVRIT for their testing and evaluation include mainly Pyranometer (Kipp and Zonen), Data logger (Campbell Scientific), Anemometer (Metone/Climatronics), Testo IR Camera System, Daystar I-V Curve Tracer, Power One Inverter, DC and AC Energy Meters (Elmeasure) and software. The under-graduate students are making good use of this facility for their mini and major projects also leading to paper publications as well. Photo 4 shows students monitoring the performance of the PV strings.



Photo 4: Under graduate students working in the field

Recently on 15th October 2014 a team from MNRE & NCPRE (IIT Bombay) conducted “**All India Solar PV modules Degradation Survey-2014**” (Photo 5 shows students with team of MNRE&NCPRE), at BVRIT. During this testing, undergraduate students were also involved and gained knowledge regarding testing of PV modules, use of instruments for I-V measurements, insulation testing, high voltage testing, dark I-V characteristics etc.



Photo 5: BVRIT Students with team of MNRE & NCPRE

A 100 kWp roof-top solar PV plant, grid connected, has been set up at BVRIT, where the continuous performance monitoring of the PV modules and the balance of systems is done by students of various departments. These students take good care of all first level maintenance aspects. Apart from the afore-mentioned activities, BVRIT also offers short term courses to its Electrical, Electronic and Mechanical Engineering students with the accent on the design, integration and installation of Solar PV Systems. Training in PVSyst (Photovoltaic system design software) is also given.

CONCLUSION

It deserves to be highlighted that India’s Research and Educational Institutions are sparing no efforts to be in sync with the developments abroad. This is further buttressed by the joint collaboration forged with premier research and educational institutions, particularly in the United States. Going by the installed PV capacity the world over, up to 2013, India with installation of 1.1 GW stands sixth after China, Japan, USA, Germany and Italy [17]. Supply and demand in the PV industry are poised to achieve equilibrium thanks to the recovery of the PV market and the rise of the energy markets. High efficiency cells are expected to become the mainstream. Energy storage is also assuming increasing significance. The outlook for PV is predicted to be ‘high penetration and low barriers’.

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