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SOLAR PHOTO-VOLTAIC CELL - POLLUTION FREE POWER SUPPLY

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ABSTRACT

The demand for power is growing rapidly. Under such conditions, environment- friendly and pollution-free, non-conventional and renewable energy sources known as 'clean and green energy' have emerged as important alternatives to conventional energy sources. The solar photovoltaic cell energy plays an important role to generate energy with respect to generate from other sources of energy. These sources are pollution free and hence clean energy apart from being unlimited/ inexhaustible. This is direct energy conversion from solar radiation to power electricity for Calculator, Watches, lights etc. Energy can be stored in terms of other sources which can be utilized when solar radiation is not available.

Enormous progress has been made in recent years on a number of photovoltaic (PV) materials and devices in terms of conversion in efficiency. Ultrahigh-efficiency (>30%) PV cells have been fabricated from gallium arsenide (GaAs) and its ternary alloys such as gallium indium phosphide (GaInP 2). The high-efficiency GaAs-based solar cells are being produced on a commercial scale, particularly for space applications. Efficiency in the range of 18%–24% have been achieved in traditional silicon-based devices fabricated from both multi-crystalline and single-crystal materials.

This paper provides a brief overview on the recent progress in PV cell efficiency based on these materials and devices.

KEYWORDS: Solar PV cells, photostatic, amorphous silicon, efficiency.

INTRODUCTION

The light from the Sun is a non-vanishing renewable source of energy which is free from environmental pollution and noise. It can easily compensate the energy drawn from the non-renewable sources of energy such as fossil fuels and petroleum deposits inside the earth. The fabrication of solar cells has passed through a large number of improvement steps from one generation to another. Silicon based solar cells were the first generation solar cells grown on Si wafers, mainly single crystals. Further development to thin films, dye sensitized solar cells and organic solar cells enhanced the cell efficiency as given in Fig.1. The development is basically hindered by the cost and efficiency. In order to choose the right solar cell for a specific geographic location, we are required to understand fundamental mechanisms and functions of several solar technologies that are widely studied. In this Paper, authors have reviewed a progressive development in the solar cell research from one generation to other, and discussed about their future trends and aspects. The paper also tries to emphasize the various practices and methods to promote the benefits of solar energy.

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a.Photovoltaics (**PV**) covers the conversion of light into electricity using semiconducting materials that exhibit the photovoltaic effect, a phenomenon studied in physics, photochemistry, and electrochemistry.

A typical photovoltaic system employs solar panels, each comprising a number of solar cells, which generate electrical power. The first step is the photoelectric effect followed by an electrochemical process where crystallized atoms, ionized in a series, generate an electric current. PV Installations may be ground-mounted, rooftop mounted or wall mounted.

Solar PV generates no pollution. The direct conversion of sunlight to electricity occurs without any moving parts. Photovoltaic systems have been used for fifty years in specialized applications, standalone and grid-connected PV systems have been in use for more than twenty years. They were first mass-produced in 2000, when German environmentalists and the Eurosolar organization got government funding for a ten thousand roof program.

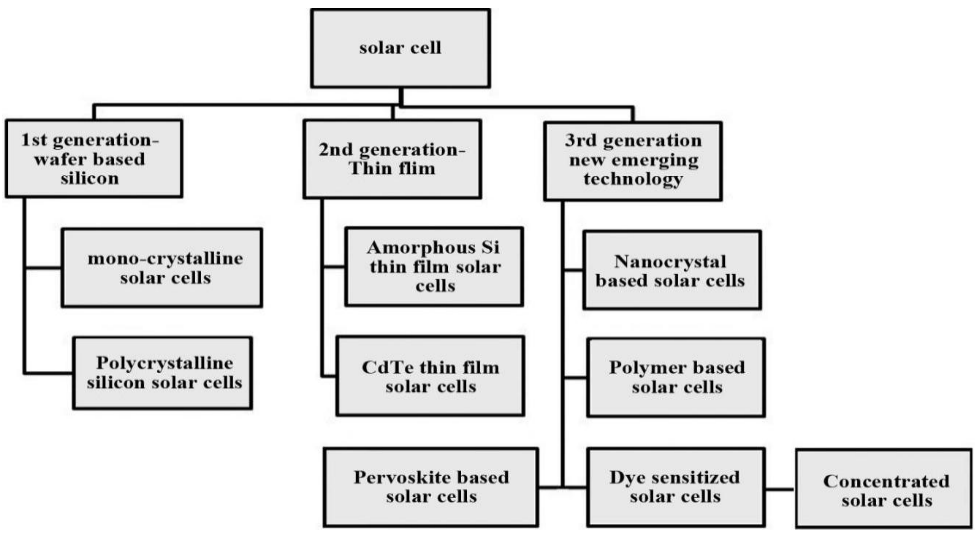

Fig.1: Various types of solar cell technologies and current trends of development

I. Poly-crystalline Silicon Solar Cell (Poly-Si or Mc-Si)

Poly-crystalline PV modules are generally composed of a number of different crystals, coupled to one another in a single cell. The processing of poly-crystalline Si solar cells is more economical, which are produced by cooling a graphite mold filled containing molten silicon. Poly-crystalline Si solar cells are currently the most popular so- lar cells. They are believed to occupy most up to 48% of the solar cell production worldwide.

During solidification of the molten silicon, various crystal structures are formed. Though they are slightly cheaper to fabricate compared to mono-crystalline silicon solar panels, yet are less efficient ~12% - 14%.

II. Second Generation Solar Cells—Thin Film Solar Cells Most of the thin film solar cells and a-Si are second generation solar cells, and are more economical as compared to the first generation silicon wafer solar cells. Silicon-wafer cells have light absorbing layers up to 350 µm thick, while thin-film solar cells have a very thin light absorbing layers, generally of the order of 1 µm thickness. Thin film

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solar cells are classified as; • a-Si. • CdTe. • CIGS (copper indium gallium di-selenide).

III. Amorphous Silicon Thin Film (a-Si) Solar Cell Amorphous Si (a-Si) PV modules are the primitive solar cells that are first to be manufactured industrially. Amorphous (a-Si) solar cells can be manufactured at a low processing temperature, thereby permitting the use of various low cost, polymer and other flexible substrates. These substrates require a smaller amount of energy for processing. Therefore, a-Si amorphous solar cell is comparatively cheaper and widely available. The "amorphous" word with respect to solar cell means that the comprising silicon material of the cell lacks a definite arrangement of atoms in the lattice, non-crystalline structure, or not highly structured. These are fabricated by coating the doped silicon material to the backside of the substrate/glass plate. These solar cells generally are dark brown in color on the reflecting side while silverish on the conducting side. The main issue of a-Si solar cell is the poor and almost unstable efficiency. The cell efficiency automatically falls at PV module level. Currently, the efficiency of commercial PV modules vary in the range of 4% - 8%. They can be easily operated at elevated temperatures, and are suitable for the changing climatic conditions where sun shines for few hours.

IV. Cadmium Telluride (CdTe): Thin Film Solar Cell Among thin-film solar cells, cadmium telluride (CdTe). Cheaper, economically viable photovoltaic (PV) devices, and it is also the first PV technology at a low cost. CdTe has a band gap of ~1.5 eV as well as high optical absorption coefficient and chemical stability. These properties make CdTe most attractive material for designing of thin-film solar cells. CdTe is an excellent direct band gap crystalline compound semiconductor which makes the absorption of light easier and improves the efficiency. It is generally constructed by sandwiching between cadmium sulfide layers to form a p-n junction diode. The manufacturing process involves three steps: Firstly, the CdTe based solar cells are synthesized from poly-crystalline materials and glass is chosen a substrate. Second process involves deposition, i.e., the multiple layers of CdTe solar cells are coated on to substrate using different economical methods. It is already mentioned that CdTe has a direct optimum band gap (~1.45 eV) with high absorption coefficient over 5 × 1015/cm. Therefore, its efficiency usually operates in the range 9% - 11%. CdTe solar cells can be made on polymer substrates and flexible. However, there are various environmental issues with cadmium component of solar cell. Cadmium is regarded as a heavy metal and potential toxic agent that can accumulate in human bodies, animals and plants. The disposal of the toxic Cd based materials as well as their recycling can be highly expensive and damaging too to our environment and society. Therefore, a limited supply of cadmium and environmental hazard associated with its use are the main issues with this CdTe technology.

V. Copper Indium Gallium Di-Selenide (CIGS): Solar Cells CIGS is a quaternary compound semiconductor comprising of the four elements, namely: Copper, Indium, Gallium and Selenium. CIGS are also direct band gap type semiconductors. Compared to the CdTe thin film solar cell, CIGS hold a higher efficiency ~10% - 12%. Due to their significantly high efficiency and economy, CIGS based solar cell technology forms one of the most likely thin film technologies. The processing of CIGS are done by the following techniques: sputtering, evaporation, electro-chemical coating technique, printing and electron beam deposition. In addition, the sputtering can be a two or multistep process involving with deposition and subsequent interaction with selenium later, or can be a one-step reactive process. However, evaporation is similar to the sputtering in the sense that it can be used in a single step, two-step or multiple processing steps. The substrates for CIGS material can be chosen from glass plate, polymers substrates, steel, aluminum etc. The advantages of CIGS thin film solar cells include its prolonged life without a considerable degradation. These properties of CIGS indicate an easy solution to enhance the efficiency.

Third Generation Solar Cells: Third generation cells are the new promising technologies but are not commercially investigated in detail. Most of the developed 3rd generation solar cell types are:

1) Nano crystal based solar cells.

2) Polymer based solar cells.

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3) Dye sensitized solar cells.

4) Concentrated solar cells.

Solar energy is a general term referring to any process that turns sunlight into energy. Two common forms of solar energy are used today: Solar photovoltaic cells and solar thermal technology. Solar thermal technology uses the heat generated from sunlight to create energy. Most commonly, this can be used to heat water for a house or other projects. Or, with increasing complexity, it can turn the heat into electricity. Unfortunately, much of this technology is too expensive and complex to be practical in the United States on any large scale. However, solar photovoltaic cells are a far more promising technology. They provide a simple way of turning light directly into energy. This paper will examine how this technology works on a basic level while accessing the possible benefits and problems this technology has. It will also examine possible technology in the future in an attempt to overcome these problems.

SOLAR PHOTOVOLTAIC CELLS

Photovoltaics(PV) covers the conversion of light into electricity using semiconducting materials that exhibit the photovoltaic effect, a phenomenon studied in physics, photochemistry, and electrochemistry. A photovoltaic cell uses semiconductor material to transform light into electrical energy. Photons from light hitting the material excite electrons, releasing them from their atoms into the material. Once electrons are excited, they are able to move freely within the material. The semi-conductor then serves to force the electrons in the desired directions. By creating a junction of a p and n type semiconductor, an electrical potential is created. The electrons move from the n-type to the p-type. Meanwhile, the positively charged atoms move from the p-type to the n-type. As a result, the n-type material gains a positive charge and the p-type gains a negative charge. It has promising chances of reducing carbon dioxide emissions and thus reducing global warming. But, it still cannot compete economically with current energy means and as a result, more research must be dedicated into the cause in order for its benefits to be fully realized.

Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material. Materials presently used for photovoltaics include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium selenide/sulfide. Copper solar cables connect modules (module cable), arrays (array cable), and sub-fields. Because of the growing demand for renewable energy sources, the manufacturing of solar cells and photovoltaic arrays has advanced considerably in recent years.

The demand for power is growing rapidly. Under such conditions, environment- friendly and pollution-free, non-conventional and renewable energy sources known as 'clean and green energy' have emerged as important alternatives to conventional energy sources. The renewable energy sources are clean and inexhaustible as they rely on solar radiation energy which comes on Earth in terms of Photons is one of the primary sources of energy.

The primary objective of the worldwide photo-voltaic (PV) solar cell research and development is to reduce the cost of PV cells and modules to a level that will be competitive with conventional ways of generating power. One way to achieve this is to significantly increase the conversion efficiency of PV materials and devices. Major advances have been made in recent years in improving the efficiency of almost all of the leading PV materials and devices. Basically, there are two approaches to increasing the efficiency of solar cells:

(1) By selecting the semiconductor materials with appropriate energy gaps to match the solar spectrum and the optimizing their optical, electrical, and structural properties.

(2) By innovative device engineering, which enables more effective charge collection as well as better utilization of the solar spectrum through single and multi-junction approaches.

A. Requirements: Energy Scenario, Current and Projected Generation Capacity, Research & Development, Manufacturing, Silicon Technology, Thin Film Technology, Plasmonic, Organic PV, Dye Sensitized Solar Cells, Perovskite Solar Cells, Storage Technologies, Balance of Systems, PV Cleaning

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Systems, Tracker, PV Industry Waste Disposal, Performance and Reliability, Fuel Cells, Fly Wheels, Super capacitors, Batteries, Hybrid Systems, Standalone Systems, Mini & Micro Grid , Rooftop PV, Inverters, Solar Pumps, Raw Material, Demand Projections, Cost Projections, Building Integrated PV, Railways, Rural Applications, Telecom, Transport, Energy Efficiency, Capacity Building, Human Resources, SEZ, Cluster Approach, Investment, Policy.

B. Photovoltaic solar growth forecasts

As of June 2016, the forecast for photovoltaic solar installations is approximately 5 GW in the calendar year 2016. The country saw about 2.2 GW installed in the first half of 2016, more than all of the solar installations in 2015. India's solar projects underway stood at approximately 22 GW with about 13 GW under construction and about 9 GW in the Request for Proposal (RfP) process.

Table 1: Top 10 PV Production Countries (MW) in 2015

Sl.	Country	Residential (USD)	Commercial (USD)	2015	Added Capacity
1	Germany	2.4	1.8	38,200	1,900
2	China	1.5	1.5	28,199	10,560
3	Japan	4.2	3.6	23,300	9,700
4	Italy	2.8	1.9	18,460	
5	United States	4.9	4.5	18,280	6,201
6	France	4.1	2.7	5,660	927
7	Spain			5,358	
8	UK	2.8	2.4	5,104	2,273
9	Australia	1.8	1.7	4,136	910
10	Belgium			3,074	
11	India				616
12	South Korea				909
13	South Africa				800

C. Solar PV in India- Opportunity to be tapped

India stands at a solar installed capacity of nearly 2.9 GW as on November 2014. Despite our huge potential, government will and incentive mechanisms, large scale deployment of PV will be feasible only if PV generation costs shall achieve the grid parity. The generation cost has been brought down from the initial high of approximately INR 17/unit to about INR 6.5 /unit. However, further reduction in price is still required to obtain grid parity and it will be possible when we shall be able to address the following measures:

- Higher conversion efficiency
- Less material consumption
- Application of new and locally available materials
- Innovations in low cost manufacturing processes
- Mass production
- Optimization of technologies for balance of systems
- Indigenous manufacturing of solar PV equipment
- Generating skilled work force

The Government plans to scale up solar to a cumulative 100GW by 2022. MNRE has already prepared a way forward for achieving the targets envisaged and has listed out the immediate actions required by the Government and interventions from various stakeholders including regulators, distribution companies and financial institutions. Achievement of these targets would not only contribute to long term energy security of country and ecological security by reduction in carbon emissions, but also generate large direct and indirect employment generation opportunities in solar and allied industries like glass, metals, heavy industrial equipment, etc.

Solar power is a sustainable solution for meeting energy needs, reducing dependence on depleting fossil fuels, providing additional revenue to the Government through taxes and duties and making productive use of abundant wastelands for power plants as well as manufacturing hubs. It will also create jobs across the value chain from R&D to manufacturing, installation and maintenance. With the targets of 100GW, the employment numbers are going to shoot up in next 5 -10 years.

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D. Strengthening R&D base

As per the National solar mission, a major R&D initiative has to be set up which would focus firstly, on improvement of efficiencies in existing materials, devices and applications and on reducing costs of balance of systems, establishing new applications by addressing issues related to integration and optimization, secondly, on developing cost-effective storage technologies which would address both variability and storage constraints.

Setting up of institutional capacity like national centre of excellence may be worked out to promote this sector and to encourage various premier research institutes in India to cater the technology interface with international research organizations and technology collaborations to bring forth the R&D capability of Indian institutions.

Short-term R&D must focus on making the PV industry more competitive. Industry would be pushed for investment in short-term R&D and as the PV industry grows, this pressure may increase. Government, however, may take a view on medium and long-term R&D. These views will underpin long-term improvements in technologies and enable breakthroughs that could give such technologies a decisive advantage in energy markets. This will ensure that Solar PV can compete successfully, without subsidy, once external environmental costs and other contributions to social goals (e.g. access, security) are taken into account.

HISTORICAL USAGE OF SOLAR PHOTOVOLTAIC CELL ENERGY

Throughout history, various forms of renewable and non-renewable energies have been employed.

Solar power as a direct energy source has not been captured by mechanical systems until recent human history, but was captured as an energy source through architecture in certain societies for many centuries. Not until the twentieth century was direct solar input extensively explored via more carefully planned architecture (passive solar) or via heat capture in mechanical systems (active solar) or electrical conversion (photovoltaic). Increasingly today the sun is harnessed for heat and electricity.

A. Generating electricity:

For large, commercial size horizontal-axis wind turbines, the generator is mounted in a nacelle at the top of a tower, behind the hub of the turbine rotor. A speed-increasing gearbox may be inserted between the rotor hub and the generator, so that the generator cost and weight can be reduced.

Commercial size generators have a rotor carrying a field winding so that a rotating magnetic field is produced inside a set of winding called the stator. While the rotating field winding consumes a fraction of a percent of the generator output, adjustment of the field current allows good control over the generator output voltage. Very small wind generators (a few watts to perhaps a kilowatt in output) may use permanent magnets but these are too costly to use in large machines and do not allow convenient regulation of the generator voltage.

Electrical generators inherently produce AC power. Older style wind generators rotate at a constant speed, to match power line frequency, which allowed the use of less costly induction generators. Newer wind turbines often turn at whatever speed generates electricity most efficiently. The variable frequency current is then converted to DC and then backs to AC, matching the line frequency and voltage. Although the two conversions require costly equipment and cause power loss, the turbine can capture a significantly larger fraction of the wind energy. In some cases, especially when turbines are sited offshore, the DC energy will be transmitted from the turbine to a central (onshore) inverter for connection to the grid.

B. **Key R&D thrust areas**

- Thrust areas which need to be undertaken by Indian R&D fraternity to make India a leading nation in SPV technology and its applications to remain globally competitive with state-of-the-art:
  - R&D for production of poly-silicon, the basic material for producing crystalline silicon. Without this basic material India will not be able to compete globally and will remain an importer

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of solar cells and modules from abroad.

• Development of indigenous manufacturing equipment for the production of PV cells and modules and other items. With imported equipment Indian products will not be cost effective.

• Strong R&D base is needed to support Indian industries to remain globally competitive. In addition India should do frontline Research and Development in different areas of emerging SPV Technologies for which comprehensive plan with targets have to be worked out. Major thrust areas under the technology heads are as below:

➢ **Silicon technology**

1. Development of crystalline (single crystal) silicon solar cell efficiency of 20% and above
2. Development of crystalline silicon (single crystal) solar cell with Interdigited Back Contact (IBC) with efficiency 24% and above.

➢ **Thin Film Solar Cell Technologies**

1. Development of silicon based Thin Film solar cell Technologies with stabilized efficiencies of 15%
2. Development of CZTS Thin Film Technology with efficiency 15% and above

➢ **New & futuristic technologies**

1. HIT cell Technology
2. Development of HIT Cell Technology with efficiency 23%
3. Development of Inter-digited Back Contact HIT cell Technology with efficiency 25% and above.
4. Development of Dye sensitized soar cell with initial efficiency above 15%
5. Development of stabilized and Reliable Perovskite cell with efficiency 22% and above
6. Development of organic /polymer soar cells with initial efficiency 12% and above

✓ Development of low cost and efficient storage technologies

✓ Development of innovative Balance of Systems including power electronics

✓ Development of equipment for manufacturing of PV Modules

SOLAR PV CELL

The Solar Photo Voltaic (SPV) technology which enables the direct conversion of sun light into electricity can be used to run pumps, lights, refrigerators, TV sets, etc., and it has several distinct advantages, since it does not have moving parts, produces no noise or pollution, requires very little maintenance and can be installed anywhere. These advantages make them an ideal power source for use especially in remote and isolated areas, which are not served by conventional electricity making use of ample sunshine available in India, for nearly 300 days in a year.

Solar radiation reaches the Earth's upper atmosphere at a rate of 1,366 watts per square meter (W/m2). While traveling through the atmosphere, 6% of the incoming solar radiation (insolation) is reflected and 16% is absorbed resulting in a peak irradiance at the equator of 1,020 W/m². Average atmospheric conditions (clouds, dust, and pollution) reduce insolation by 20% through reflection and 16% through absorption. In addition to affecting the quantity of insolation reaching the surface, atmospheric conditions also affect the quality of insolation reaching the surface by diffusing incoming light and altering its spectrum.

Photovoltaic panels currently convert about 15% of incident sunlight into electricity; therefore, a solar panel in the contiguous United States on average delivers 19 to 56 W/m² or 0.45-1.35 kWh/m²/day.

A recent concern is global dimming, an effect of pollution that is allowing less sunlight to reach the Earth's surface. It is intricately linked with pollution particles and global warming, and it is mostly of concern for issues of global climate change, but is also of concern to proponents of solar power because of the existing and potential future decreases in available solar energy. The order of magnitude is about 4% less solar energy available at sea level. Sometimes mostly increased reflection from clouds back into outer space.

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After passing through the Earth's atmosphere, most of the sun's energy is in the form of visible and infrared radiations.

A. Current developments

For best performance, terrestrial PV systems aim to maximize the time they face the sun. Solar trackers achieve this by moving PV panels to follow the sun. The increase can be by as much as 20% in winter and by as much as 50% in summer. Static mounted systems can be optimized by analysis of the sun path. Panels are often set to latitude tilt, an angle equal to the latitude, but performance can be improved by adjusting the angle for summer or winter. Generally, as with other semiconductor devices, temperatures above room temperature reduce the performance of photovoltaics.

A number of solar panels may also be mounted vertically above each other in a tower, if the zenith distance of the Sun is greater than zero, and the tower can be turned horizontally as a whole and each panels additionally around a horizontal axis. In such a tower the panels can follow the Sun exactly. Such a device may be described as a ladder mounted on a turnable disk. Each step of that ladder is the middle axis of a rectangular solar panel. In case the zenith distance of the Sun reaches zero, the "ladder" may be rotated to the north or the south to avoid a solar panel producing a shadow on a lower solar panel. Instead of an exactly vertical tower one can choose a tower with an axis directed to the polar star, meaning that it is parallel to the rotation axis of the Earth. In this case the angle between the axis and the Sun is always larger than 66 degrees. During a day it is only necessary to turn the panels around this axis to follow the Sun. Installations may be ground-mounted (and sometimes integrated with farming and grazing)[23] or built into the roof or walls of a building (building-integrated photovoltaics).

TYPES OF TECHNOLOGIES

Many technologies have been developed to make use of solar radiation. Some of these technologies make direct use of the solar energy (e.g. to provide light, heat, etc.), while other technologies produce electricity.

- ❖ Direct or Indirect
- ❖ Passive or active
- ❖ Concentrating or non-concentrating

ADVANTAGES AND DISADVANTAGES OF SOLAR POWER

Advantages

a. The 122 PW of sunlight reaching the earth's surface is plentiful compared to the 13 TW average power consumed by humans.

b. Solar power is pollution free during use. Production end wastes and emissions are manageable using existing pollution controls. End-of-use recycling technologies are under development.

c. Facilities can operate with little maintenance or intervention after initial setup.

d. Solar electric generation is economically competitive where grid connection or fuel transport is difficult, costly or impossible. Examples include satellites, island communities, remote locations and ocean vessels.

e. When grid connected, solar electric generation can displace the highest cost electricity during times of peak demand (in most climatic regions), can reduce grid loading, and can eliminate the need for local battery power for use in times of darkness and high local demand; such application is encouraged by net metering. Time-of-use net metering can be highly favorable to small photovoltaic systems.

f. Grid connected solar electricity can be used locally thus minimizing transmission /distribution losses (approx. 7.2%).

g. Once the initial capital cost of building a solar power plant has been spent, operating costs are low when compared to existing power technologies.

Disadvantages

a. Limited power density: Average daily insolation

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in the contiguous U.S. is 3-7 kWh/m^2 usable by 7-17.7% efficient solar panels.

b. Locations at high latitudes or with substantial cloud cover offer reduced potential for solar power use.

c. Like electricity from nuclear or fossil fuel plants, it can only realistically be used to power transport vehicles by converting light energy into another form of energy (e.g. battery stored electricity or by electrolyzing water to produce hydrogen) suitable for transport.

d. Solar cells produce DC which must be converted to AC when used in currently existing distribution grids. This incurs an energy penalty of 4-12%.

CONCLUSION

The basic demand of a human life is a good health and better life uses appliances which facilitates to us a frictionless conditions. So energy is the key tool for these basics. Renewable energy sources helps to give the pollution free energy economically. In near future non-conventional energy sources should have more percentage of generation of energy in comparison of conventional sources.

Remarkable progress has been made in recent years in improving the conversion efficiencies of a number of PV devices. Ultrahigh-efficiency (η>30%) solar cells have been fabricated from gallium arsenide and its ternary alloys. Record-level efficiencies have been achieved on a silicon-based solar cell based on single-crystal and polycrystalline silicon. Various thin-film technologies such as amorphous silicon, CIGS, and CdTe materials and devices continue to show significant advances in their conversion efficiency. Some exciting possibilities are emerging on new PV devices with moderate efficiencies and potential for lower cost.

The crystalline silicon heterojunction structure adopted in photovoltaic modules commercialized as Panasonic's HIT has significantly reduced recombination loss, resulting in greater conversion efficiency. The structure of an interdigitated back contact was adopted with our crystalline silicon heterojunction solar cells to reduce optical loss from a front grid electrode, a transparent conducting oxide (TCO) layer, and a-Si:H layers as an approach for exceeding the conversion efficiency of 25%. As a result of the improved short-circuit current (J_{sc}), we achieved the world's highest efficiency of 25.6% for crystalline silicon-based solar cells under 1-sun illumination (designated area: 143.7 cm^2).

A. Best Research-Cell Efficiencies

The most efficient type of solar cell to date is a multi-junction concentrator solar cell with an efficiency of 46.0% produced by Fraunhofer ISE in December 2014. The highest efficiencies achieved without concentration include a material by Sharp Corporation at 35.8% using a proprietary triple-junction manufacturing technology in 2009, and Boeing Spectrolab (40.7% also using a triple-layer design). The US company SunPower produces cells that have an efficiency of 21.5%, well above the market average of 12–18%.

One of the major causes for the decreased performance of cells is overheating. The efficiency of a solar cell declines by about 0.5% for every 1 degree Celsius increase in temperature. This means that a 100 degree increase in surface temperature could decrease the efficiency of a solar cell by about half. Self-cooling solar cells are one solution to this problem. Rather than using energy to cool the surface, pyramid and cone shapes can be formed from silica, and attached to the surface of a solar panel.

Global installed PV capacity reached at least 177 gigawatts in 2014, enough to supply 1 percent of the world's total electricity consumption. Solar PV is growing fastest in Asia, with China and Japan currently accounting for half of worldwide deployment.

B. Applications

Epitaxial wafers can be grown on a monocrystalline silicon "seed" wafer by atmospheric-pressure CVD in a high-throughput inline process, and then detached as self-supporting wafers of some standard thickness

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(e.g., 250 µm) that can be manipulated by hand, and directly substituted for wafer cells cut from monocrystalline silicon ingots. Solar cells made with this technique can have efficiencies approaching those of wafer-cut cells, but at appreciably lower cost.

C. MODERATE-EFFICIENCY LOW-COST SOLAR CELLS: (η>12%)

A new type of PV cell based on the dye-sensitization of thin (10–20µm) nanocrystalline films of TiO2 in contact with a non-aqueous electrolyte has received a great deal of attention worldwide. The cell is very simple to fabricate and, in principle, its color can be tuned through the visible spectrum, ranging from being completely transparent to black opaque by changing the absorption characteristics of the dye. The highest present efficiency of the dye-sensitized photochemical solar cell is about 11%. The cell has the potential to be a low- cost PV option. Unique applications include PV power windows and photoelectrochromic windows.

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