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A Survey on Energy Demand and Solar Photovoltaic Electricity

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Abstract— Energy is a key to the advancement and prosperity of human life. More and more energy consumption is expected in future to sustain the current human development. The predicated energy consumption for 2050 will amount to as much as 30TW. The question is how to supply all that energy? The primary solution is to burn more fossil fuels or build more nuclear power plants. However the greenhouse gasses produced by burning fossil fuels have been responsible for global warming, and the unanswered question of safe disposal of radioactive waste from nuclear plants raises several issues. In that respect, solar photovoltaic electricity is one of the best options for sustainable future energy requirements of the world. At present, the PV market is growing rapidly at an annual rate of 35–40%, with PV production around 10.66 GW in 2009. Si and GaAs monocrystalline solar cells efficiencies are very close to the theoretically predicted maximum values. But the production cost of this technology is high, around $1.50 per peak watt. Thin-film PV technology substantially reduces the cost of solar cells. Production cost of CdTe thin-film modules is presently around $0.76 per peak watt and efficiency is of 16.5% which is the maximum recorded value.

Index Terms— Carrier Multiplication, Crystalline Si Technology, Intermediate Bands, PV effect, Solar Photovoltaic, Band-Gap Energy, Thin Film Technology.

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1 Introduction

Greenhouse gasses – carbon dioxide, methane, nitrous oxide, hydrocarbons and chlorofluorocarbons – have been surrounded the earth's atmosphere like a clear thermal blanket, allowing the sun's warming rays in and trapped the heat close to the earth surface. But the increased use of fossil fuels has significantly increased greenhouse gasses emissions, particularly carbon dioxide, creating an enhanced greenhouse effect, known as global warming. Another problem is that, oil is not a renewable resource. Its supply will eventually be depleted, took millions of years to generate and going to finish in a single life time. So supplying the future energy demand is really a big issue for us.

Presently, the world energy consumption is 10 terawatts (TW) per year, and by 2050, it is projected to be about 30 TW. The world will need about 20 TW of non-CO2 energy to stabilize CO_2 in the atmosphere by the mid-century. The simplest scenario to stabilize CO_2 by the mid-century is one in which photovoltaics (PV) and other renewables are used for electricity (10 TW), hydrogen for transportation (10 TW), and fossil fuels for residential and industrial heating (10 TW) [1]. Thus, PV will play a significant role in meeting the world future energy demand. The present age is considered as the "tipping point" for PV [2].

2 Renewable Energy Sources

Most of the renewable energy comes from either directly or indirectly from the sun. Sunlight or solar energy can be used directly for heating and lighting homes and buildings, for generating electricity solar cooling and a variety of commercial and industrial uses. The sun heat also drives the winds, whose energy is also captured with the wind turbines. Then the winds and the sun cause water to evaporate. When this water vapor turns into rain or snow and flows downhill into rivers or streams, its energy is captured using hydroelectric power. Along with the rain and snow, sunlight causes plants to grow. The organic matter that makes up those plants is known as biomass. Biomass can be used to produce electricity, transportation fuels or chemicals. The use of biomass for any of these purposes is called biomass energy.

The energy of the ocean's tides come from the gravitational pull of the moon and the sun upon the earth. In fact, the ocean energy comes from a number of sources. The energy of the ocean waves are driven by both the tides and the winds. The sun also warms the surface of the ocean more than the ocean depths, creating a temperature difference that can be used as an energy source. All these forms of ocean energy can be used to produce electricity. Geothermal energy taps the earth's internal heat for a variety of uses, including electric power production and the heating and cooling of buildings.

The world already uses 0.6 TW of the 0.9 TW of economically feasible hydroelectric power. Through enough biomass fuel could be theoretically grown, such crops would need to occupy an unrealistic 31% of the land on earth. Wind power is irregular and relatively scarce, with only 2 TW available globally, in practical terms. There are few ideal sites for geothermal energy but our drilling technology is not sufficiently advanced to economically access that form of energy. On the other hand, the sun continuously showers the earth with enormous amount of photons. This resource must be harvested. This is the most promising source of alternative energy.

3 PHOTOVOLTAIC (PV) EFFECT

The power of sunlight incident on the earth is about 125,000 TW [4]. That is about 10,000times more than the world current demand. The sun will be available for a very long time for us.

The best way to utilize the energy of the sun is by converting it into electrical energy. Solar cells perform this conversion based on photovoltaic effect. Solar cells are totally silent and nonpolluting. They require little maintenance and have a long lifetime. Compared to other renewable energy sources such as wind and water, they are less noisy and less likely to fail. The PV effect was discovered in 1839 by Becquerel while studying the effect of light on electrolytic cells. A long period was required to reach sufficiently high efficiency. Solar cells were first designed for very specialized uses such in spacecrafts. They can now be found on every day use appliances.

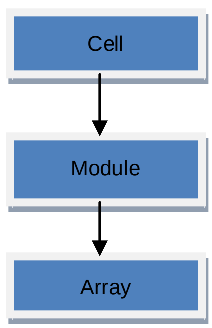

Fig 1: Constituents of a Solar Panel

The solar cells convert sunlight directly into electricity. Solar cells are made of semiconducting materials. When sunlight is absorbed by these materials, the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electricity. This process of converting light to electricity is called the photovoltaic (PV) effect. Solar cells are typically combined into modules that hold about 36/72 cells; about 10 of these modules are mounted in PV arrays that can measure up to several meters on a side. These flat-plate PV arrays can be mounted at a fixed angle facing the sun or they can be mounted on a tracking device that follows the sun, allowing them to capture the most sunlight during day time.

4 EFFICIENCY LIMIT OF SOLAR CELLS

The efficiency of a solar cell was first analyzed by Shockley and Queisser in the year of 1961 [3]. According to them, the thermodynamic efficiency for an ideal single homo-junction cell is about 31% [3]. If the energy of the photon strikes is less then the energy of the band gap of the semiconductor materials, losses of photon occurs. If the energy of the photon strikes is much more greater then the energy of the band gap of the semiconductor materials, thermal relaxation of carrier occurs, called phonon. In the classic case, every photon absorbed causes in a solar cell produces at most one electron–hole pair. But in short-wavelength range a-Si solar cell has quantum efficiencies higher than 1. The energy in access of band-gap is used to for second electron-hole pair generation. Several methods have been proposed to increase the power conversion efficiency of solar cells. Some of them are given below.

4.1 The Intermediate Band Solar Cells (IBSC)

In general case, the energy levels within a semiconductor band are considered as non-radiative recombination center. But when we say about intermediate band solar cells, these intermediate levels must behave as radiative recombination centers. This centers are called "intermediate bands" [5].

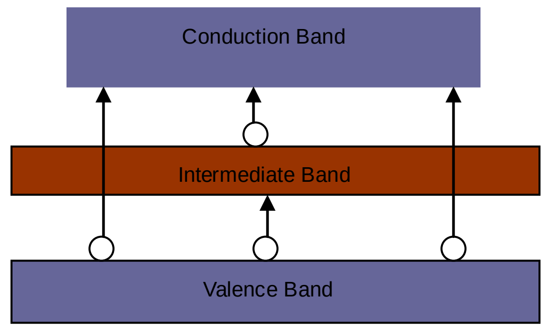

Fig 2: The intermediate band solar cell

To manufacture an intermediate band solar cell, the IB material has to be sandwiched between conventional p-type and n-type materials. Thus IB material is isolated from contacts. When photons strike with an amount of energy above the band gap, electrons jump from the valance to the conduction band, as it normally does in a conventional semiconductor solar cell. But when a photon strikes with an amount of energy less than the energy of the band gap, first an electron jumps from valance band to intermediate band then intermediate band to conduction band. In that case, it requires the IB to be partially filled with electrons and implies that the Fermi level has to cross it. This the one of the methods by which we can increase the efficiency of solar cells.

4.2 Carrier Multiplication

Another option to increase the efficiency of a solar cell is to use carrier multiplication effect. Carrier multiplication involves the generation of multiple electron-hole pairs from the absorption of a single photon. It increases power conversion efficiency in the form of increased solar cell photocurrent. When carrier multiplication is active, the effective photon to pair generation is greater than 1(one), for photon energies greater than twice the band-gap.

From the Figure 3, we see that when a photon strikes with an amount of energy greater than the twice of the band-gap, electrons jumps from the lowest level of the valence band to the highest level of the conduction band. In normal case, when carrier multiplication is not active, the electron drops down to the lowest level of the conduction band relaxing the extra energy as heat. But when the carrier multiplication is active the electron drops down to the lowest level of the conduction band creating another free electron. In this way, carrier multiplication helps us to increase the efficiency of a solar cell.

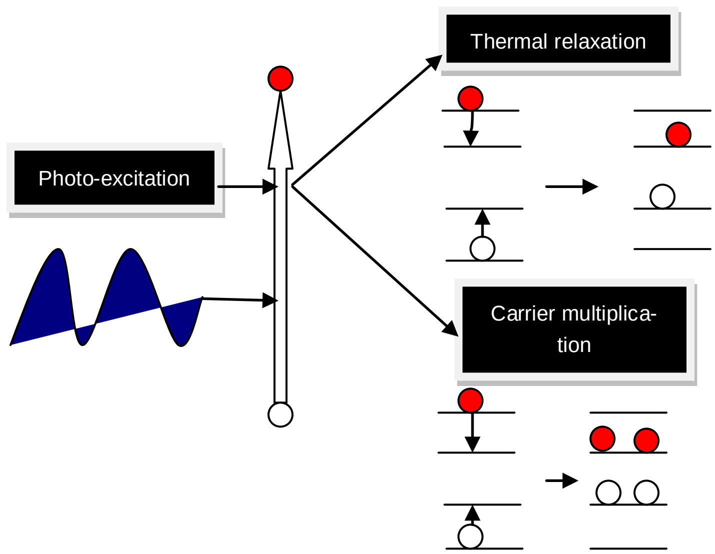

Fig 3: Carrier Multiplication Effect

4.3 Multi-Junction Device

Multi-junction solar cells are one of the most common and successful third generation solar cells. The multi-junction concept was considered theoretically in the case of ideal cells operating in the radiative limit, to ascertain the maximum efficiency of photovoltaic conversion [6]. In a single p-n junction solar cell, any photon with energy lower than the material's band gap will not be absorbed and any photon greater than the band gap will lose energy due to thermal relaxation. But a multi-junction solar cell contains multiple different tandem p-n junctions. These p-n junctions have semiconducting band-gaps spread out over the spectral distribution of the sun, arranged in decreasing order. When sun light passes through the cell, these tandem p-n junctions filter the light ensuring that the light is absorbed in the most efficient junction.

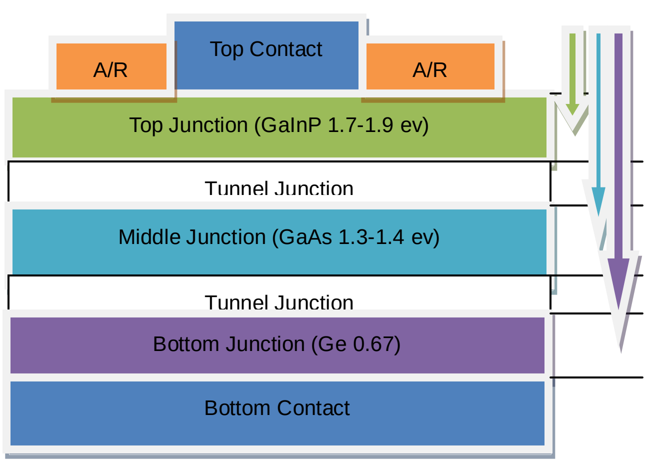

Fig 4: The Internal diagram of a multi-junctioned solar cell.

From the Figure 4, we found that, if a photon have energy in between 1.3 eV to 1.4 eV then the electron is absorbed in yellow sectioned junction, not in blue or red sectioned junction. This design is capable of improving solar cell efficiency by increasing the range of photons absorbed from the solar spectrum while also minimizing their thermalization losses.

5 Conclusion

In the most recent decade, 24.7% efficiency was achieved in crystalline silicon solar cells[7], 16.7% efficiency was achieved in thin –film cadmium telluride (CdTe) solar cells [8] and 19.5% efficiency was achieved in thin –film copper-indium-gallium-diselenide (CIGS) solar cells [9]. Today, the majority of solar cells are made of crystalline silicon. Silicon's availability is huge, but crystalline Si technology cells require an expensive production procedure. Silicon is fragile and it is an indirect band-gap material. Both of these features require production of relatively thick cells. So, transition to less material and low cost thin-film is essential for PV production. Thin film PV module currently have a world wide production of about 12% of world total PV module production. Although commercially not established as well as Si, thin-film polycrystalline solar cells, such as CdTe, CIS and CIGS, have a great advantage of significantly lower the production cost. Today, the goal of research and development in photovoltaic conversion is to produce commercially, viable solar cells that have the following features: 1) low cost 2) high conversion efficiency and 3) long and stable operating lifetime. It is anticipated that the CdTe PV is the potential candidate to the shared dream of humanity, clean and affordable energy from the sun, for all in anywhere.

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