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REVIEW ON SEMICONDUCTOR MATERIALS FOR APPLICATION IN PHOTOVOLTAICS

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ABSTRACT

Semiconductor materials are reviewed in the context of their application in photovoltaics .Solar cells based on single crystal silicon are facing tough competition from the solar cells which are manufactured with thin films of materials such as Cadmium telluride. Other polycrystalline material like copper indium gallium diselenide has also made significant contribution in this field. For photovoltaics, organic solar cells are being explored extensively. Looking at the world energy requirements in near future, there is an urgent need to expand the canvas of photovoltaic materials while addressing the issues of cost, sustainability and environmental safety.

1.0 INTRODUCTION

According to European Union estimates of future requirements , the World energy consumption by 2050 will almost be doubled.In order to keep carbon emmission level at present level,an additional power of 15 TW from non conventional sources shall be required.The power obtained from Sun's radiation incident on Earth can fill up this energy gap.Photovoltaics , therefore can make a significant contribution to meet global energy requirement of 2050.Hence , there is urgent need to explore new range of PV materials and to make them sustainable and cost effective by improving the processess,which are available for solar cell industry.The present paper reviews the application s of various semiconductor materials in photovoltaics

2.1SILICON

Crystalline silicon has been widely used in PV technology. With long historical background and technology base the present day markets for power modules are still dominated by crystalline silicon (31). As a PV material, it is very well understood, and its related technology continues to grow rapidly. Semi-automated Fabrication techniques for growing pure and high quality Si material are available today (38).Silicon solar cells, are available in monocrystalline, multi-crystalline and amorphous forms. Crystalline silicon solar panels had over 80 per cent market share in 2009, while other thin film solar cells had only 20 per cent market share. Processes are being explored by the industry so as to reduce the cost by 50% for PV grade silicon which would eventually reduce the cost of crystalline silicon power module. Polycrystalline cells with efficiencies above 19% and thickness of 5 μm are possible with the use of light trapping techniques, (4)

2.2 AMORPHOUS SILICON

The first Hydrogenated amorphous silicon (a-Si:H) cell with less than 1% efficiency was made in 1973. Since then it has become an important alternative to polycrystalline or crystalline silicon.(44).Amorphous silicon has many large area device application such as solar cells, panel displays and photoreceptors etc.(1,14,19,32) With its high optical absorption and photoconductivity(33), a-Si:H based single junction solar cells have shown an efficiency of 12% (20). Other than having high light absorbing properties, amorphous silicon can be grown on inexpensive substrates like plastic, glass or steel. However the main drawback of amorphous silicon based cells was the presence of dangling bonds which were identified as light induced defects prevalent in the intrinsic layer of the structure which resulted into loss of efficiency up to 50%(3,45). With the introduction of two stacked amorphous silicon cells and extra thin intrinsic layer, the degradation less than 10% for solar cells has been achieved. The other drawback of low efficiency has also been addressed by the researchers by putting in better design and fabrication and thereby reducing recombination in the intrinsic layer and predicting efficiency up to 12% for large submodules. Multijunction solar cells comprising of alloys of amorphous Si with varying band gap and stacked upon each other provide higher efficiency as these structures utilizes light in more effective manner. Theoretical efficiency of such configuration were estimated as 17% for two junction cell (2) and for three junction cell as high as 24% (42)

2.3CdTe

Cadmium telluride (CdTe) polycrystalline thin films have all the benefits of amorphous silicon. Being highly absorbent and by using lesser material, they are also suitable to any latest manufacturing processes. Among the thin film technology based solar panels, CdTe was referred as the most widely used material in the year 2009 by one of the manufacturing companies named first Star(15)

The other benefits are that they are not subjected to any induced degradation by light. Various deposition techniques can be used. Electrodeposition and Spray pyrolysis methods of deposition used for CdTe are very inexpensive and have shown high throughput. The problems associated with the Polycrystalline thin films are that Cadmium telluride shows difficulty in contacting p-type CdTe and therefore performance gets degraded. However this problem has also been solved with the application of p-i-n structure, which has n-CdS window, intrinsic CdTe layer and p-ZnTe. Such type of modifications and improvements have resulted in to increased efficiency for large size CdTe submodules to more than 7% and for small-area cells upto 11% (20). CdTe and CuInSe2 are also being used as a material for two junction devices by the scientists to achieve an efficiency more than 20% (48). Another problem with CdTe is the mineral scarcity, it is estimated that due to resource limitation the possible contribution of this solar cell by 2050 may be restricted to below 1% of additional power required by that time(22)Therefore sustainability, cost and scarcity of CdTe requires planning in the deployment of such PV solar cells as it quite demanding.

2.4 III-V MATERIALS

GaAs has a band gap of 1.45 eV,which is highly absorptive as far as single junction solar cell is concerned. This feature makes it an ideal PV material. The highest theoretical efficiencies with GaAs and its alloys such as AlGaAs and Indium Gallium Arsenide InGaAs have been obtained in the order of 39%(Single junction solar cell under conc. Light)(5), which is higher than that of Silicon (29). An efficiency of 31.0% for a two junction GaAs/Si cell have been reported under concentrated sunlight (20,34).GaAs has also been used to make single crystal thin film solar cell and a record efficiency of 22.4% has been reported (20,34). Apart from having higher efficiency, these materials have shown better radiation hardness than Si which makes III-V compound semiconductors a better choice in space applications. With the application of high concentration systems in terrestrial PV market, these materials of higher efficiency than Si, have opened up new possibilities .The required area of solar cell material in these systems is reduced up to three times as compared to conventional flat modules, therefore III-V materials have become cost effective too. To enhance efficiency,multijunction designs comprising of GaAS, AlGaAs and InGaAs have been worked out. With monolithic fabrication and matching of lattice constants, such combination are reported to have an efficiency in the order of 35 to40(50)

2.5 CuInGaSe2 (CIGS) SOLAR CELLS

CIGS solar cells have favorable properties for PV applications. $CuInSe_2$ with a band gap of 1.53eV becomes the ideal material for photovoltaics.Moreover,there is an advantage that band gap of $CuInSe_2$ can be engineered by alloying it with Ga or Al.(21).Variation from 1.0-1.72eV in band gap as function of Ga content has been reported, which also affects other parameters(17)
In terms of laboratory efficiency, CIGS Cells have crossed 20% barrier for 1 sun(30).Module efficiency have also been reported to be around 10%(35). Coevaporation or sputtering processes are being used to fabricate CIGS cells. These techniques uses selenium atmosphere. Researchers at IBM have developed low cost method to counter cheaper CdTe Technology (26) and to give 12% efficiency. Electrodeposition method is also being explored by researchers to give efficiency over 10%(6,39)

2.6 ORGANIC CELLS

Organic photovoltaic materials are important because of their application to low cost solar cells. With their lightweight and flexibility these PV cells can easily be integrated into a given structure(13,27,28). On account of these properties, a massive research work has been carried out on these materials during the last decade. From 2001 to 2012,the efficiency has been increased from 2.5% to 9% for these materials (8,9,10,16,18,23,24,36,37,40,41,46,47).Polymer molecules of poly(3-hexyl thiophene) (P3HT) which are used as organic material have two main advantages over its inorganic counterpart. Firstly their absorption coefficient is very high ($\geq 10^5$ cm^{-1}) and secondly their density is much lower as compared to polycrystalline Si(12).These two factors allow organic cells to use very thin films (~ 50-200 nm) with good absorption(43,) and to use smaller amount of material so as to reduce the cost and weight of these organic cells. The bulk heterojunction is the most widely used geometry for organic solar cell .Fullerene acts as electron acceptor(11) and P3HT (poly-3-hexyl thiophene) act as electron donar and in ideal case the excitons (electron hole pair) are allowed to reach donar acceptor interface before their recombination takes place in bulk heterojunction solar cell (49)

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