© November 2024 | IJIRT | Volume 11 Issue 6 | ISSN: 2349-6002

Design of Low Cost and Highly Efficient Un-doped Carrier Selective Hetero contact Solar Cells with SiO2 as Surface Passivation

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Abstract: Photovoltaic (PV) technology, which converts light into electricity, can assist to meet rising energy demands. c-Si solar cells have a market share of approximately 95% and an efficiency range of 20% to 25%, which is less than the theoretical limit of 29.43% but has a longer reliability of more than 20 years. Low efficiency is caused by optical, recombination, and spectral losses, as well as parasitic absorption and Auger recombination. SHJ technology, which uses n-a-Si:H and p-a-Si:H as carrier-selective contacts and i-a-Si:H as surface passivation, achieves a high efficiency of 26.7%. However, placing doped a-Si contacts at high temperatures is challenging and produces hazardous vapours. Transition metal oxide (TMO) passivated contacts can be employed as an alternative material, with efficiencies of 24.75% and a potential of more than 28.4%. TMO's asymmetric hetero-contacts, carrier transport methods, material property optimization, and perspective can increase passivation and efficiency while lowering manufacturing costs and providing a levelized energy cost to society.

Keywords: c-Si solar cells, carrier-selective heterocontacts, surface passivation, transition metal oxide (TMO)

1. INTRODUCTION

Energy is a basic human requirement, yet conventional sources such as coal, oil, and gas are insufficient to provide it. To fulfil the increasing energy demand, nontraditional sources such as biomass, wind, sun, and tide are required. Solar power is a popular, renewable, and environmentally benign alternative to fossil fuels. Photovoltaic and photothermal technologies both use solar energy, with photovoltaic cells directly converting sunlight into electricity [1-2]. Silicon is commonly utilized in solar cells due to its abundance, nontoxicity, accessibility, and low cost. Silicon solar cells rely on PN junctions for manufacturing. The theoretical efficiency of PV solar cells is 29.43%, with a 1.1 eV band gap known as the Shockley-Queisser limit. Solar cells are classified into several types, including crystalline (c-Si), monocrystalline and polycrystalline, thin film technology, quantum dot, polymer and organic, dye-sensitized, perovskites, kesterite, TiO_2, and tandem solar cells. c-Si solar cells dominate the photovoltaic (PV) technology industry, accounting for 95% [3-4].

In HIT solar cell technology, undoped hydrogenated a-Si thin layers use surface passivation to reduce recombination losses. Doped hydrogenated amorphous silicon thin films utilized as carrier selective contact with interdigitated base contact reach 26.7% efficiency. Transition metal oxide (TMO) connections between titanium oxide and molybdenum oxide can reduce parasitic losses while being environmentally benign and cost-effective. TMOs currently have an efficiency of around 25%, with the potential to reach 28.4%. The primary goal with solar cells is to increase efficiency while lowering production costs, resulting in a levelized cost of electricity to society. This article discusses DFCSC design concepts, fabrication processes, and performance developments, with a focus on new materials and improved cell designs [5-7].

2. SILICON HETEROJUNCTION TECHNOLOGY (SHJ)

SHJ c-Si solar cells separate & transmit charge through doped a-Si:H contacts. Doping process is a complex & costly and produces hazardous gases. Intrinsic a-Si layers are used for surface passivation; however, they need precision plasma-enhanced chemical vapor deposition, which increases production costs [8-10]. TMOs with suitable work functions are utilized in dopant free carrier selective contacts (DFCSCs) to form selective electron and hole connections that do not require doping. These materials form heterojunctions with silicon, enabling efficient charge separation and transport. Surface passivation is achieved by using alternative materials such as SiO_2, which simplifies the fabrication process and lowers the need for high-temperature processing [11-13].

3. THE SIGNIFICANCE OF LOW-COST EFFICIENT SOLAR CELL DESIGNS

Solar energy is becoming increasingly popular because to its efficient designs, sustainability, economic viability, and energy independence. It is getting more inexpensive, particularly for larger upfront payments [14-15]. Grid parity is critical for lowering fossil fuel use and addressing climate change. Affordable solar solutions can promote energy independence in countries that rely on imported fuels while also balancing demand and supply as the world's population grows by 10 billion by 2050 [16-17].

4. NEEDS FOR EFFECTIVE HETEROJUNCTIONS FOR C-SI SOLAR CELLS

Carrier selectivity is achieved using heterojunction band alignments, which limit carrier flux and inhibit interface defect recombination. Energy offset spikes are reduced by keeping them low in the carrier transport band and high during carrier blocking. Hole-selective layers, such as MoO_3, tungsten oxide, vanadium pentoxide, and nickel oxide, have modest valence band offsets but large conduction band offsets, allowing holes from Si to make selective contact while inhibiting holes [18-20]. Electron-selective contacts, such as TiO_2, ZnO, and HfO_2, have a large and narrow conduction band offset, allowing electrons Si to transfer to the electron-selective contact while inhibiting holes. Carrier selective contact reduce the recombination losses and improved the efficiency and further reduced the manufacturing cost of solar cells. An effective interface passivation of defects and dangling bonds is also required, which can be accomplished by forming new bonds with the heterojunction material [21-23].

5. DESIGN PRINCIPLES FOR LOW COST AND HIGHLY EFFICIENT SOLAR CELL

Innovative materials such as transition metal oxides, dopant-free surface passivation with SiO_2, carrier selectivity, heterocontact formation, and device architecture are being used to build low-cost and highly efficient c-Si solar cells. Transition metal oxides such as TiO_2 and MoO_3 are being studied as carrier-selective contacts, giving low-cost alternatives with desirable electrical properties. SHJ c-Si SCs use doped a-Si:H connections, however the method is expensive, time-consuming, and releases hazardous gases [24-26]. TMO carrier selective connections form efficient electron and hole picking contacts while reducing surface recombination. Alternative surface passivation methods, such as thermally generated silicon dioxide, can reduce recombination at the silicon surface by neutralizing surface defects and decreasing interface recombination velocity. Heterojunction designs, nanostructured surfaces, thin-film layers, and double-sided solar cells all enhance carrier transport, light absorption, and efficiency in solar cells. These tactics increase light absorption, decrease reflection loss, and capture light from both sides. An illustration shows a double heterocontact contact SC with a passivation layer of SiO_2, TiO_2, and MoO_3 on both sides. ITO is applied above the MoO_3 coating, followed by an Ag coating with a bus bar and finger pattern as the front contact, and an Al coating above the TiO_2 coating toward the back side of the wafer as the rear contact, as shown in figure 1 [27-30].

6. DESIGNING STEPS OF DOUBLE HETEROCONTACT CONTACTS IN SOLAR CELLS

The illustration displays a double heterocontact contact SC with a SiO_2 passivation layer on both sides of the substrate, TiO_2 on one and MoO_3 on the other. ITO is applied above the MoO_3 coating, followed by an Ag coating with a bus bar and finger pattern as the front contact, and an Al coating above the TiO_2 coating on the wafer as a rear contact, as shown in figure 1.

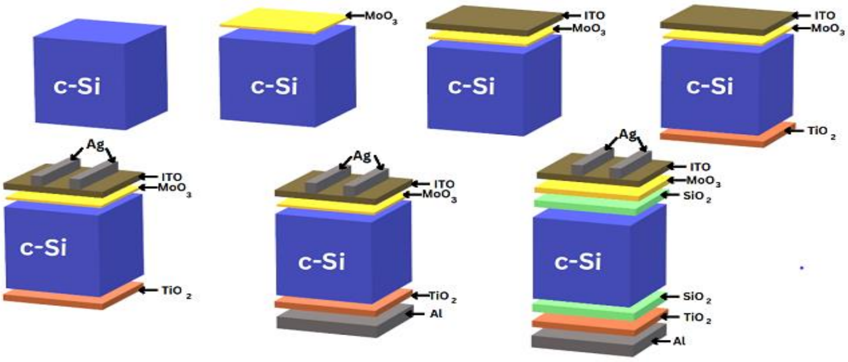

Figure 1: Designing Steps Double Heterocontact Contacts Solar Cell [10]

7. NOVEL DESIGN C-SI SOLAR CELL

Figure 2 depicts a unique arrangement for TMO double-contact c-Si SCs. A unique double-passivated c-Si solar cell design employs two passivation layers of SiO2 or Al2O3 on the front and back sides of the silicon wafer. This design minimizes surface recombination, enhances charge carrier extraction, and boosts overall efficiency. The use of front- and rear-side passivation layers, metal connectors, and an antireflection layer increased solar cell performance. Passivated contacts on the front and back surfaces work as electrical conduits for accumulating photo-generated charge carriers, resulting in low contact resistance and little shading effects. ITO is put on the front surface of TMO double-contact silicon solar cells to reduce reflection and increase light trapping in c-Si absorber layers, hence boosting light absorption and crystalline silicon solar cell performance [31-33,11].

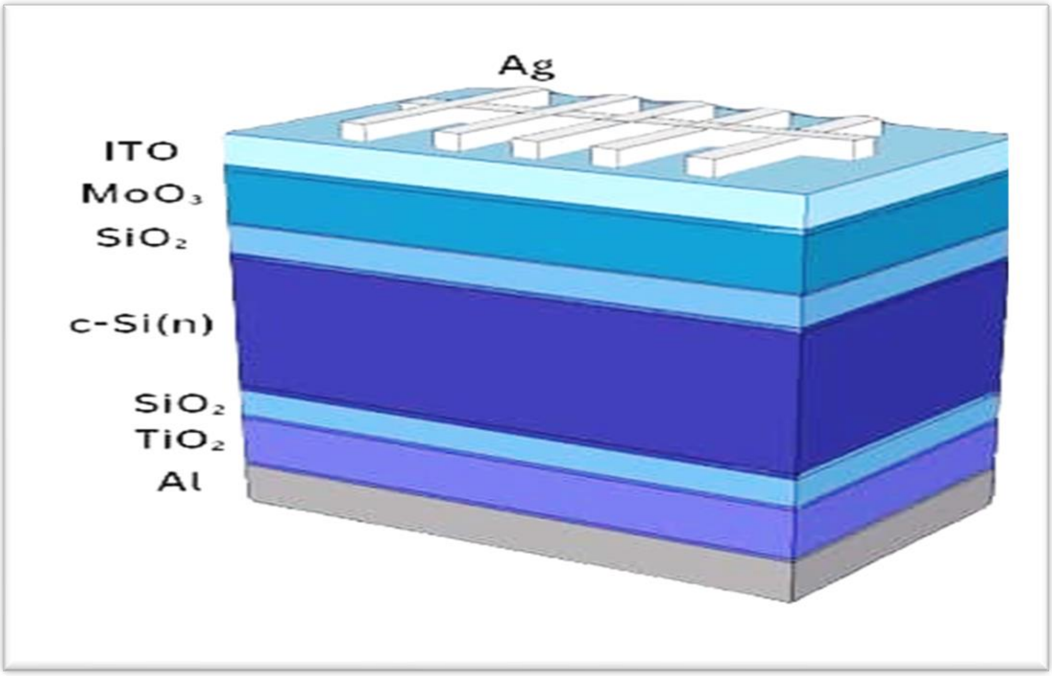

Figure 2: Systematic Diagram of Design of the c-Si Solar Cells [6,11]

8. COST REDUCTION STRATEGIES

Thin wafer technology, low-temperature processing, and simplified device fabrication are critical to lowering costs in solar cell manufacturing. Traditional wafers are usually 180-200 microns thick, but reducing them to less than 100 microns can drastically cut material use and costs [34-36]. Dopant-free designs can be manufactured at lower temperatures, lowering energy consumption and production costs. The elimination of intrinsic amorphous silicon passivation and precise doping enables more efficient manufacture. Spray pyrolysis or spin coatings of metal oxide layers provide low-cost manufacturing alternatives to sophisticated vacuum-based methods [37-39].

9. FABRICATION AND PERFORMANCE IMPROVEMENT

Charge carrier collection and transfer, surface passivation, and light control methods all help to increase SCs efficiency. TiO_2 and MoO_3 enhance open circuit voltage (Voc) and fill factor (FF) by boosting carrier extraction and decreasing minority carrier recombination. Surface passivation, particularly with SiO_2, reduces recombination losses and increases efficiency. Texturing and anti-reflective coatings improve light absorption. The study found that dopant-free heterocontact solar cells (DFCSCs) can achieve efficiencies comparable to high-efficiency c-Si cells. Undoped SCs using TiO_2 and MoO_3 as electron and hole-selective contacts (HSC) achieved 25% efficiency, 784 mV, 77% FF, and 41 mA/cm2 using pulse laser deposition, making the building process easier and cost-effective [40-42,11].

10. CONCLUSION

Solar power is a renewable, dependable, noiseless, cost-free, clean, and environmentally friendly technology used in a variety of applications including road traffic signals, artificial satellites, space shuttles, photo-detectors, road lighting, medical research, battery charging, and electromagnetic radiation detection. It is a sustainable alternative to fossil fuels because the sun is expected to last billions of years and fossil fuel resources are running out. Solar PV systems have a 25-year life cycle, minimal greenhouse gas emissions, and cheaper operating and maintenance costs than other renewable energy sources. The research aims to improve solar cell efficiency and lower production costs. Doped hydrogenated a-Si selective contacts have a 26.7% efficiency, while TMO contacts have efficiencies better than 23.5% for MoO_3 and TiO_2. Dopant-free carrier selective heterocontact solar cells (DFCSCs) provide an inexpensive, high-efficiency alternative to photovoltaic technology. They eliminate doping and inherent a-Si passivation, which simplifies manufacturing and reduces costs. Transition metal oxides like TiO_2 and MoO_3 have high carrier selectivity, whereas passivation materials like SiO2 reduce recombination losses. This strategy provides a significant step toward more affordable and sustainable solar energy choices. TMO double-asymmetric hetero-contact/passivated contacts have an efficiency of approximately 25% and a potential of more than 28.4%, which can be improved further using HBC technology. The primary objective is to increase efficiency while lowering production costs, with solar technology hoping to achieve 27 % efficiency for less than US$ 0.03/W within five years.

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