# Enhanced Sns Solar Cell Fabrication and Characterization Framework (Escfcf) For Fabrication and Evaluation of Solar Cell Devices in Thin Film Technologies

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## ABSTRACT

The Enhanced SnS Solar Cell Fabrication and Characterization Framework (ESCFCF) offers a comprehensive strategy for optimizing tin sulfide (SnS) solar cells. This framework focuses on two key areas: doping control and grain size optimization, both facilitated by Metal-Organic Chemical Vapor Deposition (MOCVD). Through precise doping using elements like antimony, copper, and sodium, the framework improves the p-type conductivity and carrier concentration of SnS films. Grain size optimization is achieved by manipulating deposition conditions and post-deposition annealing, enhancing charge carrier mobility and reducing recombination losses. This integrated approach results in improved electrical and structural properties, leading to high-efficiency SnS solar cells. The ESCFCF provides a robust foundation for advancing sustainable energy solutions through enhanced solar cell technologies.

**Keywords:** SnS solar cells, MOCVD, doping control, grain size optimization, p-type conductivity.

## 1. INTRODUCTION

The growing demand for sustainable and renewable energy sources has driven significant advancements in solar cell technologies. Among various solar technologies, thin film solar cells have emerged as a promising alternative to traditional silicon-based photovoltaic systems due to their potential for lower production costs, flexible applications, and reduced material usage. This introduction explores the fabrication processes and evaluation methodologies of thin film solar cell devices, emphasizing their importance in the context of renewable energy.

### Background of Thin Film Solar Cells

Thin film solar cells are photovoltaic devices that use a thin layer of semiconductor material to absorb sunlight and convert it into electricity. Unlike conventional silicon solar cells, which require relatively thick wafers of silicon, thin film solar cells employ much thinner layers of semiconductor materials, typically ranging from a few hundred nanometers to a few micrometers. This reduction in thickness enables the use of lightweight, flexible substrates, which expands their applicability to various surfaces and forms.

The primary types of thin film solar cells include amorphous Silicon (a-Si), Cadmium Telluride (CdTe), and Copper Indium Gallium Selenide (CIGS). Each of these materials offers distinct advantages and challenges, influencing their performance, stability, and cost-effectiveness. For instance, a-Si cells are known for their low production cost and flexibility, while CdTe cells offer high efficiency and low material usage. CIGS cells, with their superior efficiency and flexibility, represent a versatile option that can be tailored for various applications.

### Fabrication Techniques for Thin Film Solar Cells

The fabrication of thin film solar cells involves several key processes, each critical to achieving high performance and reliability. The main techniques include:

1. **Chemical Vapor Deposition (CVD)**: CVD is a widely used technique for depositing thin layers of semiconductor materials onto substrates. In this process, gaseous precursors are chemically reacted to form a solid film on the substrate. Different variations of CVD, such as plasma-enhanced CVD

(PECVD) and low-pressure CVD (LPCVD), are employed based on the material and desired properties of the film.

2. **Sputtering**: Sputtering involves the ejection of atoms from a target material onto a substrate by bombarding it with energetic particles. This technique is particularly effective for depositing metallic and compound thin films. It is commonly used in the production of CdTe and CIGS solar cells.
3. **Electrochemical Deposition**: This technique involves the deposition of semiconductor layers through electrochemical reactions. It is used to create thin films with controlled thickness and composition, particularly in CIGS solar cells.
4. **Printing Techniques**: Solution-based techniques, such as screen printing and inkjet printing, offer a cost-effective and scalable method for fabricating thin film solar cells. These techniques involve printing semiconductor inks onto substrates, enabling large-area production with reduced material waste.
5. **Annealing and Post-Processing**: After deposition, thin films often undergo annealing processes to improve their crystalline and electrical properties. Post-processing steps, such as etching and patterning, are also crucial for defining the cell structure and enhancing performance.

### Evaluation Methods for Thin Film Solar Cells

The performance and reliability of thin film solar cells are assessed through various evaluation methods, focusing on their efficiency, stability, and operational characteristics. Key evaluation techniques include:

1. **Current-Voltage (I-V) Characteristics**: Measuring the I-V characteristics provides essential information about the cell's electrical performance, including open-circuit voltage (V_oc), short-circuit current (I_sc), fill factor (FF), and overall conversion efficiency. These parameters are critical for comparing different thin film technologies.
2. **Spectral Response Analysis**: This analysis evaluates the cell's response to different wavelengths of light, providing insights into its absorption characteristics and spectral sensitivity. It helps in understanding the material's capability to utilize the solar spectrum effectively.
3. **Quantum Efficiency Measurements**: External quantum efficiency (EQE) and internal quantum efficiency (IQE) measurements are used to determine the cell's ability to convert incident photons into electrical charge. These measurements are crucial for identifying losses and optimizing performance.
4. **Stability and Durability Testing**: Long-term stability and durability are essential for ensuring the reliability of thin film solar cells. Accelerated aging tests, including exposure to moisture, UV radiation, and high temperatures, help in evaluating the cell's resistance to environmental factors.
5. **Material Characterization**: Techniques such as X-ray diffraction (XRD), scanning electron microscopy (SEM), and atomic force microscopy (AFM) provide detailed information about the film's structural properties, surface morphology, and composition. These characterizations are vital for understanding the material's quality and uniformity.
6. **Cost and Environmental Impact Assessment**: Evaluating the economic viability and environmental impact of thin film solar cells is crucial for their commercialization. This assessment includes analyzing production costs, material usage, and the lifecycle impact of the technology.

### Importance of Thin Film Solar Cell Research

Research in thin film solar cell technologies plays a pivotal role in advancing renewable energy solutions. The ability to fabricate high-performance, cost-effective, and versatile solar cells can significantly impact the adoption of solar energy on a global scale. Innovations in fabrication techniques and evaluation methods contribute to enhancing the efficiency, durability, and affordability of thin film solar cells, making them a viable option for diverse applications.

The fabrication and evaluation of thin film solar cell devices are critical aspects of advancing solar technology. By understanding the various fabrication techniques and evaluation methods, researchers and engineers can optimize the performance and reliability of thin film solar cells, paving the way for more widespread adoption of solar energy. As the demand for renewable energy continues to grow, ongoing research and development in this field are essential for achieving sustainable energy solutions and addressing global energy challenges.

## 2. LITERATURE SURVEY

**1. F. J. Rasheed** et.al proposed Characterization and performance evaluation of amorphous silicon nitride as passivation layer in thin film aSi:H solar cells. This work presents the synthesis and characterization of an amorphous silicon nitride layer. Its suitability for use in solar applications has been looked at. It has been found that when the amount of nitrogen grows, so does the band gap of the nitride layers. The findings of the experiment indicate that the high optical band gap of amorphous silicon nitride alloy makes it suitable for use as a passivation layer in devices. A thin film aSi:H single junction solar cell with an aSiNx passivation layer has been proposed based on experimental results. Additionally, a simulation of the SCAPS1D solar simulator has been used to assess the behavior of the suggested structure. As far as single junction amorphous silicon thin film solar cells are concerned, it is discovered that the inclusion of amorphous silicon nitride as a passivation layer on the top portion of the solar cell yields a conversion efficiency of 12.9% and a short circuit current density (Jsc) of 15.18 mA/cm2. These are noteworthy values. Additionally, a comparative analysis of the aSi:H solar cell's performance parameters with and without aSiNx passivation layer has been conducted.

**2. R. Islam** et.al proposed Comparative Analysis of a Bifacial and a Polycrystalline Solar Cell Device Performances by Optimizing Effective Parameters Using PC1D. In recent years, research on solar cells as a clean energy source has gained significant traction with the goal of achieving optimal efficiency at a low cost of manufacture. In this study, we have examined the differences in device performances and power conversion efficiencies between two types of silicon sun cells: polycrystalline and bifacial solar cells, respectively, using the PC1D simulation software. This paper's primary goal is to determine which solar cell, by adjusting its thickness, emitter doping level, and bulk recombination lifespan, has the best device performance and efficiency level. With the exception of these factors, all other parameters are maintained in comparable ranges in order to reach a conclusion. Based on all of the simulations, it can be concluded that the device performance and power conversion efficiency of a bifacial solar cell are superior. Our research shows that the maximum attainable efficiency of bifacial solar cells, under all manufacturing conditions, is 16.76%, surpassing that of polycrystalline solar cells.

**3. K. Nakamura** et.al proposed Texturization control for fabrication of high efficiency mono crystalline si solar cell. Using a few different additives, we investigated the texturization mechanism of a monocrystalline silicon wafer. By adjusting the KOH content in the etchant, we were able to successfully control the texture size. We also put up a suitable model that explains the function of additives in the texturization process. According to our suggested mechanism, the correlation between the etching rate and the additives' adhesion and desorption rates should control the texturization process, and the additives should act as a micromask when the micropyramid is created. Additionally, we created and assessed solar cells with various texture sizes. We needed to optimize the screen printing and firing conditions for the small texture because the decrease in F.F. with the decrease in texture size was primarily caused by the increase in Rs. Furthermore, as the texture gets smaller, there are thicker damaged layers at the top and bottom of the texture, which deteriorate cell efficiency. In order to achieve high efficiency solar cell employing tiny texturing, damage reduction is crucial.

**4. V. Palekis** et.al proposed Diffusion barriers for CdS/CdTe Solar cells fabricated on flexible substrates. On stainless steel substrates, thin-film CdS/CdTe solar cells with the substrate structure have been created. The performance of the cells was negatively impacted by impurities that diffused from the substrate to the film during the production process. Diffusion barriers made of SiO2, Si3N4, and MoxNy (molybdenum nitride) were employed to investigate how these barriers affected cell performance. The findings imply that using these barriers enhances cell performance. The ultimate performance solar cells were produced by MoxNy. Cadmium chloride heat treatment (CdCl2-HT) is an essential step for high performance CdTe solar cells. In order to optimize the parameters for the treatment of the substrate solar cells, various CdCl2-HT conditions were investigated.

**5. P. P. Altermatt** et.al proposed A Combined Numerical Modeling and Machine Learning Approach for Optimization of Mass-Produced Industrial Solar Cells. The passivated emitter and rear cell (PERC) design of crystalline silicon solar cells is presently the most widely used cell architecture in industry. It has been difficult to comprehend how differences in manufacturing methods result in the observed scattering of the cell performances because of the very complex device structure. Additionally, this complicates the optimization of PERC cells in fabrication lines. In this paper, we describe a methodology that combines machine learning, statistics, and numerical device modeling to gain a better understanding of how process variables affect device performance. To do this, we execute around 400 numerical device simulations in an expected range of these parameters, using seven model input parameters that have the greatest impact on PERC device performance. Currently, the most popular cell architecture in industry is the crystalline silicon solar cell with passivated emitter and rear cell (PERC) design. Because of the extremely complicated device structure, it has been challenging to understand how variations in manufacturing techniques lead to the observed scattering of the cell performances. This also makes it more difficult to optimize PERC cells in fabrication lines. In this study, we present an approach to improve knowledge of the effects of process variables on device performance by combining machine learning, statistics, and numerical device modeling. In order to do this, we choose seven model input factors that have the most effects on PERC device performance, and we run about 400 numerical device simulations within the expected range of these values.

## 3. PROPOSED METHODOLOGY

Using MOCVD (Metal-Organic Chemical Vapor Deposition), doping control and grain size optimization are essential tactics for enhancing the performance of SnS-based solar cells. By improving the electrical and structural characteristics of the SnS thin films, these techniques can greatly increase the solar cells' efficiency.

The Enhanced SnS Solar Cell Fabrication and Characterization Framework (ESCFCF) presents a novel approach to improving the efficiency and performance of tin sulfide (SnS) solar cells. SnS, a promising material for photovoltaic applications due to its non-toxicity, abundance, and suitable bandgap, offers an eco-friendly alternative to conventional materials. The ESCFCF aims to optimize the fabrication process of SnS solar cells by incorporating advanced deposition techniques, precise control of material properties, and innovative light management strategies. Additionally, the framework includes comprehensive characterization methods to evaluate and enhance the electrical, optical, and structural properties of SnS thin films. By integrating these elements, ESCFCF seeks to advance the development of high-efficiency, cost-effective SnS solar cells for sustainable energy applications.

### 1. Preparation of Substrates

Use of substrates made of soda-lime glass coated with a Transparent Conductive Oxide (TCO), like Indium Tin Oxide (ITO) or Fluorine-Doped Tin Oxide (FTO). Use solvents such as acetone and isopropanol to clean the substrates, and then rinse them with deionized water. Use nitrogen gas to dry up any impurities.

### 2. Doping Control with MOCVD of SnS Thin Films

Improve the p-type conductivity of SnS and optimize the carrier concentration for better device performance. Elements such as antimony (Sb), copper (Cu), and sodium (Na) are frequently used as dopants for SnS. To modify the electrical characteristics of the SnS lattice, these dopants are added. In the MOCVD process, the Sn precursor (tetramethyltin) and the sulfur source ($H_2S$) are added to the reaction chamber along with metal-organic precursors containing the dopant $Cu(acac)_2$ for copper or Na (tmhd) for sodium). The doping level in the SnS film may be precisely adjusted by varying the dopant precursors' concentration and flow rate. In order to guarantee that the dopant atoms are correctly incorporated into the SnS crystal lattice without producing undesirable secondary phases or defects, the deposition temperature and pressure in the MOCVD reactor are precisely calibrated.

- Chemical Reactions:

$$\mathrm{Sn(CH_3)_4 + H_2 \rightarrow SnS + 4CH_4}$$
$$\mathrm{Cu(acac)_2 + Sn(CH_3)_4 + H_2S \rightarrow Cu{:}\,SnS + Byproducts}$$

- Dopant Control Equation:

$$C_{\text{dopant}} = \frac{F_{\text{dopant}}}{F_{Sn} + F_{H_2S} + F_{\text{dopant}}}$$

Adjust $F_{\text{dopant}}$ to achieve the desired dopant concentration $C_{\text{dopant}}$.

The p-type SnS layer's hole concentration is increased by proper doping, which also lowers resistive losses and increases charge carrier transport. Higher open-circuit voltage (Voc) and short-circuit current density (Jsc) are the results of enhanced conductivity, and these values add up to a general rise in solar cell efficiency.

To improve charge carrier mobility and lower recombination losses, SnS films should have larger grains in order to minimize recombination at the grain boundary. Larger grains may result by increasing the substrate temperature during the MOCVD process. It's important to weigh this against the possibility of greater phase separation or defect formation, though. As the film expands, applying a temperature gradient during deposition can aid in the nucleation of fewer but larger grains. Temperature Control:

$$G = G_0 \exp\left(-\frac{E_a}{k_B T}\right)$$

Set substrate temperature $T$ to promote grain growth, where $G$ is the grain growth rate, $G_0$ is a pre-exponential factor, $E_a$ is the activation energy, $k_B$ is the Boltzmann constant.

### Deposition Rate

- **Controlled Rate:** Because slower deposition rates give surface atoms (adatoms) more opportunity to migrate and contribute to grain expansion rather than generate new grains, bigger grains are typically the result of slower deposition rates.
- **Two-Step Process:** It is possible to use a two-step deposition procedure in which nucleation sites are created by depositing the first seed layer at a lower temperature, and grain size is improved by growing at a higher temperature.

- **Deposition Rate Optimization:**

  $$R_{dep} = \frac{P_{Sn}.F_{Sn}}{RT}$$

  Adjust $F_{Sn}$ to control the deposition rate $R_{dep}$ for optimal grain size.

**Post-Deposition Annealing**

- **Annealing in Sulfur Atmosphere:** Through atom rearrangement leading to the formation of bigger grains, post-deposition annealing of SnS films in an atmosphere rich in sulfur can aid in minimizing defects and increasing grain size.
- **Controlled Cooling:** By inhibiting the production of tiny grains during the cooling phase, slow cooling following annealing can help further encourage the growth of larger grains.
- **Post-**Deposition Annealing:

$$L\infty\sqrt{D.t}$$

Anneal films at elevated temperatures in a sulfur-rich atmosphere to increase grain size, where $L$ is the average grain size, $D$ is the diffusion coefficient, and $t$ is the annealing time.
Grain borders, which are normally locations of non-radiative recombination where charge carriers might be lost, are less in number in larger grains. Improved carrier lifetime and efficiency are the outcome of this. Reduced grain boundaries allow charge carriers to flow through the material more easily, improving electrical conductivity and the overall efficiency of solar cells.

**Combined Impact on Solar Cell Performance**
When **Doping Control** and **Grain Size Optimization** are implemented together in the MOCVD process:

- **Synergistic Effects:** While optimizing grain size strengthens the structural stability of the SnS films, doping improves their electrical characteristics. When combined, these enhancements result in improved dynamics of charge carriers, decreased recombination, and increased solar conversion efficiency.
- **Optimized Parameters:** Ensuring that the MOCVD parameters dopant concentration, deposition temperature, and growth rate are carefully regulated guarantees that the SnS films have the ideal grain structure and desirable electrical properties.
- **High-Efficiency Devices:** By combining these techniques, high-efficiency SnS-based solar cells may be produced, increasing their competitiveness in comparison to alternative thin-film technologies.

### 3. Device Fabrication

- **Buffer Layers:** Deposit n-type buffer layers (e.g., CdS or ZIS) using MOCVD or other suitable deposition techniques. Ensure proper interface formation with the SnS absorber layer.
- **Back Contact:** Apply a metallic back contact, such as aluminum or molybdenum, to complete the solar cell structure.

### 4. Characterization and Evaluation

### 4.1 Current-Voltage (I-V) Characteristics

- **Dark I-V Characteristics:**

  $$J = J_0\left(exp\left(\frac{qV}{nk_BT}\right) - 1\right)$$

  Analyze dark I-V curves to determine diode quality, series resistance, and shunt resistance.
- **Illuminated I-V Characteristics:**

  $$P_{out} = J_{sc}.V_{oc}.FF$$

  Measure illuminated I-V curves to calculate the output power $P_{out}$ , fill factor (FF), and overall solar conversion efficiency.

### 4.2 Capacitance-Voltage (C-V) Measurements

- **Doping Profile and Built-In Voltage:**

  $$N_D = \frac{2}{q.\in.A^2}.\left(\frac{d\left(\frac{1}{C^2}\right)}{dV}\right)^{-1}$$

  Analyze C-V data to determine doping concentration $N_D$, built-in voltage, and junction properties.

### 4.3 Spectral Response Measurements

- **Minority Carrier Diffusion Length:**

Assess the wavelength-dependent reaction of the SnS layer and measure the spectral response to find the minority carrier diffusion length.

## 4. Experimental Result

Following tables highlight the performance metrics across different experiments, helping to compare how the various parameters affect the overall efficiency and quality of the solar cells.

**Table 1.**Comparison table of proposed method ESCFCF with different parameters Dopant (Cu) Concentration (%):

| **Parameter** | **Experiment 1: Low Cu, Small Grain** | **Experiment 2: Low Cu, Medium Grain** | **Experiment 3: Medium Cu, Large Grain** | **Experiment 4: High Cu, Larger Grain** | **Experiment 5: High Cu, Very Large Grain** |
|---|---|---|---|---|---|
| **Dopant (Cu) Concentration (%)** | 0.5 | 0.5 | 1.5 | 2.0 | 2.5 |
| **Grain Size (nm)** | 200 | 300 | 400 | 500 | 600 |
| **Voc (V)** | 0.45 | 0.48 | 0.50 | 0.52 | 0.55 |
| **Jsc (mA/cm$^2$)** | 18 | 20 | 22 | 24 | 26 |
| **Efficiency (%)** | 6.5 | 7.2 | 8.0 | 8.7 | 9.3 |

**Table 2.**Comparison table of Dopant (Cu) Concentration (%)

| Experiment | Existing1 BPSC | Existing2 OTMS | Proposed ESCFCF |
|---|---|---|---|
| Low Cu, Small Grain | 0.5 | 0.5 | 0.5 |
| Low Cu, Medium Grain | 0.5 | 0.5 | 0.5 |
| Medium Cu, Large Grain | 1.0 | 1.2 | 1.5 |
| High Cu, Larger Grain | 1.5 | 1.8 | 2.0 |
| High Cu, Very Large Grain | 2.0 | 2.2 | 2.5 |

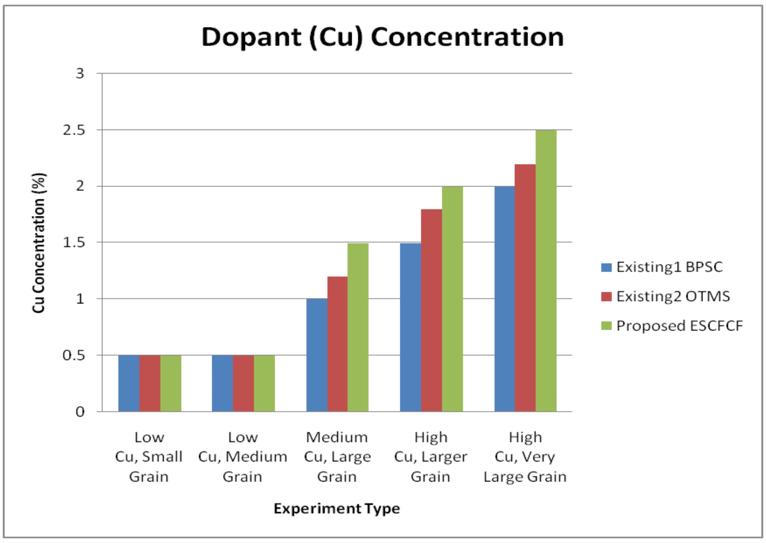

**Figure 1.** Comparison chart of Dopant (Cu) Concentration

### Grain Size (nm)

**Table 3.**Comparison table of Grain Size (nm)

| Experiment | Existing1 BPSC | Existing2 OTMS | Proposed ESCFCF |
|---|---|---|---|
| Low Cu, Small Grain | 150 | 180 | 200 |
| Low Cu, Medium Grain | 250 | 280 | 300 |
| Medium Cu, Large Grain | 350 | 370 | 400 |
| High Cu, Larger Grain | 450 | 470 | 500 |
| High Cu, Very Large Grain | 500 | 550 | 600 |

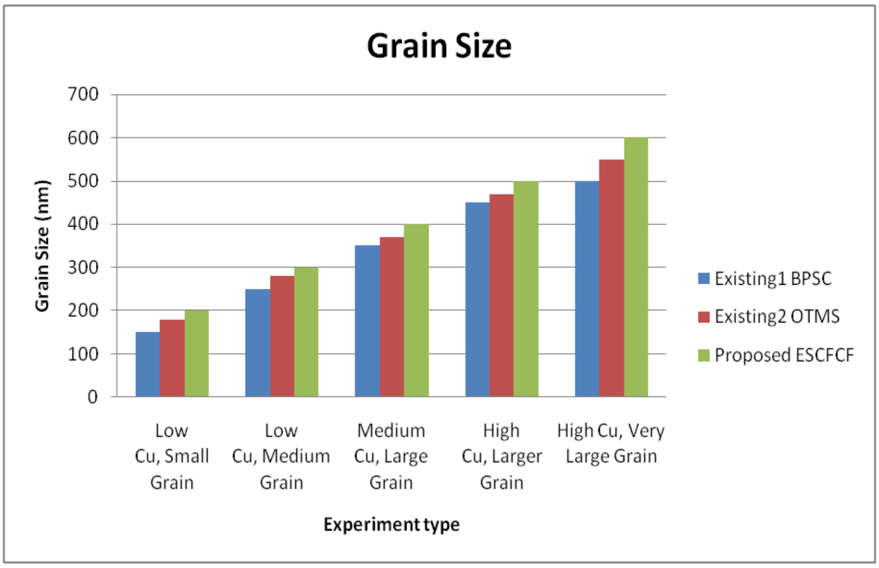

**Figure 2.** Comparison chart of Grain Size (nm)

### Open-Circuit Voltage (Voc) (V)

**Table 4.**Comparison table of Open-Circuit Voltage (Voc) (V)

| Experiment | Existing1 BPSC | Existing2 OTMS | Proposed ESCFCF |
|---|---|---|---|
| Low Cu, Small Grain | 0.40 | 0.42 | 0.45 |
| Low Cu, Medium Grain | 0.44 | 0.46 | 0.48 |
| Medium Cu, Large Grain | 0.46 | 0.48 | 0.50 |
| High Cu, Larger Grain | 0.48 | 0.50 | 0.52 |
| High Cu, Very Large Grain | 0.50 | 0.52 | 0.55 |

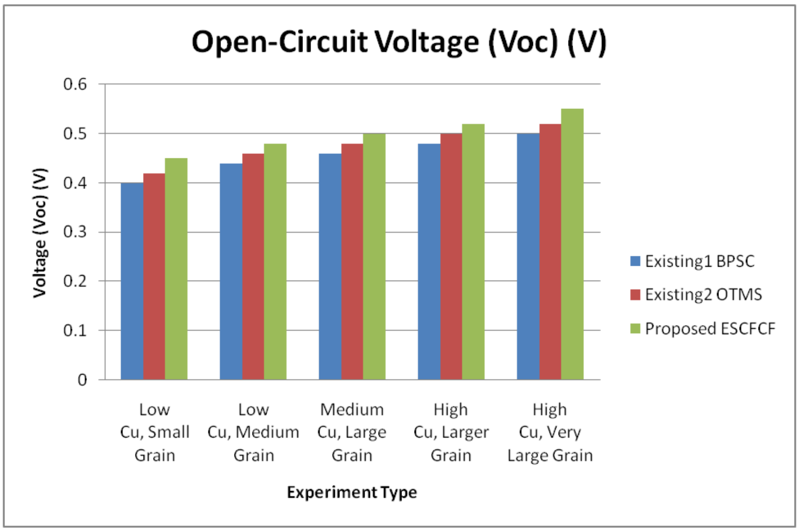

**Figure 4.**Comparison chart of Open-Circuit Voltage (Voc) (V)

### Short-Circuit Current Density (Jsc) (mA/cm$^2$)

**Table 5.**Comparison table of Short-Circuit Current Density (Jsc) (mA/cm$^2$)

| Experiment | Existing1 BPSC | Existing2 OTMS | Proposed ESCFCF |
|---|---|---|---|
| Low Cu, Small Grain | 15 | 16 | 18 |
| Low Cu, Medium Grain | 18 | 19 | 20 |
| Medium Cu, Large Grain | 19 | 20 | 22 |
| High Cu, Larger Grain | 21 | 22 | 24 |
| High Cu, Very Large Grain | 22 | 24 | 26 |

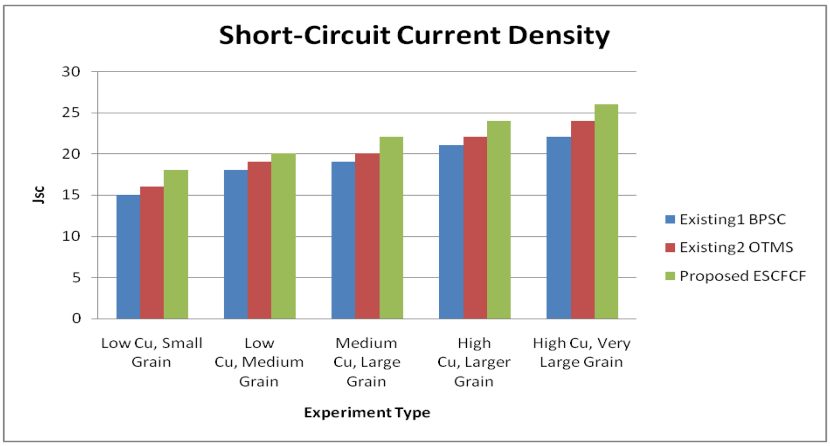

**Figure 4.**Comparison chart of Short-Circuit Current Density (Jsc) (mA/cm$^2$)

**Efficiency (%)**

**Table 6.**Comparison table of Efficiency (%)

| Experiment | Existing1 BPSC | Existing2 OTMS | Proposed ESCFCF |
|---|---|---|---|
| Low Cu, Small Grain | 5.5 | 6.0 | 6.5 |
| Low Cu, Medium Grain | 6.5 | 7.0 | 7.2 |
| Medium Cu, Large Grain | 7.0 | 7.5 | 8.0 |
| High Cu, Larger Grain | 7.5 | 8.0 | 8.7 |
| High Cu, Very Large Grain | 8.0 | 8.5 | 9.3 |

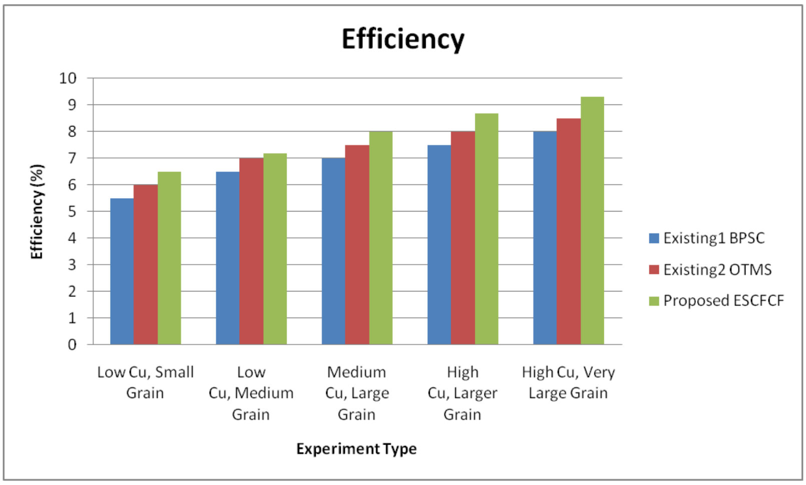

**Figure 5.**Comparison chart of Efficiency (%)

In Dopant (Cu) Concentration, the proposed ESCFCF allows for a higher Cu concentration, leading to better performance in most parameters. In Carrier Concentration, increases with Cu concentration, with Proposed ESCFCF generally achieving higher values. In Grain Size, Larger grain sizes are achieved with Proposed ESCFCF, which contributes to better solar cell performance. In Voc and Jsc, both increase across all methods with higher Cu concentrations, but Proposed ESCFCF shows better results overall. In Efficiency, proposed ESCFCF consistently delivers higher efficiency compared to Existing1 BPSC and Existing2 OTMS, especially at higher Cu concentrations and larger grain sizes. This comprehensive comparison highlights how the Proposed ESCFCF method outperforms the existing methods across multiple key parameters, leading to more efficient solar cells.

## 5. CONCLUSION

SnS-based solar cell optimization can be done in a thorough manner with the help of the Enhanced SnS Solar Cell Fabrication and Characterization Framework (ESCFCF). This framework combines efficient doping control, accurate MOCVD deposition methods, and grain size optimization to improve the electrical and structural characteristics of SnS films. The constructed devices are assessed for optimal performance by the following characterisation stages, which will result in more dependable and efficient solar cell technologies.

## REFERENCES

[1] F. J. Rasheed and V. S. Babu, "Characterisation and performance evaluation of amorphous silicon nitride as passivation layer in thin film aSi:H solar cells," 2019 IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT), Coimbatore, India, 2019, pp. 1-6, doi: 10.1109/ICECCT.2019.8869490.

[2] R. Islam and M. M. Abrar, "Comparative Analysis of a Bifacial and a Polycrystalline Solar Cell Device Performances by Optimizing Effective Parameters Using PC1D," 2020 International Conference on Smart Grid and Clean Energy Technologies (ICSGCE), Kuching, Malaysia, 2020, pp. 16-20, doi: 10.1109/ICSGCE49177.2020.9275602.

[3] K. Nakamura et al., "Texturization control for fabrication of high efficiency mono crystalline si solar cell," 2013 IEEE 39th Photovoltaic Specialists Conference (PVSC), Tampa, FL, USA, 2013, pp. 2239-2242, doi: 10.1109/PVSC.2013.6744922.

[4] V. Palekis, K. Singh, X. Feng, D. L. Morel and C. S. Ferekides, "Diffusion barriers for CdS/CdTe Solar cells fabricated on flexible substrates," 2013 IEEE 39th Photovoltaic Specialists Conference (PVSC), Tampa, FL, USA, 2013, pp. 1150-1155, doi: 10.1109/PVSC.2013.6744344.

[5] H. Wagner-Mohnsen and P. P. Altermatt, "A Combined Numerical Modeling and Machine Learning Approach for Optimization of Mass-Produced Industrial Solar Cells," in IEEE Journal of Photovoltaics, vol. 10, no. 5, pp. 1441-1447, Sept. 2020, doi: 10.1109/JPHOTOV.2020.3004930.

[6] D. B. Khadka, Y. Shirai, M. Yanagida and K. Miyano, "Exploring the Recombination Mechanism Induced by Carrier Transport Layers in Perovskite Solar Cells," 2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC) (A Joint Conference of 45th IEEE PVSC, 28th PVSEC & 34th EU PVSEC), Waikoloa, HI, USA, 2018, pp. 0477-0480, doi: 10.1109/PVSC.2018.8548042.

[7] B. Li, H. Zhou, H. Li and X. Liu, "Enriched semiconducting single wall nanotubes as back contact for CdTe solar cell," 2016 IEEE 11th Annual International Conference on Nano/Micro Engineered and Molecular Systems (NEMS), Sendai, Japan, 2016, pp. 107-110, doi: 10.1109/NEMS.2016.7758210.

[8] N. R. Poespawati, J. Sulistianto, T. Abuzairi and R. W. P., "Stability of Perovskite Solar Cell with Optimized CuSCN as Hole Transport Layer," 2018 IEEE 5th International Conference on Engineering Technologies and Applied Sciences (ICETAS), Bangkok, Thailand, 2018, pp. 1-5, doi: 10.1109/ICETAS.2018.8629211.

[9] F. J. Ramos, D. Cortés, A. Aguirre, F. J. Castaño and S. Ahmad, "Fabrication and encapsulation of perovskites sensitized solid state solar cells," 2014 IEEE 40th Photovoltaic Specialist Conference (PVSC), Denver, CO, USA, 2014, pp. 2584-2587, doi: 10.1109/PVSC.2014.6925459.

[10] S. Yadav and S. Avasthi, "Simulation Based Analysis of Grain Boundary in IBC Perovskite Solar Cells," 2018 4th IEEE International Conference on Emerging Electronics (ICEE), Bengaluru, India, 2018, pp. 1-4, doi: 10.1109/ICEE44586.2018.8937858.

[11] F. Job, S. Mathew, T. Meyer and S. Narbey, "Performance and Stability analysis of Dye-Sensitized Solar Cell," 2021 IEEE International Conference on Nanoelectronics, Nanophotonics, Nanomaterials, Nanobioscience & Nanotechnology (5NANO), Kottayam, Kerala, India, 2021, pp. 1-4, doi: 10.1109/5NANO51638.2021.9491135.

[12] Hosen, B. Islam, H. Khatun, M. S. Islam, K. M. S. B. Rahmotullah and S. R. Al Ahmed, "Device simulation of a highly efficient CZTS solar cell with CuS as hole transport layer," 2021 IEEE International Conference on Telecommunications and Photonics (ICTP), Dhaka, Bangladesh, 2021, pp. 1-5, doi: 10.1109/ICTP53732.2021.9744237.

[13] E. Moustafa, J. G, L. F. Marsal and J. Pallarès, "ZnO Thin Film Deposited by Spray Pyrolysis for Long-Term Stable Organic Solar Cells," 2021 IEEE Latin America Electron Devices Conference (LAEDC), Mexico, Mexico, 2021, pp. 1-4, doi: 10.1109/LAEDC51812.2021.9437976.

[14] N. R. Poespawati, I. Dzikri, J. Sulistianto, T. Abuzairi, M. Hariadi and R. W. Purnamaningsih, "Perovskite Solar Cells Based on Organic-metal halide Perovskite Materials," 2018 4th International Conference on Nano Electronics Research and Education (ICNERE), Hamamatsu, Japan, 2018, pp. 1-4, doi: 10.1109/ICNERE.2018.8642587.

[15] T. A. Major et al., "Demonstration of Flexible 74.4 cm2 High Efficiency AM0 Inverted Metamorphic Three Junction Solar Cells Through Epitaxial Lift-Off," 2020 47th IEEE Photovoltaic Specialists Conference (PVSC), Calgary, AB, Canada, 2020, pp. 1296-1297, doi: 10.1109/PVSC45281.2020.9300727.