Electroluminescence Imaging For Defect Analysis In Polycrystalline Solar Cells

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Abstract— Solar energy offers a vast range of applications across industrial and daily contexts, driven by its potential as a clean, sustainable alternative to conventional fuels. However, inherent defects may arise during the manufacturing, transportation, and installation of solar cells, leading to reduced power generation efficiency. To address this challenge, this study presents the application of Electroluminescence (EL) imaging as a non-destructive technique for assessing solar cells, focusing on the identification of defects and performance variations. EL imaging is employed to detect microcracks and other flaws in both flexible and rigid polycrystalline solar cells.

This research details the use of LabVIEW and MATLAB-based image analysis methods, showcasing their effectiveness in detecting and quantifying various defects that affect solar cell reliability and efficiency, including electrical losses, microcracks, and fractures. The LabVIEW approach highlights its robust capabilities in analysing electroluminescence images, while the MATLAB-based method underscores its utility in detailed image processing for defect identification and quantification. The study encompasses the essential tools, image processing techniques, and foundational physical principles required to extract meaningful information from EL images. By providing a comprehensive overview of EL imaging and diagnostic techniques for solar cells, this research contributes to advancements in solar energy conversion technologies and enhances the understanding of solar cell performance assessment.

Keywords—Electroluminescence, SMU, LabView, MATLAB, polycrystalline flexible/Rigid cells.

I. INTRODUCTION

The increasing demand for reliable and sustainable energy sources has propelled significant advancements in solar cell technology. Solar cells, or photovoltaic devices, are fundamental in the global shift toward eco-friendly energy production. Ensuring the dependability and efficiency of solar cell technology is vital due to the various stresses and potential flaws encountered during manufacturing and usage, which can result in diminished performance and reduced operational lifespan.

Visualizing and characterizing defects in solar cells are essential for optimizing their performance. Electroluminescence (EL) imaging has emerged as a powerful, non-destructive diagnostic technique that provides unique insights into the internal structure and functioning of photovoltaic systems. By applying an electrical bias and capturing EL images, researchers can identify and analyse structural and electrical imperfections, including microcracks that impact the electrical and mechanical performance of solar cells. This process allows for real-time detection and analysis, supporting improved quality control and reliability in solar energy technologies.

Electroluminescence imaging is especially valuable in ensuring the quality of solar cells during production, contributing to the advancement and broader adoption of solar technology. By identifying areas that require improvement, manufacturers can refine their processes to enhance yields and minimize defects. EL imaging can be integrated into production lines for immediate feedback, allowing adjustments in manufacturing parameters to maintain high standards in photovoltaic cell quality. High-resolution EL imaging has proven useful not only for detecting flaws in solar cells but also in other components of photovoltaic systems. The process involves inducing infrared emissions through electrical activation, which are captured by specialized cameras to create detailed visual representations. Damaged cell regions appear dark in EL images, signalling malfunctions that need attention.

The foundational principles of solar cells involve the photovoltaic effect, where semiconductor materials convert sunlight into direct current (DC) electricity. This conversion depends on the formation and separation of electron-hole pairs when exposed to photons. Understanding and diagnosing defects in this process through EL imaging is critical for improving manufacturing, quality assurance, and overall energy output. Both LabVIEW and MATLAB-based image analysis methods play significant roles in this domain, aiding in the detection and quantification of defects such as microcracks, fractures, and electrical losses.

This paper emphasizes the importance of EL imaging and image analysis for solar cell diagnostics, discussing how these techniques are used to visualize flaws and assess performance. By employing image processing methods, researchers can gain meaningful insights that drive enhancements in solar cell production and contribute to the evolution of renewable energy technology.

II. EXPERIMENTAL PROCEDURE

A. I-V Characterization of PV Cell

I-V characteristics can be readily generated through the utilization of a source-measure unit (SMU), a testing instrument capable of sourcing and measuring both current and voltage. This assessment was conducted under artificial sunlight conditions.

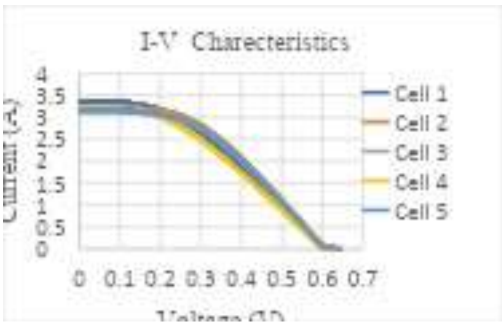


Figure (a) Flexible cells

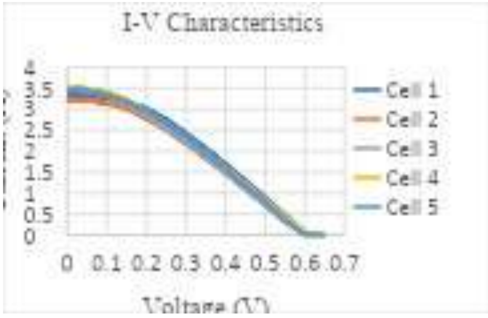


Figure (b) Rigid cells

Figure 1. I-V Characteristics of polycrystalline solar cells

Figure(1a) shows I-V characteristics for five samples of Polycrystalline flexible and Figure(1b) shows I-V characteristics of five samples of polycrystalline rigid solar cell samples.

B. Electroluminescence Test for PV Cell and LabVIEW Based Defect Detection

Figure 2 presents a non-invasive technique for detecting microcracks and assessing the quality of solar cells. Photovoltaic (PV) cells exhibit electroluminescence, emitting light when an electric current flow through them. This phenomenon enables the examination of potential hidden structural defects in PV cells and modules. It provides insight into the current distribution within the PV cell, aiding in defect diagnosis. To capture electroluminescence (EL), a specialized camera equipped with near-infrared sensitive filters ([8] - [9]) is required. This camera feature allows for the identification of cell damage at any stage in a cell's lifespan. Following the acquisition of the EL image of the solar PV cell, image processing techniques were employed to assess image quality and pinpoint any imperfections. Figure 3 illustrates the LabVIEW block diagram utilized for defect detection and calculation of the area affected by defects. The LabVIEW software facilitates processes such as grayscale conversion, as detailed in Figure 4. This approach enables the identification and differentiation of issues like dead cells, soldering defects, microcracks, cell cracks, and wafer defects for precise calculations.

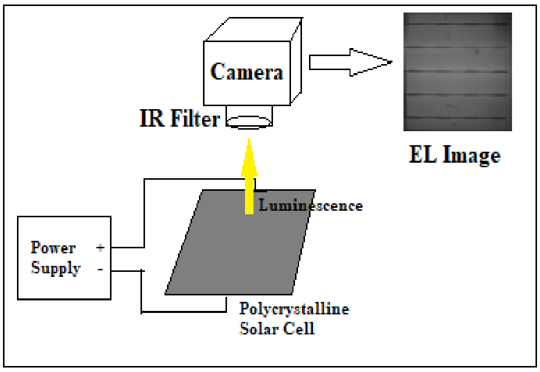


Figure 2: EL image test setup

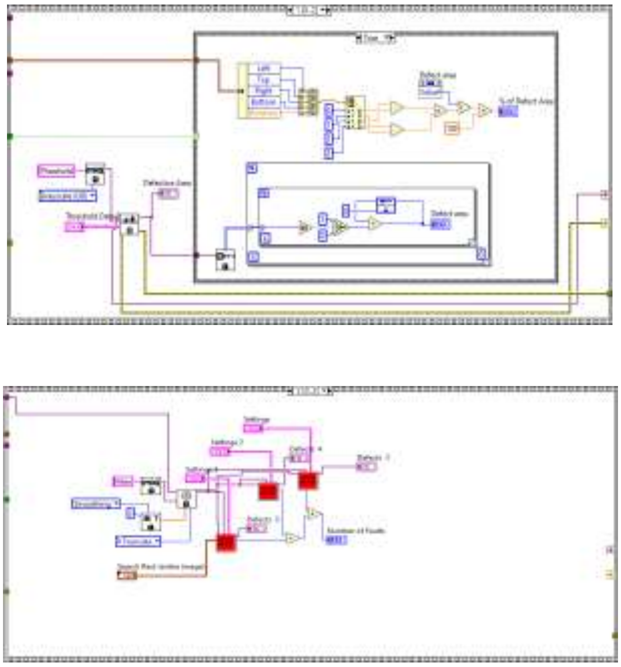


Figure 3: LabVIEW based image processing for defect detection.

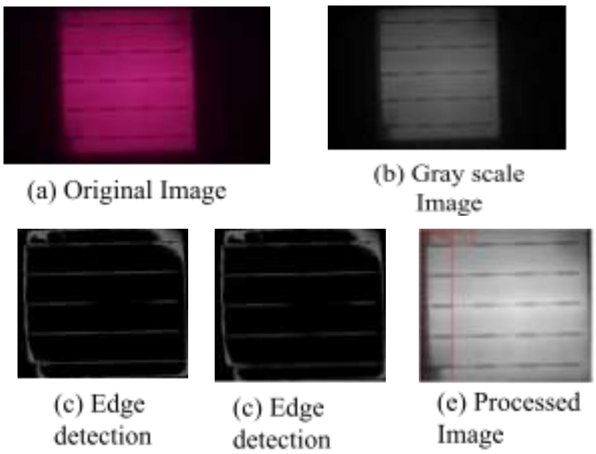


Figure 4: Steps involved in image processing for defect detection.

III. IMAGE PROCESSING UISING MATLAB

MATLAB image processing software was used in this work to analyze defects. The EL picture identifies a variety of abnormalities, including as dead cells, soldering flaws, microcracks and cell fractures.

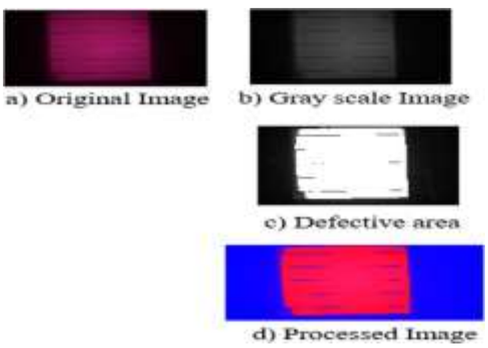


Figure 3: Image processing for defect detection using MATLAB.

In image processing, a grayscale picture is one in which each pixel is represented by a single intensity value, often between 0 and 255. The lack of color in grayscale photographs results in a range of grey tones, with '0' being black and '255' denoting white. Images in grayscale are often represented as 2D matrices, where each entry represents a pixel's intensity. A grayscale image's pixel intensity values represent each pixel's brightness.

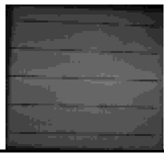
The filtered image undergoes conversion to binary by applying a threshold set at 0.7 for pixel intensity level comparison. This process involves mapping all 256 intensity levels to values between zero and one. Pixels are then classified as black or white.

IV. RESULT AND DISCUSSION

The image processing analyses using both LabVIEW and MATLAB were conducted on the same set of electroluminescence (EL) images of five distinct polycrystalline rigid photovoltaic (PV) cells and five polycrystalline flexible PV cells. This approach allowed for a comparative analysis to evaluate the performance and effectiveness of each image analysis method in identifying and quantifying defects within the cells.

LabVIEW Image Analysis: Table 1 and 2 presents the results obtained from processing the EL images with LabVIEW. Each cell was analysed to determine the number of fractures and defects, and the percentage of defect area was calculated for each sample. Figure 5 shows a graph that illustrates the correlation between the different PV cells and their respective defect percentages, providing a visual assessment of the distribution of defects. The LabVIEW-based analysis effectively detected and quantified defects, making it a valuable tool for understanding defect density and distribution in rigid and flexible cells.

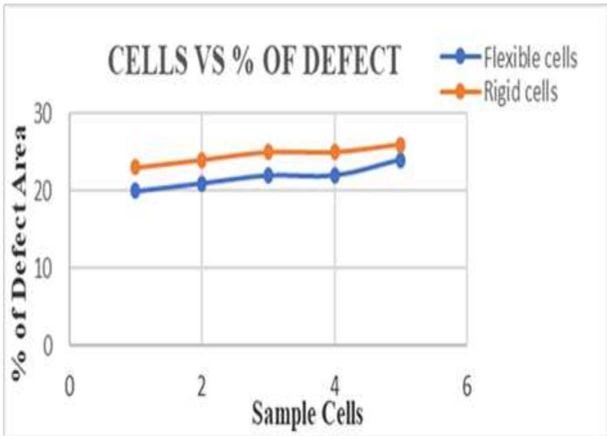
Table 1: Results and Tabulations of Polycrystalline Flexible PV Cells

Cell	Polycrystalline Flexible PV Cells		
	% of Defect Area	No. of fault	Output Image
1	0	0	
2	1	3	
3	4	4	
4	5	2	

5	8	7	

Table 2: Results and Tabulations of Polycrystalline Rigid PV Cells

Cell	Polycrystalline Rigid PV Cells		
	% of Defect Area	No. of fault	Output Image
1	5	12	
2	**6**	**3**	
3	**7**	**2**	
4	**11**	**8**	
5	**13**	**5**	



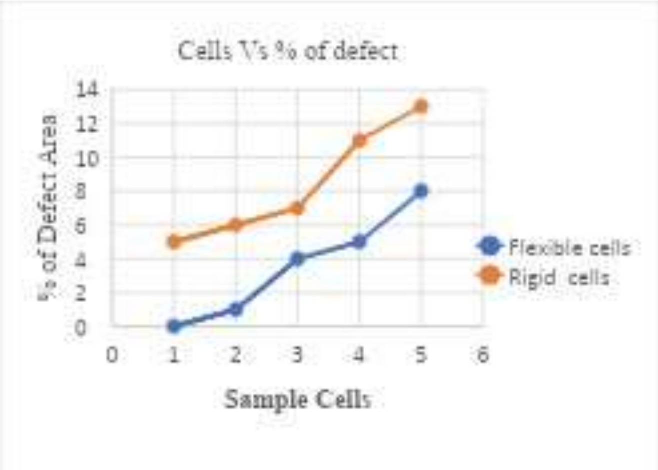


Figure 5: Graph of Sample Cells vs % of Defect Area

MATLAB Image Analysis: Similarly, Tables 3 and 4 outline the results of EL image analysis conducted using MATLAB for the same five polycrystalline rigid and five flexible PV cells. MATLAB's image processing capabilities facilitated a detailed examination of the defects, enabling precise quantification of defect areas and fracture identification. Figure 4 displays a graph showing the correlation between the percentage of defects and the analysed cell samples, reinforcing the effectiveness of MATLAB for this type of diagnostic analysis.

Table 3: Results and Tabulations of Polycrystalline Flexible PV Cells

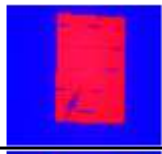
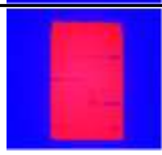
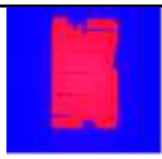
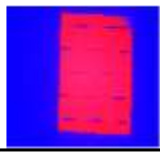
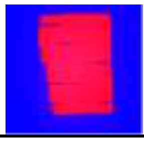
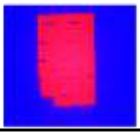
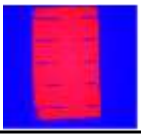
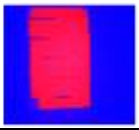
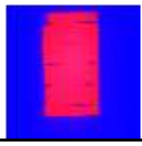
Cell	Polycrystalline Flexible PV Cells		
	% of Defect Area	No. of fault	Output Image
1	20	10	
2	21	6	
3	22	8	
4	22	8	
5	24	4	

Table 4: Results and Tabulations of Polycrystalline Rigid PV Cells

Cell	Polycrystalline Rigid PV Cells		
	% of Defect Area	No. of fault	Output Image
1	23	2	
2	24	2	
3	25	3	
4	25	2	
5	26	3	

Comparison and Implications: Both LabVIEW and MATLAB demonstrated effectiveness in analysing the same set of EL images for defect identification and quantification. The results revealed that each method provided complementary insights: LabVIEW excelled in calculating defect percentages efficiently, while MATLAB offered more granular visualization and detailed analysis. The comparative analysis shows that integrating both tools can enhance the robustness of defect analysis in solar cell diagnostics.

The graphs representing the defect areas in relation to the PV cell samples underscore the significance of defect detection in determining solar cell performance. The analysis confirms the importance of employing high-resolution EL imaging coupled with advanced image processing techniques to ensure quality control in solar cell manufacturing. By detecting and quantifying defects early in the production process, manufacturers can optimize production methods and improve overall cell reliability and efficiency.

V. CONCLUSION

This study highlights the importance of Electroluminescence (EL) imaging as a non-destructive and effective diagnostic tool for identifying and analysing defects in polycrystalline photovoltaic (PV) cells. By employing both LabVIEW and MATLAB-based image processing methods on the same set of EL images from rigid and flexible PV cells, this research underscores the complementary strengths of each approach in defect detection and analysis.

The LabVIEW-based method demonstrated strong capabilities in calculating and visualizing the percentage of defect areas, making it efficient for rapid assessment in a production environment. Conversely, the MATLAB-based image analysis method provided a more detailed and comprehensive visualization of defects, enabling a deeper understanding of the defect structure and distribution within the cells. The combined use of these tools offers a robust framework for enhancing the accuracy and depth of solar cell diagnostics.

Incorporating EL imaging and advanced image processing techniques into the production process can significantly improve quality control measures, allowing manufacturers to identify defects early and make timely adjustments to reduce defects and enhance overall solar cell reliability. This approach supports the ongoing development of solar energy technologies, contributing to more efficient and sustainable energy solutions.

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