AL-Bahir
Journal for Engineering and Pure Sciences
BJEPS

Volume 6 | Issue 1 Article 4

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Recommended Citation
Israil, Mohd; Sharma, Arvind Kumar; and Gupta, Ekta (2025) "Novel Approach for the micro cracks detection of solar wafers and cells," *Al-Bahir*: Vol. 6: Iss. 1, Article 4.
Available at: https://doi.org/10.55810/2313-0083.1083

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Source of Funding

No Funding Available

Conflict of Interest

No conflict of Interest

Data Availability

Publicly avilable

Author Contributions

Study of Existing research techniques and given new approach too

REVIEW

Novel Approach for the Micro Cracks Detection of Solar Wafers and Cells

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Abstract

This paper deals with the review of various existing technique for the microcracks detection in silicon solar cell and wafer. In addition to this, we proposed a novel approach for the machine learning technique for the inspection of the cracks those are existed in the solar cell and wafer and not able to detect by the naked eyes. There are many techniques have been developed by the various researchers around the world to inspect solar cells for defect. All the techniques discussed in this article having some features and some weakness too. This paper present here gives the two-fold solution for the microcrack detection that will benefit the scientist and engineers for the development of the machine vision system to find out the cracks in the solar cells and solar wafers.

Keywords: Machine learning, NIR, NIR LED, Solar wafer, Solar cell, Segmentation, Microcracks

1. Introduction

The need for clean and renewable energy has grown significantly because of rapid industrial expansion, population growth, and technical breakthroughs [1,2]. To combat the present energy problem and for the replacement of dirty, non-renewable energy sources with affordable, environmentally friendly, and sustainable energy produced from freely available sun energy, which is clean and abundant, solar energy has recently a great attention for the research [3,4]. In making of solar cell, silicon is important part as for the solar around 80 % part of it made from silicon. As the demand of the solar cell is increasing day by day as it is much better alternate of the fossil fuel energy. It is clean and green and freely available and not to worry about the limited stocks of fossil fuels energy [5].

As we have the limited stock of silicon and the demand is increasing exponentially, so to compensate the feedstock shortage of silicon, the manufacturer of solar cell reducing the thickness of the silicon wafers from silicon ingot daily and these days it went down to size of 100 μm of less [5,6]. It has been shown in Fig. 1 shows that how a wafer is manufactured from the raw silicon. This technique of solar wafer manufacturing is known as wire sawing technology which is used to cut down the silicon wafers from the large silicon ingot [5–7]. While slicing the wafers to get higher productivity and minimum chance of breakage the wire saw must be precise and balanced. Slicing thinner is one of the reasons of breakage in addition to this; to make it cost effective, wafer manufacturers are increasing the size of the wafer to reduce the overall production cost. Generally, solar wafers of are about of about 400 mm^2 and more are now available in the current market [8].

The above technology of the production makes wafer processing and handling much and more challenging which leads cell breakage or poor performance of the finally assembled PV unit because the handling process which may lead the defects in the solar wafers in form of cracks and scratches. These cracks can be different in size may be from macro level to micro level, it is also to be noted that the width of the cracks of order 100 μm is to be

Received 20 September 2024; revised 5 December 2024; accepted 5 December 2024.
Available online 17 January 2025

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https://doi.org/10.55810/2313-0083.1083

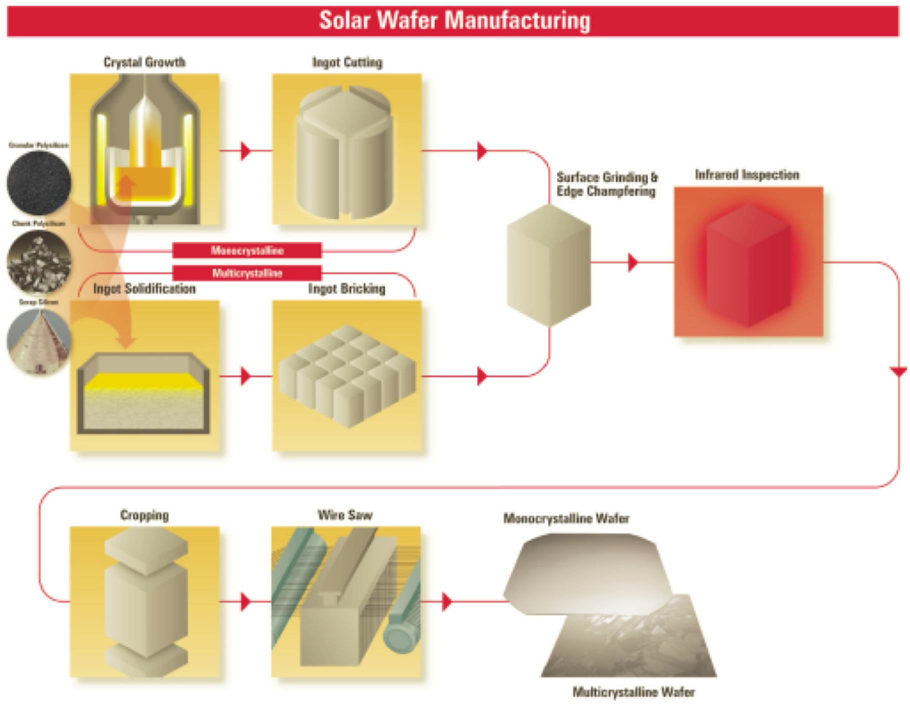

Fig. 1. Wafer manufacturing process.

considered as microcrack. Based on the silicon ingot from which the solar wafer is sliced, two types of solar cells exist namely polycrystalline and monocrystalline silicon solar cell and both the cells can have micro-cracks. Fig. 2 is the sample of image of solar cell which is having microcracks that is highlighted in Fig. 2. The main feature of the crack in the solar cell is that it is having low grey level. Because of its size, the above-mentioned defects cannot be seen by naked eyes resulting, manufacturing of solar panels of lower quality if a flaw in the solar wafers or cells goes unnoticed. In the worst situation, a solar cell may even fail, which could result in malfunctioning photovoltaic (PV) modules [6–10]. Furthermore, as Fig. 2's image of the polycrystalline solar wafer illustrates, there are numerous grains of all sizes and shapes. As a result, it is exceedingly difficult to distinguish between a grain border and a microcrack using basic machine vision learning techniques. Therefore, it is critical to create an inspection system for identifying and assessing this kind of flaw (see Fig. 3).

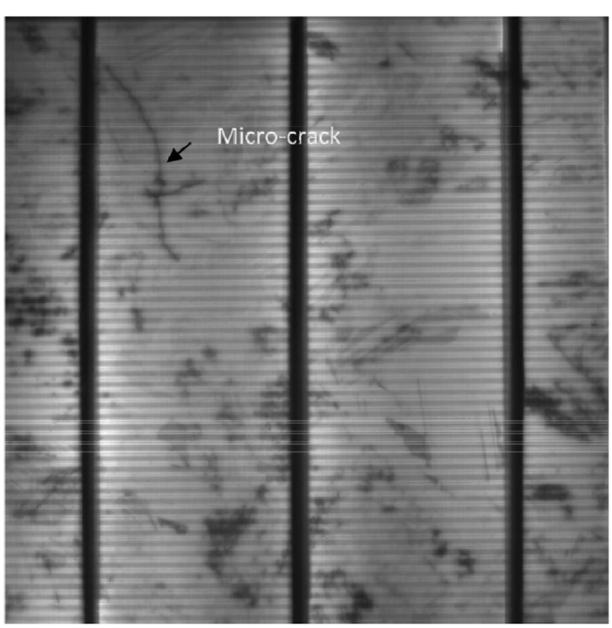

Fig. 2. Polycrystalline solar cell with micro-crack.

To achieve optimal outcomes, it is recommended that the system be non-contact to maintain the surface and subsurface integrity of silicon wafers both prior to and following evaluation, as well as throughout the whole production process [9–11]. Many researchers have been using the image process to find out the microcracks in the building too [12–14]. This paper's primary goal is to discuss popular and cutting-edge methods for solar wafer microcrack detection. A few of the most noteworthy aspects of these approaches are noted and examined in detail with the intention of offering help for the beginner and advance researcher of the solar cell industry.

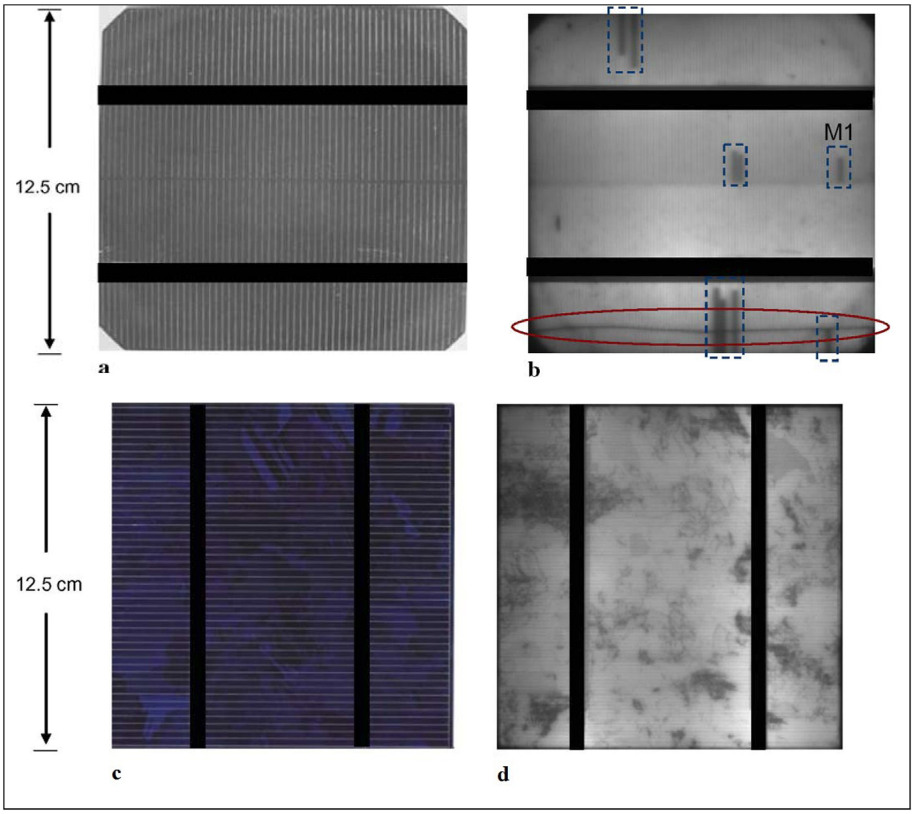

Fig. 3. Optical image of a defected mono-crystalline silicon solar cell, (b) the corresponding EL image of (a), (c) optical image of defected poly-crystalline silicon solar cell, (d) the corresponding EL image of (c).

2. Existing microcrack detection techniques

The identification of microcracks in solar wafers and solar cells has been the subject of numerous research studies to date. The two most often studied techniques are electron beam induced current (EBIC) and laser beam induced current (LBIC) [7–11].

The identification of microcracks in solar wafers and solar cells has been the subject of numerous research studies to date. The two most often studied techniques are electron beam induced current (EBIC) [15,16] and laser beam induced current (LBIC) [17–20].

Both EBIC and LBIC are very powerful techniques for defect detection and for the detection of impurities in solar cells. Both EBIC and LBIC operate by locally injecting minority carriers, which are then collected via a p-n junction or a Schottky diode that is built on the surface of the sample. This measurement closely resembles how a solar cell functions. While EBIC is better suited for high-resolution imaging of the type of luminescence in which electrons are excited into the conduction band using electrical current by connecting the cell in forward bias mode, LBIC, which has a slightly lower resolution than EBIC, is typically used to map the entire cell. Few researchers used other technologies that are based on convention image setup based on self-learning features and low-rank matrix recovery [21].

Both the techniques give acceptable results but with there are some limitations also, as these techniques can be applied for the solar cell not for the wafer, as need the contacts to connects the cell. Although there are, other promising techniques such as ultrasonic vibration [22–25] electrical characterization [26], and infrared lock-in ultrasound thermography but the problem with this technology that we need to touch the wafer, can lead to further defects. Another testing such as optical testing such as photoluminescence [27–30]; electroluminescence imaging [26,31–34].

3. Proposed technique

In the proposed technique, the image is captured first with the help of a novel camera set-up as shown in Fig. 4, which consists of, a NIR camera, and the lighting source is used which is the setup of NIR

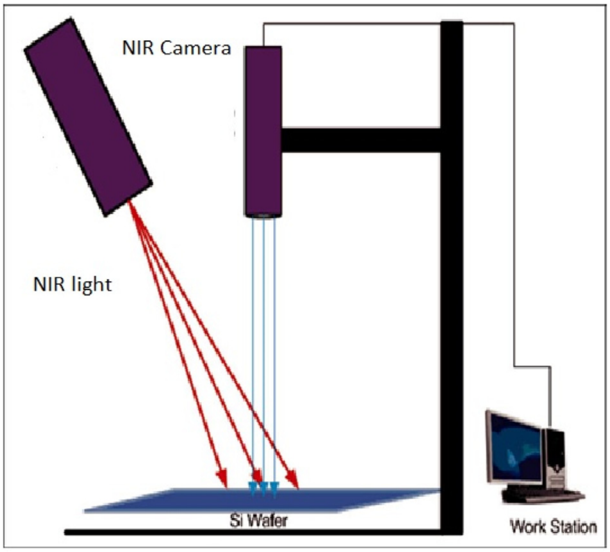

Fig. 4. The image acquisition set up.

LEDs available in the market, secondly the image captures is stored in the computer to do the further filtering as given in the next section.

3.1. Segmentation using Niblack's algorithm

By sliding a window over the image and using the local mean and standard deviation for each additional pixel in the window, Niblack proposed a method for constructing a threshold surface [26]. With a continuous gradient that is highly adjustable to effectively separate objects, the threshold value for a pixel inside the fixed neighborhood is a linear function of the mean and standard deviation of the nearby pixels. The neighborhood's size is very adjustable since it was selected to be both tiny enough to preserve local characteristics and large enough to muffle noise.

Fig. 5 shows examples of the results of this method's image processing. This figure demonstrates where the wafers' cracks were found to be present. Fig. 5, which depicts two distinct types of wafers with microcracks, demonstrates the effectiveness and correctness of Niblack's algorithm. Fig. 5(b) shows the outcome of Niblack's segmentation before filtering whereas Fig. 5(a) shows the original image. This picture illustrates how image processing enhances the presence of small items such as noise and undesired objects. The binary image of this figure contains a few little things that are not necessarily faults, according to a close analysis of the image. Size filtering can be utilized to get rid of these artifacts.

3.2. Region growing process

For high-speed inline inspection devices, the image processing algorithm must be swift enough to extract the microcrack. Approaches based on regional growth are two times faster than Niblack's method, claim Chiou et al. [23]. Originally developed by Refs. [35,36], the region-growing technique has been further developed resulting in much more sophisticated techniques like region splitting [37–40]. The region grew as the image was sharpened using a gradient process [41]. The noise is subsequently

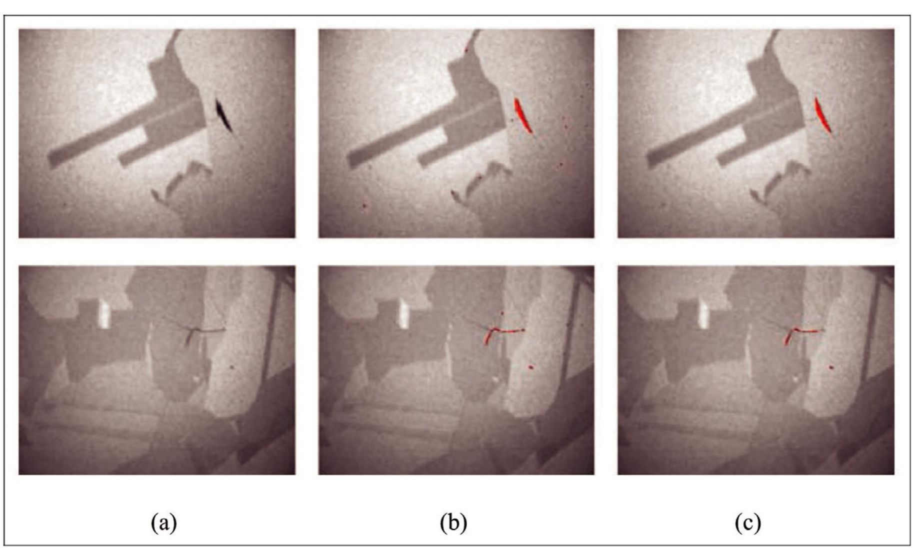

Fig. 5. (a) Sample image of polycrystalline silicon wafer; (b) Niblack's segmentation results before labelling and size filtering; (c) after labelling and size filtering.

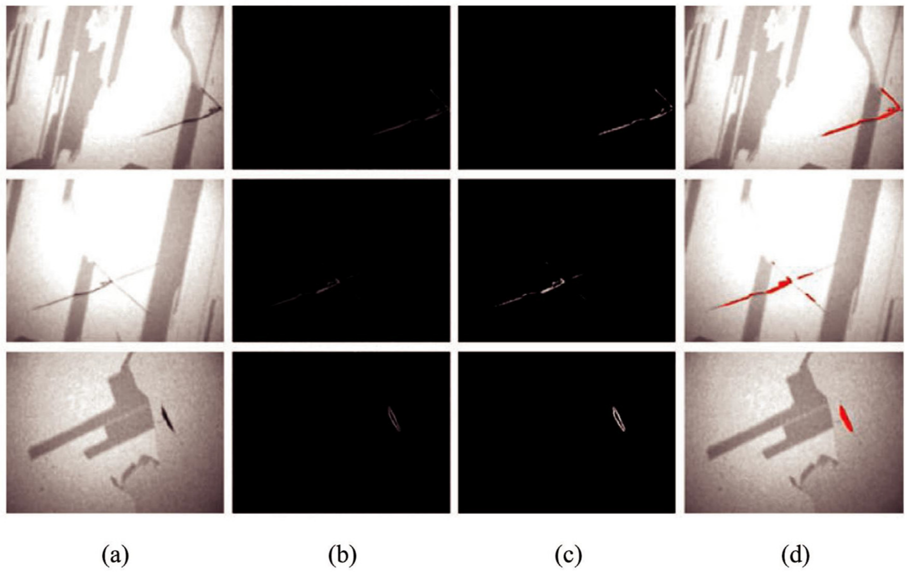

Fig. 6. Region growing images: (a) original; (b) gradient; (c) region growing; and (d) results after component labelling and size filtering.

removed using component identification and size filtering [41,42]. The gradient procedure is used to improve the edge of the image.

When a region is growing, a seed pixel is first considered, and subsequently nearby pixels that are comparable to the seed pixel are added. Once one region's growth slows, another seed is chosen, and the procedure is repeated for the remaining regions. After then, the nearby regions are combined into a single, huge region using the merging technique. Referring to this figure, three original polycrystalline silicon wafers with micro-cracks are given in Fig. 6(a). The respective gradient image of the samples is given in Fig. 6(b). In Fig. 6(c), the images after region growth are reproduced. These are the small objects present in the form of noise which can also be seen in Fig. 6(c). The Presence of these artifacts can be eliminated by using size filtering or by using blob analysis. Resulting the improvement is produced as show in Fig. 6(d).

4. Conclusion

This paper presents several imaging set-ups for the detection of microcracks other than our two-fold strategy. The work presented, was done by choosing a good technique for image acquisition along with image processing technique. In this paper technique for the image acquisition is NIR imaging, it is imaging set-up in which NIR camera is used. It is the very successful imaging device for the solar wafer/cell because in forward bias conditions, the solar device also emits NIR light. Information related to micro-crack defects can be extracted using digital filtering and image processing. Popular techniques include region growing and segmentation algorithms which produced significant results.

Data availability statement

Publicly available data.

Ethics

We are dedicated to conducting research with the highest ethical standards and integrity. Our research endeavours are guided by the following principles: We respect the dignity, rights, and autonomy of all individuals involved in our research. We ensure informed consent is obtained from participants and that their privacy and confidentiality are protected. We maintain transparency in our research processes and findings. Our research is subject to rigorous peer review and we openly share our methodologies and results. We conduct our research with honesty and integrity, avoiding any form of fabrication, falsification, or plagiarism. We take full responsibility for the accuracy and reliability of our research findings.

Funding

No funding available.

Conflicts of interest

There are no conflicts of interest.

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