Micro crack imaging of silicon solar cells with SEM (Scanning Electron Microscopy)

W Gunawan*, S Stepanus, L Lisapaly, F Mustari and H S Sutomo
Department of Electrical Engineering, Universitas Kristen Indonesia Jakarta, Jakarta, Indonesia

*Wawen11maret2018@gmail.com

Abstract. Both monocrystalline and polycrystalline silicon based solar cells are proven to be widely used in the photovoltaic industry compared to other solar cell material such as titanium oxide or germanium due to abundant materials and economical production processes, however the problem occurs due to internal (crack) defects in the silicon wafers. The cracks of silicon solar cells occur due to the manufacturing process or when applying them to the field in a relatively short time. Research was also carried out to determine the cause of the cracks and how much damage had occurred that affected the performance of silicon solar cells. By using SEM (Scanning Electron Microscopy) we will prove that, is it clear that the damage caused by production failure of external influences causes defects (micro cracks), holes, burns and so on. The advanced technology owned by SEM is expected to be reliable to find the location of the damage quickly and precisely because the result displayed are very accurate so that it is expected to be an evaluation for the solar cell production process in the future.

1. Introduction
Solar cell is a cell consisting of semiconductor materials such as silicon, titanium oxide, germanium and so on which is used as a medium to convert sunlight energy so that it can produce direct current (DC) electrical energy. In the process solar cell production, storage, and installation, it was found that many solar cells were damaged, such as cracks or breakages and other damage. The formation of cracks in solar cells is related to the mechanical strength of the material as well as the processing required to produce cells [1]. The overall strength of the wafers is known to be related to the size, density and distribution of the defects [2]. In order to obtain cells of the required size, processing plays an important role because it can cause cracks and damage to the posterior cells reducing production yields and increasing production costs. Steps that can cause cracking during the manufacturing process include sawing and cutting the silicon ingot or bricks, depositing the conductive contact film, drafting wafers, soldering the contacts to the cell surface, and mounting the cells to make solar modules [3]. For example, it has been found that the aluminum backing affects the mechanical behavior of cells; increases the flexural strength of silicon solar cells but it is remarkable that this fact depends on parameters such as thickness, porosity, bismuth glass concentration and thickness of the eutectic layer; the latter increases fracture strength by inducing plasticity in cells [2]. In the case of polycrystalline silicon solar cells it is known that the fracture strength is closely related to the intrinsic properties of the material as grain size and boundaries, as well as crystal orientation; and features such as micro defects and cracks [2]. The efficiency of solar cells is affected by the entire manufacturing process. Cracking and other defects
represent decreased conductivity leaving the site zone disconnected or inactive for electrical purposes which means loss of power output and decreased efficiency [4]. Defects and excessive stress in the manufacturing process can cause cracks in cells. These cracks reduce the performance of the solar cells by creating an inactive zone in the cells which reduces efficiency and modules [5,6]. This is the reason why solar cell manufacturers have introduced in-line tools to detect cracks and other defects [7]. Matching production requires a reliable and fast method of rejecting unusable wafers and increasing overall production efficiency [8,9]. Therefore the research was carried out again with the aim of knowing the causes of defects, cracks in solar cells, and knowing the exact picture of the damage.

2. Methods
The research method used in this research is descriptive method, which describes the cracks that occur, and we will provide the visible image results from SEM and analyze how much damage is caused by defects (micro cracks) with varying magnification results so that it looks clear. Damage caused by micro cracks in the solar cells. The research was conducted by conducting literature studies from various papers related to the use of solar cells, then taking solar cell samples and testing them at the Center for Zoology Research Laboratory, Indonesian Institute of Sciences (LIPI) Cibinong, Bogor Regency, West Java by registering first. On the http://elsa.lipi.go.id site, the registrant fills in the user profile, then chooses a research service. Applicants will receive a confirmation email which will then receive complete details including research costs, place and time of study. The research process is carried out using a Scanning Electron Microscope (SEM) tool by carrying out a detailed examination and then the data is collected, analyzed so that it can be seen how much the level of damage has occurred, the cause and effect of the defect, in this case the defect caused by "micro cracks" on the solar cell, as shown in figure 1.

![Figure 1. Research process flow diagram.](image)

3. Results and discussions
The research was conducted using SEM at the Indonesian Institute of Sciences (LIPI) Cibinong - Bogor, is SEM brand JEOL JSM-IT200 which is located in the Zoology research center. JSM-IT200 is an easy-to-use SEM which focuses on high performance or functionality as shown above. Of course, it is very helpful for this research, where SEM has complete and very sophisticated features like as Fast observation “Zeromag” is a quick observation. You can find the specimen area or determine the analysis position with the Graphics Holder or Optical CCD image displayed on the main screen. Fast analysis “Live Analysis” is a direct, fast analysis, where the X-ray spectrum or characteristics of the measurement area and the main elements are displayed directly during the observation (Figure 2) [10].
The research was carried out by cutting a small part of the solar cell so that it can be seen using Scanning Electron Microscopy (SEM), as shown in figure 3. The solar cells are cut to 5-7 mm in size so that they can be placed in a sample tube which is then inserted into the SEM.

The solar cell sample will be seen on the monitor from the SEM display and we can clearly know the damage or defect that occurs with a certain magnification as seen in figure 4.

The horizontal / supine cross section of the first sample of cracked solar cells with a magnification of 30 can be seen in figure 5.
Figure 5. Horizontal / supine cross section of the first sample of cracked solar cells.

Figure 6. The resulting of SEM image with MAG 30.

Table 1. Specification of the resulting of SEM image with MAG 30.

| SCM_FORMAT | JEOL/MP |
|------------|----------|
| SCM_VERSION | 3 |
| SCM_DATE | 2020-07-01 |
| SCM_TIME | 09:18:01 |
| SCM_OPERATOR | JEOL |
| SCM_INSTRUMENT | JSM-IT200 |
| SCM_IMAGE_SIZE | 2560 x 1920 |
| SCM_COLOR_MODE | 0 |
| SCM_MAG | 30 |
| SCM_STAGE_POSITION | 7.148 5.845 10.600 0.000 0.000 0.000 |
| SCM_CONTRAST | 1402 |
| SCM_BRIGHTNESS | 1808 |
| SCM_ACCEL_VOLT | 5.0 |
| SCM_COMMENT | |
| SSM_VERSION | 7 |
| SSM_FIELD_OF_VIEW | 4.267mm x 3.200mm |
| SSM_SEGMENT_NUMBER | 1 1 |
| SSM_MICRON_MARKER | 500/μm |
| SSM_MICRON_BAR | 300 |
| SSM_PNU_HEIGHT | 128 |
| SSM_PNU_TYPE | 1 |
| SSM_NICKNAME | IT200 |
| SSM_DETECTOR | SED |
| SSM_WD | 13.6 |
| SSM_SCAN_TIME | 40 |
| SSM_SCAN_TYPE | 1 |
| SSM_VACUUM_MODE | HV |
| SSM_VACUUM | |
| SSM_SCAN_ROTATION | 275.3 |
| SSM_IMAGE_NUMBER | 3994 |
| SSM_DETECTOR1 | SED |
| SSM_DETECTOR2 | |
| SSM_DETECTOR3 | |
| SSM_DETECTOR4 | |
| SSM_DETECTOR1_ADD_RATIO | |
| SSM_DETECTOR2_ADD_RATIO | |
| SSM_DETECTOR3_ADD_RATIO | |
| SSM_DETECTOR4_ADD_RATIO | |
| SSM_INTEGRATION_NUMBER | 1 |
| SSM_SPECIMEN_TEMPERATURE | |
| SSM_PROBE_CURRENT | |
| SSM_GUN_VOLT | 5.0 |
| SSM_STAGE_BIAS_VOLT | 0.0 |
| SSM_COLUMN_MODE | 0 |
| SSM_MONITOR_MAGNIFICATION | 59.8125 |
| SMP_VERSION | 5 |
| SMP_GUN_TYPE | W |
| SMP_CONTRAST1 | 1402 |
| SMP_CONTRAST2 | |
| SMP_CONTRAST3 | |
| SMP_CONTRAST4 | |
| SMP_BRIGHTNESS1 | 1808 |
| SMP_BRIGHTNESS2 | |
| SMP_BRIGHTNESS3 | |
| SMP_BRIGHTNESS4 | |
| SMP_BED_COMPRESS_SUPPRESS | |
| SMP_BED_SHADOW_SUPPRESS | |
| SMP_BED_GAIN | |
| SMP_BED_SHADOW_LEVEL | |
| SMP_PROBE_NUMBER | 30.0 |
| SMP_PROBE_CURRENT_MODE | 0 |
| SMP_BEAM_SHIPT | 0.0 |
| SMP_DYNAMIC_FOCUS | 0 |
| SMP_TILT_MAG_CORRECTION | 0 |
| SMP_STAGE_DRIVE | 1 1 0 0 0 2 |
| SMP_LOW_VACUUM_MODE | 6535 |
| SMP_FIELD_IMAGE_MAGNIFICATION | |
From table 1, the results of the SEM photo in figure 5 and figure 6, it is very clear that the cracks caused by being hit by a hard object cause the glass to break and the silicon solar cell becomes badly damaged so that the flow of electrons is inhibited to produce direct current (DC) electricity. These cracks also visible from a different point of view. In the next sample we will see a cross section of the damage caused by throwing or falling rocks that penetrate / cause holes in the solar cell, because we want to know how much damage has been done (figure 7). The analysis was carried out with a magnification of 50.

![Image of SEM photo with MAG 50 magnification](image)

**Figure 7.** The resulting of SEM image with MAG 50.

**Table 2.** Specification of the resulting of SEM image with MAG 50.

| Specification                                      | Value                             |
|---------------------------------------------------|-----------------------------------|
| SCM_FORMAT JEOL/MP                                | CM_VERSION 3                      |
| SCM_DATE 2020-07-01                               | CM_TIME 08:51:25                  |
| SCM_OPERATOR JEOL                                 | CM_IMAGE_SIZE 2560 1920            |
| $CM_MAG 50$                                       | $CM_STAGE_POSITION 6.434 -6.231 10.700 0.000 0.000 0.000 |
| $CM_BRIGHTNESS 1814                              | $CM_ACCEL_VOLT 5.0                |
| $CM_COLOR_MODE 0                                  | $CM_OPERATOR JEOL                 |
| $CM_INSTRUMENT JSM-IT200                          | $CM_IMAGE_SIZE 2560 1920          |
| $CM_MAG 50$                                       | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |
| $CM_INSTRUMENT JSM-IT200                          | $CM_MAG 50$                       |

This is the result of imaging of a small hole with the specifications listed in table 2, on a polycrystalline silicon solar cell with a diameter of about 2 mm, and a hole depth of about 2 mm caused by throwing or falling rocks or other sharp objects that cause minor damage to the solar cells within plain view, but it
was clear that a large enough hole was giving from the result of the SEM image with a magnification of 50 times. From the two damage samples above, it is clear that Scanning Electron Microscopy (SEM) can be relied on to see in detail the part of the damage that occurs in polycrystalline silicon solar cells.

4. Conclusion
The results showed that material selection and fabrication were the main keys to get quality solar cells, especially silicon. Research in the laboratory using a Scanning Electron Microscope (SEM) is very helpful in determining the level of damage caused by micro cracks or small holes in silicon solar cells. With the features of SEM such as Fast Observation "Zeromag" and Fast Analysis "Live Analysis", we can quickly and directly analyze the area or location of the damage that occurred and display clearly on a computer monitor with the desired magnification. This research is still limited to the level of analyzing the damage caused by micro cracks that occur in polycrystalline silicon solar cells. It is hoped that further research will be carried out with more samples of damage to solar cells, both monocrystalline silicon solar cells, amorphous and so on, and using more complete parameters and tools so that they can become a reference for making better solar cells in the future.

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