Paper

Detection of Monocrystalline Silicon Wafer Defects Using Deep Transfer Learning

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Abstract—Defect detection is an important step in industrial production of monocrystalline silicon. Through the study of deep learning, this work proposes a framework for classifying monocrystalline silicon wafer defects using deep transfer learning (DTL). An existing pre-trained deep learning model was used as the starting point for building a new model. We studied the use of DTL and the potential adaptation of MobileNetV2 that was pre-trained using ImageNet for extracting monocrystalline silicon wafer defect features. This has led to speeding up the training process and to improving performance of the DTL-MobileNetV2 model in detecting and classifying six types of monocrystalline silicon wafer defects (crack, double contrast, hole, microcrack, saw-mark and stain). The process of training the DTL-MobileNetV2 model was optimized by relying on the dense block layer and global average pooling (GAP) method which had accelerated the convergence rate and improved generalization of the classification network. The monocrystalline silicon wafer defect classification technique relying on the DTL-MobileNetV2 model achieved the accuracy rate of 98.99% when evaluated against the testing set. This shows that DTL is an effective way of detecting different types of defects in monocrystalline silicon wafers, thus being suitable for minimizing misclassification and maximizing the overall production capacities.

Keywords—automated optical inspection, machine learning, neural network, wafer imperfection identification.

1. Introduction

Detecting silicon wafer defects is one of the challenges faced by silicon wafer manufacturers. Currently, silicon wafer inspections are performed manually by relying on visual inspection (VI) or using an automated optical inspection (AOI) process. VI involves an analysis of the products on the production line. Inspectors must visually identify any defects on the wafer surface, either using their naked eyes or under a microscope, before the finished goods are transferred for packing. Manual inspections involve a contact-based verification of the wafer surface. It is characterized by a low degree of automation and high labor intensity, as the elements need to be handled by humans. Such an approach is labor intensive, inefficient and means that the process of detecting defects is inaccurate. It may also lead to the application of various standards due to objective human judgments, thus failing to meet the strict requirements of modern industry. On top of that, early detection of defects is important, as production may be halted to address the root cause of the defect, and manufacturers may mitigate their potential economic losses (time and cost) incurred in connection with withdrawing defective wafers from circulation.

Monocrystalline silicon is commonly used for photovoltaic (PV) devices. To produce a high-quality solar panel, silicon wafers must be clean and free from any impurities. However, various types of defects may occur, such as scratches, chips and cracks. Other visual defects may also be present on the surface of solar cells due to uncontrollable factors encountered during the production phase. Many types of silicon wafer defects exist that may be detected on the wafer surface. For the purpose of our study, we obtained digital images of monocrystalline silicon wafer defects from LONGi's production facility based in Kuching, Sarawak, Malaysia.

AOI is a key technique used in manufacturing to ensure the quality of printed circuit boards assemblies (PCBA) used in electronics. By detecting incorrect, missing, and incorrectly placed component, it is a swift and accurate inspection tool ensuring that the PCBs leaving the production line are detect-free. As such, the technology is capable of replacing human inspectors, as it is faster with offers higher accuracy rates.

The AOI-based silicon wafer defect recognition process is divided into three phases, i.e. image processing, pattern recognition and classification. Image processing is used to enhance the images and extract specific, useful features. Pattern recognition, meanwhile uses statistical information or machine learning techniques to classify the features into distinct categories based on their shape, color and texture. Lastly, the classification stage allows to assign the silicon wafer defect patterns recognized to specific types. AOI is