THOMPSON RIVERS UNIVERSITY

SEM EXAMINATION OF SOLAR CELLS

PHYS 4480 research proposal

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Contents

Introduction

Photovoltaic solar cells are an important source of renewable energy. They are fragile and their efficiency can be reduced by improper handling and installation, internal defects, and breaking down with use. Defect analysis is important for analyzing the ways in which cells can be damaged and looking for performance impacting damage [1]. The scanning electron microscope (SEM) has the potential to analyze small solar cell samples in more depth and for longer periods of time than industry standard techniques like electroluminescence. Secondary electron (SE) and backscattered electron (BSE) detectors can analyze topography and locate physical damage. Energy dispersive X-ray spectroscopy (EDX) can locate impurities and determine their composition. Cathodoluminescence (CL) can show cracks and defects in the cell surface which may be hard to locate [2].

The purpose of photovoltaic (PV) panels is to generate electric power when light radiation is incident on them. Monocrystalline (MC) solar cells are essentially a diode with semiconductor structure around it to create an electric potential from incident radiation. Cells are produced from silicon substrates which are p-type doped with boron. The front of a monocrystalline wafer is textured with pyramid structures to reduce reflection, heavily n^+ doped with phosphorus to form a pn junction from the from to back of the wafer and covered with a silicon dioxide or titanium dioxide antireflection coating. The back of the wafer heavily p^+ doped to reduce carrier recombination. Contact fingers go though the coating to the n^+ region allow conduction from the front without covering large amounts of the area of the cell, the rear contact touches the back of the whole p^+ region. When a photon is incident on the n^+ region it excites an electron hole pair, which creates current when the front and back are connected by a circuit [1].

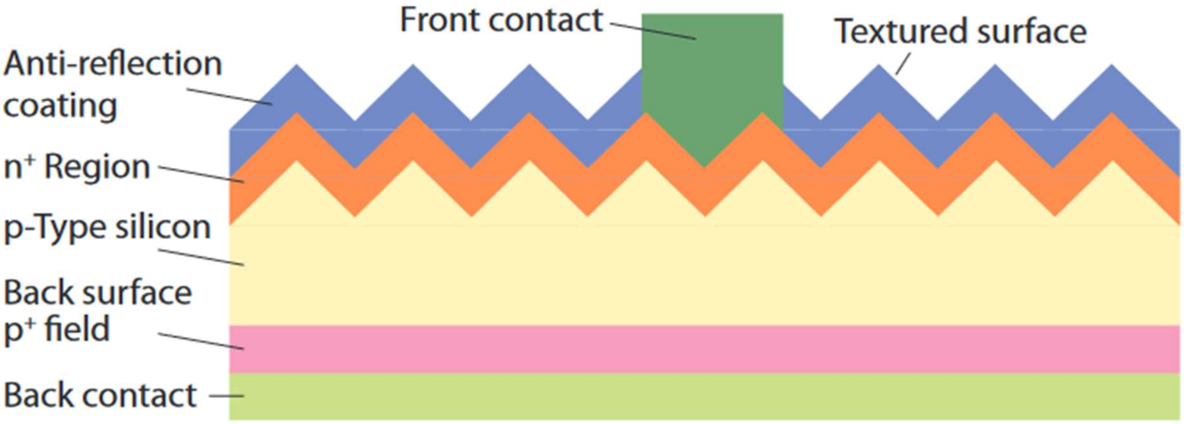

Figure 1, typical structure of a monocrystalline solar cell; the different regions are highlighted in different colours. This diagram is not to scale, the p-type silicon region is the thickest and the top contacts and anti-reflection coating are much thinner than is shown [1].

KXOB25-05X3F-TB monocrystalline solar cells are the samples for this research. These cells are sensitive to wavelengths of 300-1100 nm, with efficiency of 25% and are typical of the type used in small electronics. The device consists of three 7.20 mm by 6.59 mm cells with bus bars in between them to collect power, fingers run across the surface between the bus bars to collect current from the surface of the cell. The overall device is 1.8 mm thick, 8mm wide, and 23 mm long, see Figure 3 for a schematic of the package [3].

Figure 2, image of KXOB25-05X3F-TB solar cells [3].

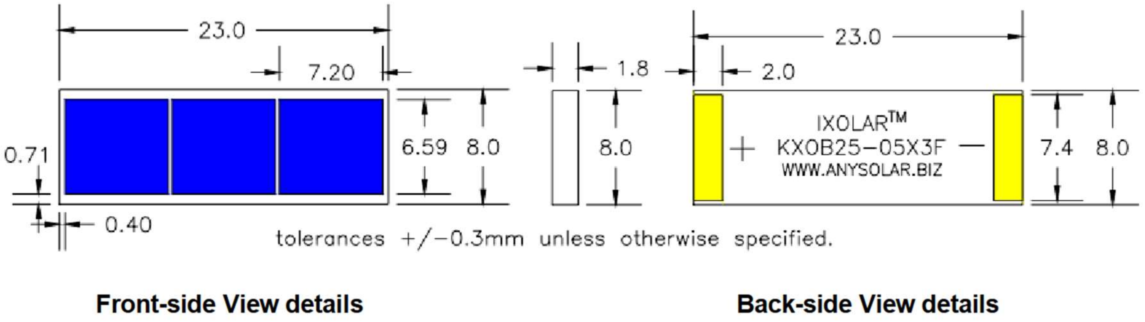

Figure 3, package schematic of a KXOB25-05X3F-TB solar cell. The left shows the front, the middle shows the narrow side, and the right shows the rear [3].

Sample preparation

A new from the package solar cell will be wiped gently with a kimwipe on the rear and sides and all around with compressed air. If a 12 mm SEM stub can be used to mount the cell even though they are larger than the stub about 5.5 mm of the cell hanging off each side of the stub with slightly more than that at the corners. If a larger stub 24 mm or larger diameter is available, it will be mounted on that. The stub will be centred on the cell, the + and – contacts on the rear will be connected to the stub using copper tape to ground the surface of the device. No coating is necessary as the front contacts on the cell will ground it. If the cell charges when examined with this preparation a small examination region will be selected close to the centre, and to one of the larger bus bars on the front and surrounded with copper tape to better ground it and reduce charging [4][2].

Examination techniques

The surface of the sample will be examined with a variety of SEM techniques to test their applicability to defect detection in solar cells. This process will be included as an example of how each of these techniques can be used on semiconductors in chapter 4 (Results and analysis) of my final PHYS 4480 report. The MC solar cell is an excellent sample for general evaluation of the applicability of SEM techniques to semiconductor samples. The cell surface is not flat, it is textured with pyramids of 1-10 µm in size and has metal contacts on it both of which can be examined with SE and BSE detectors. The coating and contact composition can be determined with EDX. CL can look for damage in the coating and changes in the electrical properties due to the presence of contacts near it. For all these examinations a sample site will be selected close to the bus bars and one of the fingers, this will allow for the detection of possible changes in properties from the presence of the contact, ensures there is a good path to ground for beam electrons [5][1].

For this the user guidance for semiconductors will be followed to minimize the beam current reduce sample damage. Images will be taken at or below 5 keV with the minimum beam current to obtain good images. Due to the surface contacts the sample area near a contact will be well grounded and charging will be minimized. Since the solar cell is designed to separate electrons with the built in potential high beam current relative to other semiconductor samples may be necessary to get good images.

Surface topography – SE, BSE

SEM images can detect surface topography; the MC cell is an excellent example of where this can be applied. The surface of the cells has a pyramid structure with size 1-10 µm etched into it during manufacturing. Using first a secondary electron detection this will be examined. By zooming in to the scale of several of these pyramids they can be directly imaged with SE and inspected. This will demonstrate the ability of the SEM for examining small semiconductor structures. For the same region BSE images will also be taken which should show the pyramid topography better than the SE images [5][2].

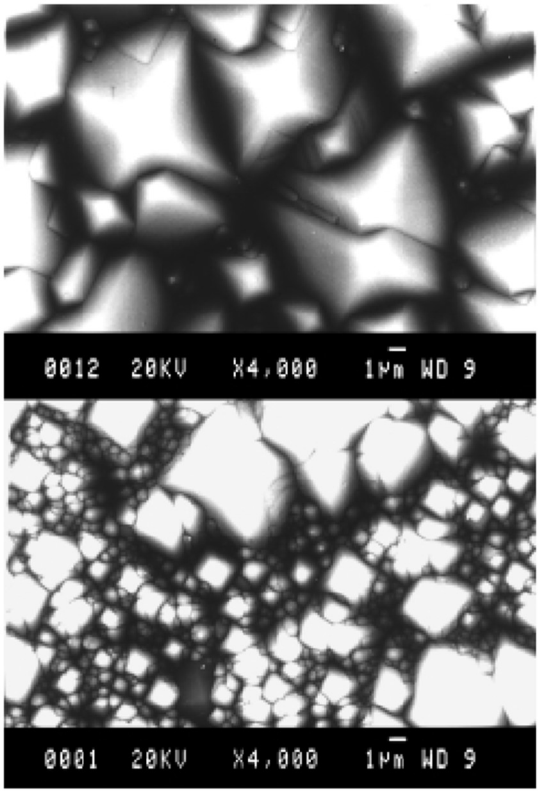

Figure 4 (right), SEM images of two different textures of silicon wafer surface [5].

Coating and contact composition - EDX

The type of coating on these solar cells is unknown, for MC cells silicon nitride, titanium oxide, or silicon oxide are typically used. The fingers are usually made of silver or a combination of silver and aluminium [1]. The coating composition will be investigated with a EDX map of the examination region, which includes the coated surface and the contact finger, more detailed spectra will be taken from the centre of the finger and a location on the coating, this will give detailed information on the composition of the coating and the finger. If any region in the area examined appears to have impurities in it these will also be examined with a detailed spectrum. The beam energy for the EDX needs to be high enough that easily detectable X-rays from Ag, Al, O, N, Ti, and Si, but as low as possible to minimize beam damage. All these except silver have K X-rays under 5 keV. Titanium has L x-rays of around 450 eV, and silver has L x-rays of 2.9 -3.6 keV [6]. A beam energy of 5 or 10 keV will be sufficient for taking these spectra, however once all other analysis has been conducted higher beam energies could be used to get a better spectrum of the device since it will more clearly show silver and titanium.

Coating damage – CL, SE, BSE

Depending on the material the coating is made from it will exhibit CL. The CL spectrum will change slightly near the contacts due to the metal semiconductor junction there. If there is physical damage like cracks the CL spectrum will also change near them [7]. An image of the area examined will be taken with the RGBCL detector to measure the CL spectrum which should be relatively uniform across the surface but increase in wavelength (decrease in energy) near the contact due to the junction. Areas where the CL spectrum changes rapidly will be examined with BSE to investigate the topography and see if the cause can be found. The CL spectrum will change colour near cracks [7]. Both potential coatings exhibit CL in the 350-900 nm range of the RGBCL [8]. If the coating is silicon dioxide it will exhibit CL from band C at 560 nm (2.21 eV) [9]. If it is titanium dioxide it will have CL in the 520 to 560 nm (2.39 – 2.22 eV) as well as near 480 nm (2.59 eV) and 580 nm (2.14 eV) depending on the crystal structure . If the CL detector is not installed in the device BSE images will be examined for areas of high brightness which may be cracks with sharp edges, and then these areas will be further inspected with BSE and SE.

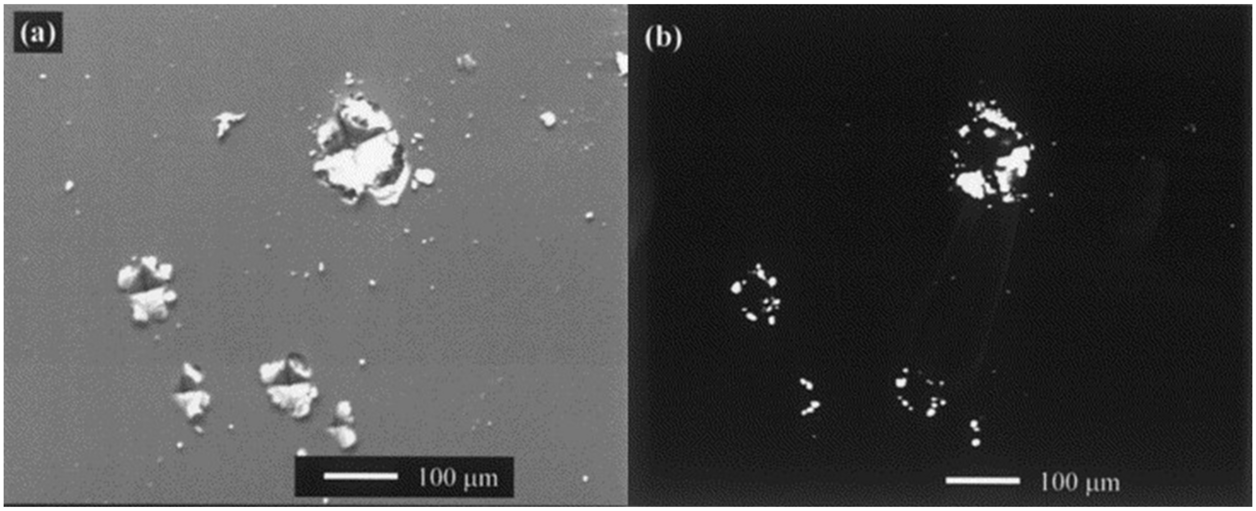

Figure 5, a porous silicon sample which has been damaged with a steel tip, (a) is with SE, (b) is with CL [7].

Conclusion

The SEM is an extremely useful tool for investigating semiconductor samples. This project will demonstrate its use on samples more complex than the simpler silicon-molybdenum wafer and zinc oxide nanoparticles already examined with it. The MC solar cell is an excellent sample for evaluating all SEM detectors on semiconductor samples. The surface topography can be examined with SE and BSE. EDX can be used to determine the composition of the coating and contacts. Cl can be used to look for surface damage and verify the coating composition. Examining the solar cell will effectively demonstrate the use of the SEM for semiconductor devices; it will provide an excellent example for my final report. If damage in the coating can be detected with this analysis the project could be extended to combine SEM and electrical characterization of physical damage to solar cells.

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