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KPAN002: Application - Solar Cell Research

"*Utilisation of a micro-tip scanning Kelvin probe for non-invasive surface potential mapping of mc-Si solar cells*" -

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Keywords

High Resolution Scanning Kelvin Probe, Multi-Crystalline Silicon, Surface Potential Mapping, Shunt Detection, Non-Invasive Surface Charge Profiling

Abstract

Researchers have applied a micro-tip Scanning Kelvin Probe to produce high-resolution surface potential maps of silicon nitride (Si_3N_4) coated multi-crystalline Silicon (mc-Si) solar cells in a non-contact, non-invasive fashion. They show this technique highlights two types of defects: localised surface charge and shunts. In the latter case they contrast the non-contact surface potential maps with contact measurements made by the Shunt scan technique. Using a guarded micro-tip with active shield they show for the first time surface potential changes at the mc-Si grain boundaries due to different mc-Si polytypes. The high resolution scanning Kelvin probe (HR-SKP) has a surface potential resolution of <10mV at a tip diameter <200mm.

Research Area

In the last decade photovoltaic power generation has grown seven-fold to in excess of 700MW. Reasons for this expansion include increased public awareness of the environmental-friendly, renewable-energy source, coupled with the increased availability of solar cell systems. Current development initiatives include mass production of low-cost, reasonably efficient cells (12–15%) utilising multi-crystalline Silicon (mc-Si).

Efficiency limiting factors in solar cells include surface reflection, incomplete or dissipative absorption, i.e. for photon energies smaller than band-gap no electron–hole pairs are produced and for photon energies much larger than band-gap excess energy is converted to heat. In addition, recombination of charge carriers in the bulk (e.g. caused by lifetime reducing impurities) and at the surface, decreases the output. Finally, resistance losses also reduce the efficiency of the cell. These losses can be subdivided in parallel resistance losses (also called shunt losses) and series resistance losses.

Manufacturing techniques in the production of Si wafers are known to generate their own particular defects impacting on the efficiency of the cell produced. These include grain boundaries, dislocations, lattice strain, interface states, impurities such as Fe, Cu, Ni, Cr, and contact resistivities between the different materials used.

Figure 1. KP Technology SKP5050 System.

Use of Kelvin Probe

Various techniques can be applied to solar cell materials characterisation, including detection of recombination, shunts and contact resistance defects. These include surface photovoltage (SPV), microwave photoconductance (m-PCD), electron/laser beam induced current (EBIC/LBIC), deep level transient spectroscopy (DLTS) and thermography, all of which are reviewed by Istratov [3]. A recently developed approach by Van der Heide, now known as Shuntscan, produces a surface map of the emitter potential which changes in the vicinity of shunts. Some of these techniques are to a greater or lesser extent invasive, i.e., the Shuntscan requires penetration of the coating by a tungsten tip, which also causes some local damage to the silicon surface of the cell.

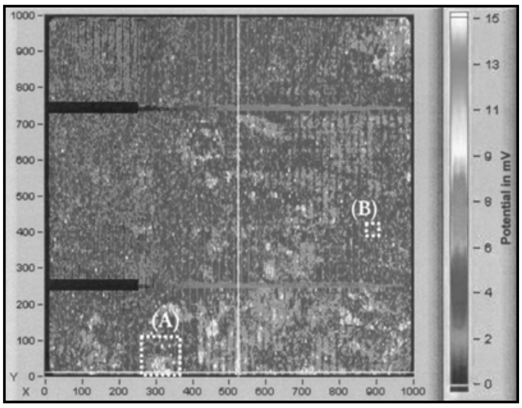
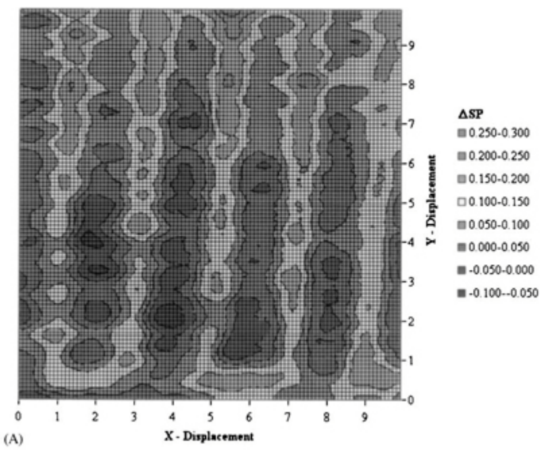


Figure 2. A (10x10) cm^2 PRAMP scan of shunt-containing solar cell under 500mV. Dotted rectangles represent the areas scanned by the Kelvin probe.

In this study the researchers have adopted an alternative approach utilising the high-resolution scanning capabilities of the KP Technology Kelvin probe (SKP), to locate solar cell defects and reveal other surface features via surface potential mapping. This non-invasive, non-contact method features <10mV surface potential resolution with tip sizes ≤200 mm. The HR-SKP consists of a vibrating electrode (μ-tip) in a parallel-plate configuration positioned above a scanning stage upon which the solar cell is mounted. The tip is vibrated using a voice- coil driver powered from a computer controlled digital sine-wave oscillator.
The 200μmm diameter tip is shielded using a sputtered layer of gold deposited on top of the 10 mm thick cladding. The automatic measurement procedure controls the (x; y; z) micro-translation (0.4mm resolution), amplitude and frequency of oscillation, tip and shield bias.



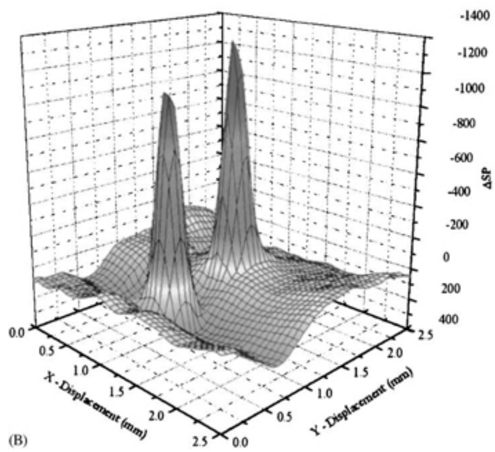


Figure 3. A (10x10)mm^2 region where the black areas indicate the shunt positions, the background structure represents the modulation of surface potential between the silver fingers and the Si_3N_4 coated silicon surface.

Figure 4. A (2.5x2.5)mm2 image showing two large surface potential excursions (<-1V) indicating regions of high local charge. The silver/silver oxide fingers have a surface potential about (200750)mV greater that of Si3N4 coated silicon.

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An utilise an 'off-null' measurement procedure featuring a tracking routine to maintain a constant average tip-to-sample spacing (normally between 100–500 mm) to within 2 mm which avoids spurious work function changes related to spacing changes. A Peltier stage can be used to control sample temperature in the range (-20 to 150°C) and light injection underneath the tip permits the surface photovoltage to be determined. The Kelvin probe provides the relative work function (Δwf), or surface potential (Δsp), between the vibrating tip and the sample surface directly under the tip. In order to generate absolute work function values the tip has to be calibrated against a known reference surface. The work function/surface potential is highly sensitive to surface conditions. Surface processing, surface chemical composition, surface charge surface contamination and surface roughness will all produce measurable changes in metal or semiconductor or work functions. We show here that surface features such as metal/semiconductor and semiconductor/ semiconductor interfaces are clearly visible in surface potential scans. Further we contrast the information provided by the (non-contact) SKP with contact electrical measurements such as the Shuntscan which indicate that SKP is sensitive to charged defects on top of the cell and to shunts within the solar cell.

High resolution SKP scans were performed in darkness with top and bottom contacts short circuited, at two sectors indicated in Figure 3 having shunts as identified by the Shuntscan and Figure 4 on an area which does not display a potential variation. The former data clearly show a correlation between regions of low surface potential located on the Si_3N_4 coated silicon surface between the silver fingers and dimensions << the Kelvin probe tip diameter. It is observed that the charging events occur on top of the metallisation and Si_3N_4 leading to the assumption that these are due to patches of a thin isolating film which is not visible under microscopic examination. The Shuntscan, being a contact technique, is not able to detect thin insulating films, however the degree of charging shown here ($\leq 10^{-7} Ccm^{-2}$) may well affect the surface recombination rate at the underlying mc-Si surface.

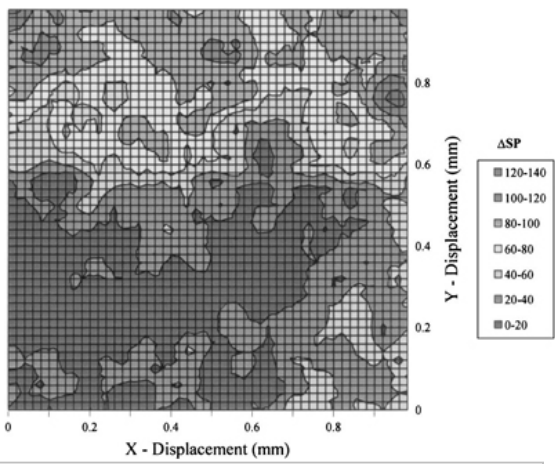

Figure 5.HR-SKP scan (in mV) of a (1.0x1.0) mm2 section of the coated mc-Si wafer not containing shunts. The data clearly show a grain boundary between two silicon polytypes, having work function/ surface potential differences of 60–70 mV

Figure 5. Shows a (1x1) mm² HR-SKP performed on a shunt free area of the solar cell across a polytype interface. A clear work function/surface potential difference between the polytypes of 60–70mV occurring in the vicinity of the grain boundary is observed. SKP topographical data indicate that the height change between the regions is <4 μmm, which strongly infers that the abrupt potential changes can wholly be ascribed to surface orientation rather than spacing changes. It is clear that polytype work function differences are visible through the thin Si_3N_4 coating. In order to obtain the required high signal-to-noise ratio an 'active' or 'driven' guard shield potential must be used to produce this image.

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Conclusion

Having demonstrated that the HR-SKP provides complementary information to that of the Shuntscan on mc-Si solar cells: discontinuities of surface potential have been observed in the same locations as the Shuntscan indicates a shunt position. In addition the modulation of surface potential produced by the differing work functions of the silver/silver-oxide finger and Si_3N_4 coated mc-Si can be readily imaged. Low surface potential patches having dimensions much smaller than the tip diameter are observed and attributed to surface charge events. These would not be observable by the Shuntscan because of its contact mode of operation. For the first time, direct evidence of polytype related surface potential variations using an actively guarded micro-tip can be reported. Such work function variations are due to the difference surface orientations that comprise the mc-Si and illustrate the surface sensitivity of the SKP system. The authors plan to proceed with the investigation of surface potential changes occurring during white-light illumination of the wafer, i.e. SPV, and time-resolved surface potential changes, i.e., DLTS in a similar fashion to that previously undertaken for single crystal silicon wafers.

Reference

1. Original publication: "*Utilisation of a micro-tip scanning Kelvin probe for non-invasive surface potential mapping of mc-Si solar cells*" - Konrad Dirscherl THE ROBERT GORDON UNIVERSITY, Iain Baikie & Gregor Forsyth, KELVIN RESEARCH CENTRE, Arvid van der Heide, ECN SOLAR ENERGY

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