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SEM EBIC characterization of SiC/Si solar cells

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ABSTRACT: A number of experimental solar cells with SiC emitters and Si bases, varying in photovoltaic efficiency from 0.1 to 5.8 %, were examined by EBIC. Defect particles were observed in the cells using EBIC. Evidence was found that suggests that the top contacts on the 0.1% cell were Schottky not ohmic in character. Quantitative EBIC linescans across these metal fingers were analysed to obtain values for L, the minority carrier diffusion length.

1. INTRODUCTION

The efficiency of Si solar cells can be increased by growing a top layer of a second semiconductor of forbidden gap energy $E_{g2} > E_{gSi}$. Incident light of photon energy $E_{ph} > E_{g2}$ will be absorbed in the layer. Then photons of energy $E_{ph} > E_{gSi}$ will be absorbed in the Si to form carrier pairs. In this way, more of the energy of the solar spectrum will be used to generate electrical power. One possible such wide gap "emitter" material is SiC.

A set of heterojunction solar cells consisting of nanocrystalline β-SiC p-type emitters on n-type Si (Figure 1) were grown and found to have photovoltaic efficiencies from 0.1 to 5.8% (Toal and Reehal 1998). This paper reports the results obtained in examining the cells in an SEM (scanning electron microscope) by the EBIC (electron beam induced current) method. By varying the beam energy and hence penetration range, measuring the EBIC gain and fitting these data to Monte Carlo simulation curves (Holt and Napchan 1994), in principle, it is possible to obtain the value of the minority carrier diffusion length in the base material and to determine its uniformity or variability (Hardingham and Holt 1995, Grunbaum et al 1995).

Monte Carlo electron trajectory simulation programs (Joy 1995) can be used to obtain data on the spatial distribution of hole-electron pairs generated by the beam and this can be applied to simulate EBIC data. EBIC curves were simulated by Napchan's well known MC-SET (Monte Carlo simulation of electron trajectories) suite of programs (Holt and Napchan 1994). Fitting experimental EBIC data to families of curves calculated in this way allows rapid evaluation of the material and device parameters involved.

2. EXPERIMENTAL METHODS

The solar cells were produced at South Bank University by electron cyclotron resonance plasma assisted chemical vapour deposition (ECR - PACVD) of the β-SiC. Their structure is shown in Figure 1.

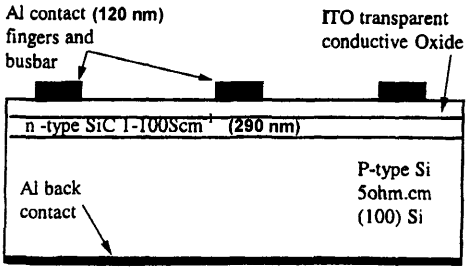
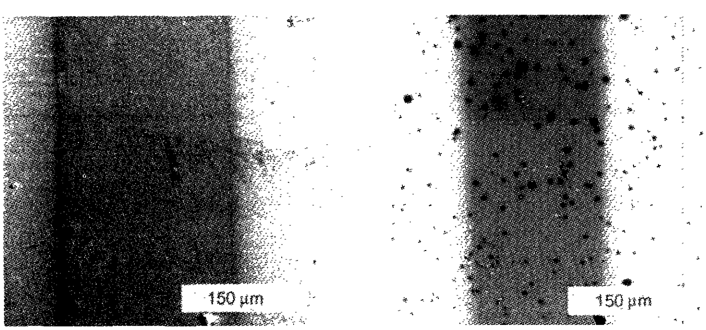


Figure 1. Schematic cross sectional diagram of the structure of the SiC/Si solar cells with ITO (indium tin oxide) layer.

The cells were characterized at Imperial College using a JEOL JSM 840A microscope plus either a Matelect EBIC system (mainly for imaging) or a Stanford Research Systems SR570 amplifier controlled and data-logged by TestPoint software (mainly for recording linescan profiles).

3. RESULTS

The lowest efficiency cell, "#116 with no ITO" appeared as shown in Figure 2. The black dots are suggestive of the incorporation of particles of foreign matter during growth. (Most of the dots in the EBIC image do not correspond to anything visible on the surface in the SEI.) The other cells all showed this same structure.



(a) (b)

Figure 2. (a) SEI and (b) EBIC images of a typical area of the lowest (0.1%) efficiency cell (#116 - no ITO) sample. The vertical dark strip is a metal finger.

EBIC linescans were recorded across the parallel metallization lines over the cells as shown in Figure 3. The dips in the linescans as the beam crosses the metal fingers, are due to the absorption of the beam energy. The scan across the high-efficiency cell gives an approximately constant value of EBIC current (Figure 3,a), but that across the low-efficiency one (Figure 3,b) falls exponentially away from the fingers. This is evidence that the contacts in the latter case were not ohmic.

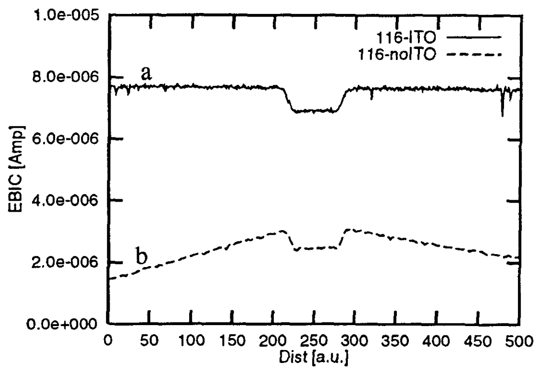


Figure 3. EBIC linescans recorded across one of the metal top contact 'fingers' of (b) the lowest efficiency (0.01 %) sample "#116 - no ITO" and (a) the highest (5.8%) efficiency cell (#116).

A series of such EBIC linescans at a series of increasing beam energies gave values for the collected current I_{EBIC}. They also give the (small) percentage variation in this quantity. This divided by the beam current, namely the gain = I_{EBIC} / I_b, was plotted against beam accelerating voltage and gave almost straight lines. Work is in progress on fitting this data to simulations calculated using the MC-SET suite of programs.

4. DISCUSSION

The reason for incorporating a layer of ITO, the well-known transparent conductor, is that the SiC layer is of high sheet resistance. Thus the ITO greatly improves current extraction. Problems with the shunt resistance were ascribed to the presence of pinholes in the film which Toal and Reehal (1998) ascribed to particulate formation in the plasma. It seems that the black spots in Figure 2(b) are direct evidence for such particulates.

Curve fitting the gain versus beam accelerating voltage involves the fitting parameters: L, the minority carrier diffusion length in the Si and the widths of the depletion regions in the Si and in the SiC. The process is a somewhat lengthy iterative one as there are a number of adjustable parameters. Initial indications are that the value of L is a few microns.

The fall of the collected current as the beam scans across the edges of the metal fingers in Figure 3, b is of exponential form. This can be explained as due to scanning across the edge of Schottky barriers so the signal falls as exp(-x/L) with distance from the edge of the metallization fingers. This is evidence of charge collection under the contact which is thus of Schottky not ohmic type. The flat EBIC response across the good device (Figure 3,a) is that to be expected for ohmic contacts so charge collection occurs only at the p-n heterojunction.

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