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INVESTIGATIONS OF DIFFUSION BARRIERS FOR APPLICATION IN BACK-CONTACTED SOLAR CELLS

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ABSTRACT: The characterization of barriers against phosphorus diffusion for application in back-contacted solar cells by using the sheet resistance imaging (SRI) method is investigated. The focus is set on a screen-printable TiO_x-layer, which is compared to a thermally grown and photolithographically patterned SiO_2-layer. Within the measurement error the effectiveness of the TiOx-layer as a diffusion barrier is proven. The high resolution of the SRI allows to observe structures in the diffused areas of very small scale.
Keywords: SRI, diffusion barrier, TiO_x

1 INTRODUCTION

In research of wafer-based silicon solar cells one focus is set on back-contacted solar cells at the moment. A good review of these cells is given in [1]. Their main advantages are the absence of shadowing losses and a simplified cell interconnection on module level. A key feature of back-contacted solar cells is a patterned emitter formation on the rear side. There are several possibilities to create such structures, one of them includes the use of diffusion barriers against phosphorus diffusion as described for example in [2,3]. Conventional diffusion barriers for silicon solar cells, as thermal SiO_2 or silicon nitride, require a high temperature and / or a masking step. For industrial application screen printable diffusion barriers offer a simple process with high throughput. One promising material is TiO_x [4]. A structured TiO_x-layer can be produced by screen-printing of a commercially available paste tested in this work. One possibility to characterize the resulting emitter formation is the measurement of sheet resistances. Due to the structure size it is not possible to use four-point-probing since edge effects lead to erroneous measurements. Therefore the TiO_x-layer as a barrier against phosphorus diffusion has been investigated using the infrared method sheet resistance imaging (SRI) [5,6]. SRI offers high lateral resolution (pixelsizes up to 45 x 45 µm² with the current experimental setup), short measurement times and the influence of edge effects is very small.

2 EXPERIMENT

2.1 Sample preparation

The TiO_x-layer used as a diffusion barrier results from a paste containing the precursor titanium ethoxide. After screen-printing the paste is dried for 5 min at 200 °C and cured for 10 min at 550 °C. The diffusion barrier was patterned as pictured in figure 1a. The pattern features two 15 mm wide bars for investigation of the base area without edge effects and lines of 80 µm (position 1 in figure 1a) to 3 mm (position 2) width for resolution analysis. The produced layers appear dark blue and lines of 300 µm width are about 100 nm to 150 nm thick. In addition a thermally grown SiO_2-layer of about 200 nm thickness was photolithographically structured with the same pattern. This layer is supposed to act as an ideal diffusion barrier with defined edges [7]. Optical microscope pictures of 1 mm lines can be seen in figure 1b and 1c. The SiO_2-line seems to have sharp edges, whereas the TiO_x-line shows transitions in the brightness of the layer towards the edges.

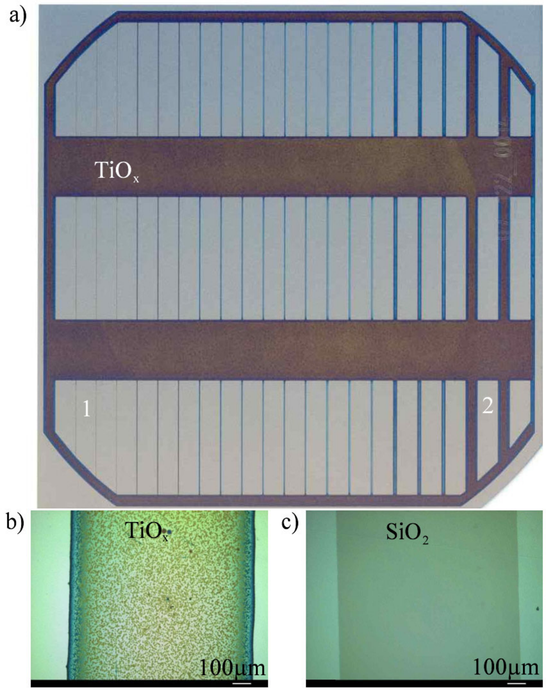

Figure 1: a) Wafer with TiO_x-structure before diffusion, b) 1mm TiO_x-barrier, c) 1 mm SiO_2-barrier

Since a removal of the TiO_x-layer is not possible with standard wet chemical etching steps on the one hand and for some cell processes the diffusion barrier layer remains on the other hand [2,3], the emitter formation was investigated with the remaining layers.

2.2 SRI measurement effects and sample description

The signal of the SRI method is based on free carrier absorption or emission of infrared light with wavelengths from 3.25 µm to 5 µm (effective range of the CCD-camera). Since it is an optical measurement, effects like reflection at interfaces have to be taken into account. Further significant absorption of the layer itself has to be excluded. Therefore samples with structured layers of either TiO_x or SiO_2 were measured before the diffusion step. A scheme of the wafer with the TiO_x-layer is pictured in figure 2a. To account for the influence of the

$POCl_3$-diffusion step on the absorption of infrared radiation in the diffusion barrier layers, a sample with the structured TiO_x-layer on top of a full area SiO_2-layer was prepared (figure 2b) to exclude any emitter formation below the TiO_x-layer.

The different layer sequences were produced on wafers with two different surface topologies to investigate signal differences due to the roughness of the material, namely a polished and an alkaline etched surface of a monocrystalline wafer.

All samples feature a full area SiO_2-layer on the rear side to exclude influences due to the possibility of inhomogeneous emitter formation or reabsorption processes.

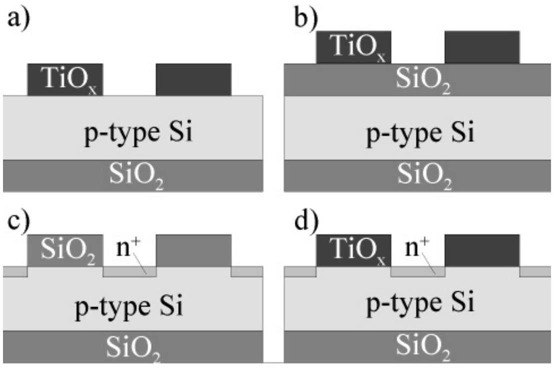

Figure 2: Produced samples, a) Wafer with TiO_x-layer without emitter formation, b) TiO_x-structure on a full area SiO_2-layer, c) SiO_2-diffusion barrier, d) TiO_x-diffusion barrier.

The diagram in figure 3 depicts the process steps used to prepare the different samples.

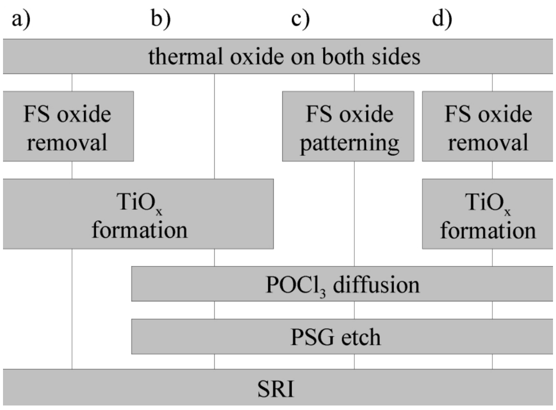

Figure 3: Diagram showing the steps for the preparation of the samples.

3 RESULTS

The SRI-measurements discussed below are all carried out in emission mode, so a higher signal coincides with a higher density of free carriers and a smaller sheet resistance. The raw data detected by the camera was converted in photon flow density units. To obtain values for sheet resistances a calibration of the signal is required. The calibration has to be carried out for both emitter and basis regions separately. For the investigation of patterned emitter formation it is preferable to consider the photon flow density to avoid singularities particularly to investigate transitions between n- and p-regions. In the following diagrams one pixel represents a wafer area of about 435 x 435 µm² unless otherwise noted.

3.1 Influence of the layers on the SRI-signal

To investigate the influence of the layers on the signal measurements before the diffusion step have been carried out. An influence should result in a visible difference between the signals of regions with and without coatings in the SRI-signal. Neither for the TiO_x-nor for the SiO_2-layer a contrast was found.

To investigate a possible change of the SRI signal of the coated regions by a $POCl_3$-diffusion step the wafers with a full area SiO_2-layer on both sides and additionally a patterned TiO_x-layer on the front side ware measured after the diffusion step. Negligible signal differences were observed either for the TiO_x- or for the SiO_x-layer.

3.2 SiO_2 diffusion barrier

The effectiveness of the 200 nm thermally grown SiO_2-layer as a barrier against phosphorous diffusion could be confirmed by using four-point-probing. For the evaluation of SRI measurements the signal of samples with and without emitter are subtracted. In the bottom half of figure 4 the laterally resolved SRI-signal of a sample with the SiO_2-barrier on a polished surface is pictured. All lines of the pattern are visible.

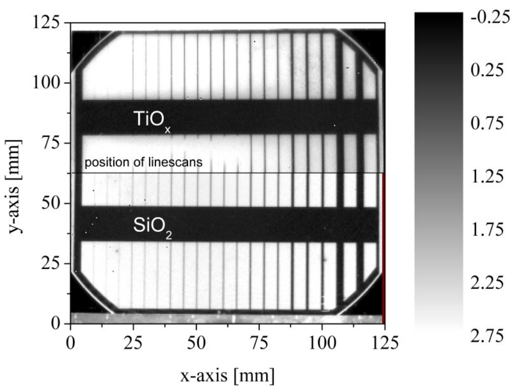

Figure 4: SRI measurements of the polished wafers, top: TiO_x-barrier, bottom: SiO_2-barrier.

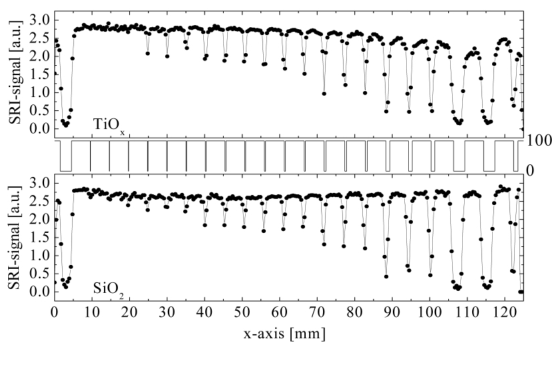

Figure 5: Linescans over the middle of wafers with selective diffusion, top: TiO_x-barrier, middle: ideal structure, bottom: SiO_2-barrier.

The signal of the basis region rises up to thinner lines (linescan in the bottom of figure 5) since the size of one pixel is in the order of the line width. The theoretical structure is shown in the middle of figure 5, 0 stands for only basis signal and 100 for the emitter signal.

In the histogram (figure 6) can be observed that the signal of the SiO_2-barrier attributed to the basis-region (left peak) is not zero. The difference might arise due to a radiation offset because of the higher total number of carriers in the measured region.

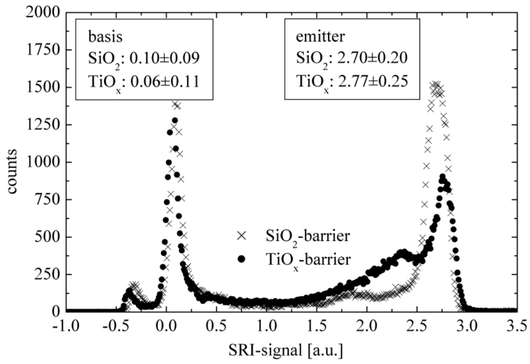

Figure 6: Histograms of the SRI-measurements of polished wafers with the different diffusion barrier layers.

The error mentioned in the histogram is the width of the gaussian fitting function. It can be regarded as measure for the error since it contains differences in the basis material like doping inhomogeneities, the neglected influence of the coating, differences in the temperatures of the two subtracted measurements and an error of the equipment.

3.3 TiO_x diffusion barrier

After measuring the SRI-signals of the SiO_2-diffusion barrier, the measurements of the samples with the screen-printed TiO_x-layer as a diffusion barrier can be compared to the above discussed values. In both the image (top half of figure 4) and the linescan (top half of figure 5) inhomogeneities in the signal belonging to the regions with emitter can be observed. Regions neighboring wide lines of the patterned TiO_x-layer (right side) have lower signals than regions next to fine lines (left side). This appearance coincides with four-point-measurements which were performed on uncoated wafers that faced the TiO_x-coated wafers during the diffusion step. The sheet resistance was increased on an area whose shape roughly corresponded to the pattern of the TiO_x-layer, so the inhomogeneities are attributed to an inhomogeneous emitter and not to an optical effect. A doping inhomogeneity could be generated by a mitigation of the diffusion caused by components of the screen-printed layer, for example parts of the layer could evaporate during the diffusion step and deposit beside the printed structure and on the uncoated wafer that faced the TiO_x-layer during the diffusion step. The effect can also be observed in the histogram (figure 6) as a shoulder on the left side of the main peak of the emitter signal. The intensity of the inhomogeneity can be influenced by the conditions of the curing step before the diffusion. An inverse effect has already been detected for phosphorus pastes in [8] using laterally resolved secondary ion mass spectrometry (SIMS) measurements.

By comparing the histograms of the SiO_2-diffusion barrier regarded as effective and the screen-printed TiO_x-layer an effectiveness of the TiO_x-layer within the error of measurement is concluded.

Therefore SRI measurements offer the possibility to control the effectiveness of barriers against phosphorous diffusion and their influence on the emitter inhomogeneity.

3.4 SRI-close-up view

In figure 7 SRI-measurements with a pixel size of about 45 x 45 µm² are pictured for both the SiO_2- (bottom) and the TiO_x-layer (top) after the diffusion step.

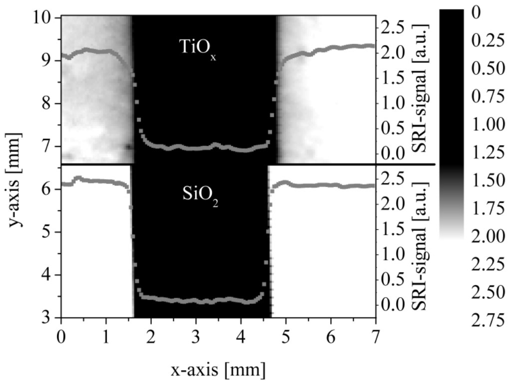

Figure 7: Detail of a SRI-close-up view of a wafer with TiO_x-barrier (top) and a wafer with SiO_2-barrier (bottom).

The transition between basis material and emitter on the surface takes place over at least four pixels even in case of the SiO_2-barrier. This corresponds to about 180 µm. In microscopy images the edges of the SiO_2-pattern were obtained to be very sharp on the scale of the pixelsize. Consequently gradients are attributed to the measurement. For the TiO_x-barrier the transition seems to be less sharp particularly in the emitter region. With enhanced optics a pixelsize of about 10 µm should be attainable [5].

3.5 Surface roughness

In figure 8 linescans over the 1.5 cm wide TiO_x-line on a polished and on an alkaline etched wafer are shown. The roughness of the alkaline etched wafer leads to an equal slope of the flanks of the SRI-signal compared to the polished sample. The edges of the basis signal of the etched wafer are somewhat rounded compared to the polished one. A possible interpretation is a difference in the radiation characteristics of the different surfaces.

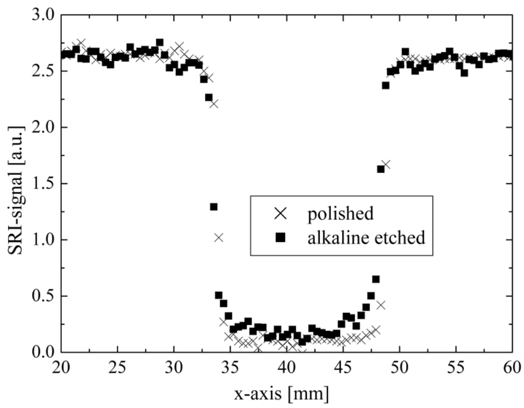

Figure 8: Linescans of the SRI-signal over the wide basis region of a polished and an alkaline etched sample with SiO_2-diffusion barrier.

4 CONCLUSION

For the first time, SRI measurements of wafers with patterned diffusion barriers SiO_2 and TiO_x have been carried out before and after emitter formation in a $POCl_3$-diffusion furnace. The influences of the diffusion barrier layers themselves on the SRI signal have been investigated and found to be very small both before and after the diffusion step. Therefore, signal contributions from the diffusion barrier interfaces and bulks can be neglected compared to the signal differences of regions with and without emitter.

The effectiveness of the SiO_2 layer as a diffusion barrier has further been tested by four-point-probing. Within measurement error the effectiveness of the SiO_2-layer as a diffusion barrier is proven. Within the scope of the SRI measurement method, it is proven that both layers are equally effective as diffusion barriers. Due to the lateral resolution of the SRI measurement method it is possible to make doping inhomogeneities visible which can occur if the screen-printed TiO_x-layer is used as a diffusion barrier.

The SRI method offers a good possibility to investigate diffusion barriers. Due to the short measurement times the lateral resolution inhomogeneities, that can occur when using screen-printed barriers, could be controlled during the process.

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