SINGLE STEP SELECTIVE EMITTER USING DIFFUSION BARRIERS

J.H. Bultman, R. Kinderman, J. Hoornstra, M. Koppes
ECN Solar Energy
PO Box 1, NL-1755 ZG Petten, The Netherlands,
tel: +31 224 564786, fax: +31 224 563214, e-mail: bultman@ecn.nl

ABSTRACT: A new selective emitter process is introduced using diffusion barriers. These barriers can be selectively screen-printed on silicon material before dopant diffusion is applied. So, only an extra print and drying step has to be introduced before diffusion. In this way selective emitters can be made with belt type diffusion using liquid dopants as well as with tube furnaces and gaseous dopants. Homogeneous SiO_2-barrier coatings have been produced up to a thickness of 1 μm without cracking. Also, doping beneath the diffusion barrier can be adjusted between 50 and 150 Ohm/sq. First selective emitters have been produced

Keywords: silicon solar cell - 1: selective emitter - 2: processing - 3

1. INTRODUCTION

Optimal emitters for silicon solar cells are a compromise between low dark currents and low contact resistivity. To obtain high efficiency, it is important to reduce the dark current of the emitter. This is possible by reducing the surface concentration of dopant beneath 10^{20} atoms/cm^3. However, for appropriate contact formation, especially for screen-printed contacts, it is necessary to have a dopant surface concentration higher than 10^{20} atoms/cm^3. Contacting homogeneous emitters is only possible with such a high surface concentration, which makes surface passivation completely impossible. Many years ago, the selective emitter approach has been introduced. With selectivity of the emitter, a low surface concentration and doping between the contacts and high surface concentration beneath the contacts is meant. In this way, good contacting and low dark currents can be obtained. Many ways have been thought of to make such a selective emitter, all with their specific advantages and disadvantages. A good overview of these methods can be found in reference [1]. In this paper, we introduce a new approach to make such a selective emitter. First results of emitter formation are presented.

2. NEW SELECTIVE EMITTER PROCESS

2.1 Principles

In figure 1, the principle of the new selective emitter approach is explained. A selectively applied diffusion barrier hinders the dopant diffusion into the silicon locally. Therefore, beneath this barrier, a lower doping level is obtained. The process sequence is shown in figure 2.

One extra step is introduced, selective print and drying of diffusion barrier paste. This process can be combined with all standard diffusion processes, including the application of liquid dopant sources and gaseous dopant sources applied in tube furnaces.

2.2 Advantages of diffusion barriers

The new method has many advantages:

1. The method can easily be introduced in any production environment because the way of diffusion is not important.
2. The emitter properties beneath the diffusion barrier can be adjusted in three ways: firstly, by changing the transparency of the layer by changing the drying conditions to make the layer more or less amorphous; secondly, by adjusting the thickness of the layer to change the transparency; thirdly, by adding dopant to the barrier to obtain higher doping beneath the diffusion barrier. The adjustment of low level doping is completely independent from the high doping level.
3. A dead layer is avoided completely because of the very low source of dopants available at the surface.

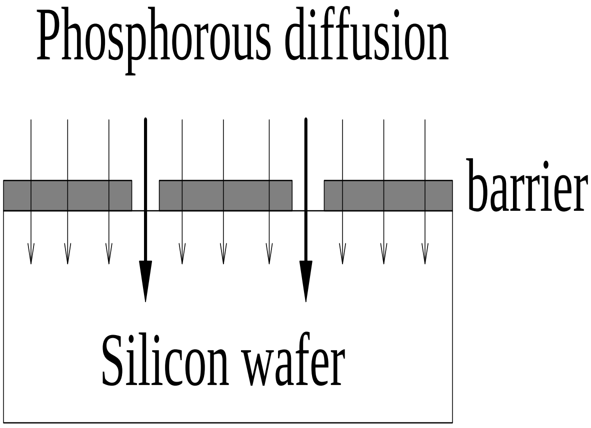

Figure 1 Principle of new selective emitter process.

Saw damage and cleaning
Printing and drying of diffusion barrier
Diffusion
Cleaning
PECVD SiN
Metallisation

Figure 2: Cell process including selective emitter process and surface passivation

2.3 Research topics

Many topics have to be researched before this process can be applied in production. The main topics are: determination of the optimal diffusion barrier properties, robust application of the barriers without chance of shunting, alignment of barrier and metallisation print.

Some of these topics have been researched by us in the last year and results are presented in the next sections.

3. EXPERIMENTAL RESULTS

3.1 Formation of barrier

The most obvious choice of diffusion barrier is SiO_2 because SiO_2 can easily be removed after diffusion and SiO_2 is always formed during the diffusion process anyway. The diffusion coefficient of phophorus in SiO_2 is rather high and we will need a rather thick layer, between 100 and 1000 nm. The most likely way of deposition is screen- printing which means that the SiO_2 has to be built into a binder system. To obtain a homogeneous barrier thickness, a rather thick layer has to be printed to overcome surface roughness of the order of several microns. The challenge is to print a thick layer, which does not spread and which forms a barrier layer with as few cracks as possible. In figure 3, a picture is shown of a homogeneous layer of SiO_2 on top of a multicrystalline wafer. Some cracks in the layer can be seen, although the surface is completely homogeneous. Pictures of other solutions show many cracks in the surface of the layer caused by quick drying. Furthermore, from this picture we can see that the layer fills in some of the surface roughness but not the higher structures. This is also known from earlier solar cells with screen-printed anti-reflective coatings, which are homogeneously blue but with a somewhat more amorphous color because of the micro-structural differences in thickness of the layer.

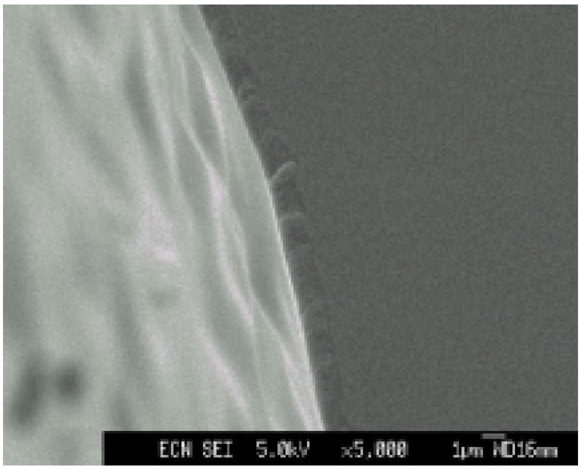

Figure 3: Scanning electron microscope photograph of a SiO_2 barrier layer of 1 µm thickness on top of a silicon wafer viewed in cross section; light material is the surface of the barrier layer.

3.2 Optimisation of barrier thickness

In figure 4, the experimental relation between emitter sheet resistance and concentration of SiO_2 in the paste is plotted. No influence is seen on the sheet resistance below 4% SiO_2 in the paste.

Optimal sheet resistances are between 100 and 150 Ohm/sq, which are obtained for a SiO_2 concentration in the paste between 8 and 10%.

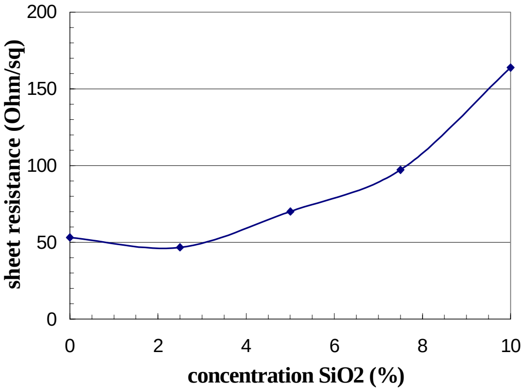

Figure 4: Sheet resistance of phosphorus emitter as a function of the amount of SiO_2 present in the screenprinted paste.

3.3 Emitter dopant concentration produced with barrier

In figure 5, the active dopant concentration profile in silicon, measured with the stripping hall method, with and without diffusion barrier has been shown. These profiles have been diffused at the same conditions besides application of barrier paste. The profile obtained with barrier layer looks like it is shifted to the right by 0.15 µm. So, only the high doping level is not there, which is caused by the lower access op dopant atoms at the silicon surface. Deeper diffusion is completely similar between diffusion with and without barrier, because this process is driven by diffusion is not influenced that much by the surface concentration. This result is exactly what we want to obtain good surface passivation: avoid the dead layer of the first 0.1 µm.

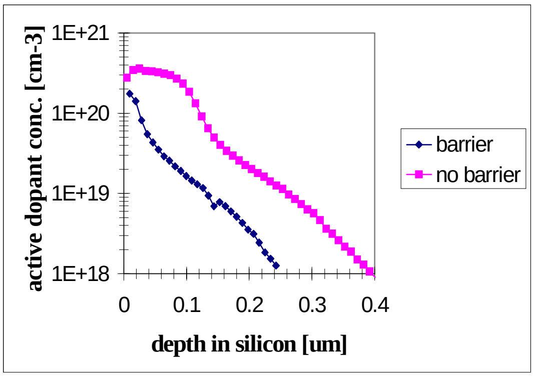

Figure 5: Stripping Hall measurements of active dopant concentration as a function of depth in the silicon for diffusion of phosphorus with and without barrier, otherwise diffused at the same parameters

3.4 Selective emitter formation

A first experiment has been done using a selective print of SiO_2-paste before phosphorus diffusion. In figure 6, the film for the screen is displayed, which shows in black the area which will be printed. This figure shows the difficult issue of our approach: avoid spreading the paste to form a layer which covers the whole surface. A very important aspect is thus the screen-print process, the paste reology, and the drying process. Simple adjustments of the pastes and screens have lead to the result depicted in figure 7, which shows the first selective emitter sheet resistance made with our approach. With an open line width of 300 µm, it can be prevented that SiO_2 will be deposited on areas where the metallisation will be printed afterwards. Also, smaller line widths have been used, but at this point our paste spreads too much to be 100% certain no paste will be deposited on the open lines.

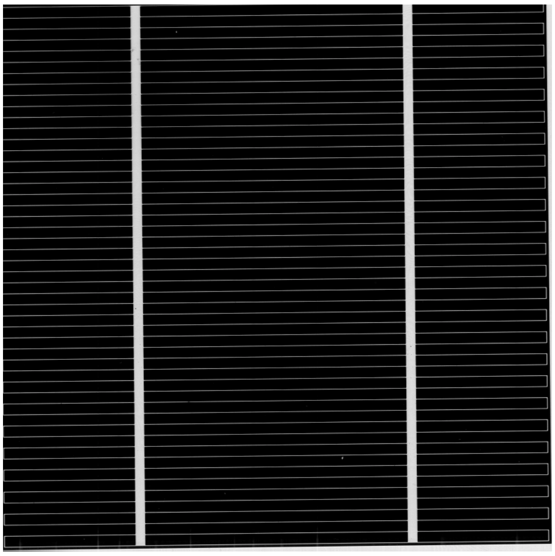

Figure 6: Film for screen-printing SiO_2-barrier for selective emitter formation.

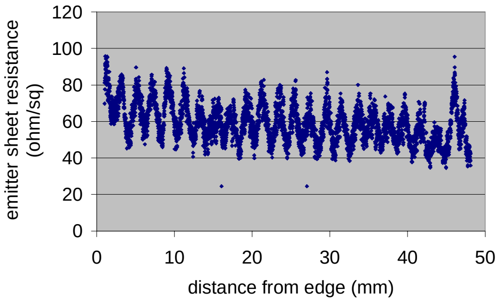

Figure 7: Localised sheet resistance measured from the edge of the wafer.

Figure 7 clearly shows selectivity of the emitter sheet resistance. The base sheet resistance is 40 ohm/sq which is the normal sheet resistance for this diffusion setting. The sheet resistance is 80 ohm/sq where the diffusion barrier is printed. The 80 ohm/sq is too low for optimal surface passivation, but with proper adjustment of paste formulation, we will be able to obtain an optimal doping level. The lines in the screen were 300 µm wide for this graph. Similar graphs were produced with 200 µm and 120 µm screens, although some of the lines could not be detected by the localised sheet resistance measurement due to spreading of the paste.

CONCLUSION

A new method of producing a selective emitter has been developed. We have shown selectivity of the emitter between 40 and 80 ohm/sq. Currently, we are working on rheology of the paste and on a settings for selectivity between 80 Ohm/sq and 200 Ohm/sq. After that, we will produce cells including selective emitter and surface passivation. The new approach will allow adjustment of the doping level between the metallisation fingers independent of the high doping level beneath the metallisation fingers, which we will use to optimise processing for high efficiency.

ACKNOWLEDGEMENT

This research has been carried out with financial support of the Netherlands Agency for Energy and the Environment (Novem).

REFERENCES

[1] J. Szlufcik, J. Horzel, F. Duerinckx, R. Einhaus, E. Demesmaeker, J. Nijs, and R. Mertens, Proc. 8th workshop cSi-solar cell materials and processes, Copper Mountain, 1998