

AN INDUSTRIALLY APPLICABLE HONEYCOMB TEXTURE

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ABSTRACT: A new method for creating a honeycomb texture has been found. It uses a directly printed inkjet mask and isotropic wet chemical etching through it. A special printing pattern has been designed so that structures smaller than the droplet diameter could be printed. After etching it yields a hexagonal honeycomb texture with etch pits of 23 μm depth and a pitch of 50 μm . The weighted reflection is 18.4 % and is hence considerably lower than most other honeycomb textures. As inkjet-printing is an already well-established, cheap and fast process this method can be easily established industrially.

Keywords: Honeycomb Texture, Texturisation, Etching, Inkjet Printing, Multicrystalline Silicon

1 INTRODUCTION

As-cut multi-crystalline wafers are normally texturized in an acidic etching solution consisting of hydrofluoric acid (HF), nitric acid (HNO_3) water and sometimes also different additives such as acetic acid (HOAc). This texturization step also removes the saw damage from the wafers. One of the main purposes of a texture is to reduce the weighted surface reflection. However the acidic texture still has a reflection of between 30 % and 23 % [1]. The lower reflection values are only achieved with a very rough surface that is difficult to passivate. Therefore the best solar cell efficiencies are normally obtained with an acidic texture that reflects 27 % of the incident light [2]. This is considerably higher than the standard texture for mono-crystalline wafers, which reflects only 12 % of the incident light. This difference in reflection is one of the major problems of multi-crystalline solar cells.

A way to overcome the difference in reflection is to apply a so-called honeycomb texture to multi-crystalline solar cells. For this texture, saw-damage free wafers are needed so the saw damage has to be removed in a first step. The second step is the masking of the wafer with a pattern that leaves hexagonally spaced holes open. In the third step the wafers are etched through the hexagonally spaced openings and the honeycomb texture is created under the mask. In the fourth step the mask is removed. Several methods for creating a honeycomb texture (HC texture) have been presented in recent times [3-5]. With isotropic etching in the third step (no plasma), they normally yield a weighted reflection of around 20 %. An ideal honeycomb texture would have a reflection of only 15 % [6]. The fact that this value has not been reached, shows that the previously created structures are not perfect. HC textures can be passivated well and hence good solar cell efficiencies can be reached [3].

Especially in combination with a polished rear surface excellent light trapping can be obtained, with a HC texture on the front surface of the wafer [7]. Therefore a HC texture should be applied on Passivated Emitter and Rear Contact (PERC) solar cells, which already have a polished rear surface. Also in this HC PERC concept only two extra production steps (applying the mask and mask removal) have to be done to obtain a HC texture since the polishing step, which is part of the PERC concept, can be used to remove the saw damage at the same time. Also with the trend to go to thinner solar cells light trapping becomes more and more important,

which makes HC textures more and more attractive.

HC textures have not been applied in industry production because especially the masking process, which has mostly been done by photo-lithography [3, 4], is too expensive or not applicable on a large scale and because at least two extra production steps have to be implemented to obtain a HC texture.

In this paper, we present a way to overcome the cost problem of HC textures by using an inkjet-printed mask. In contrast to previous methods that were used to create honeycomb textures via inkjet [8], our method uses a special pattern which allows for mask openings which are far smaller than the diameter of the inkjet droplets.

2 EXPERIMENTAL

Multi-crystalline wafers of 156 mm edge length were damage-etched and structured by inkjet printing. The rear side of the wafers was fully covered with ink and the front side was structured with two different patterns:

- a) A chessboard-like structure where each opening has four next neighbours
- b) A hexagonal structure where each opening has six next neighbours

The printer jets a hydrocarbon wax in a molten state. The ink solidifies within milliseconds after hitting the substrate. For the deposition of the wax, a Schmid DoD300 inkjet printer with a piezoelectric Spectra SE print head was used.

After inkjet printing, the wafers were sawed into smaller wafers of 30 mm edge size in order to make the following etching step easier. For etching, the 30 mm x 30 mm wafers were immersed into one litre of an etching solution consisting of 33%(v/v) HF, 65%(v/v) HNO_3 and 2%(v/v) acetic acid prepared from 50 w/w % HF, 69 w/w % HNO_3 and 100 w/w % acetic acid at 12°C. This acidic solution etches very quickly and is normally used for polishing. Both structures were etched for 9 minutes. To facilitate a more defined and developed honeycomb structure, the etch bath is agitated with a magnetic stirrer. After etching, the mask has to be stripped with acetone. In order to remove porous silicon, the wafers are then dipped in 10 % (w/w) KOH for one minute.

For characterization, topographical images of the mask before etching and the honeycomb texture after etching were taken with a confocal microscope and the weighted reflection of the HC textures was measured in the range of 250 nm and 1200 nm. The weighted

reflection is obtained by weighting with the AM1.5 spectrum and the internal quantum efficiency of a typical multi-crystalline silicon solar cell.

3 RESULTS AND DISCUSSION

3.1 Inkjet-Printing

Two different patterns were printed on the wafer front surface. The chessboard-like structure can be seen in Figure 1. It has openings of 14 μm diameter and each opening has four neighbours 52 μm apart from each other. The openings have a further set of second neighbours at a distance of 79 μm .

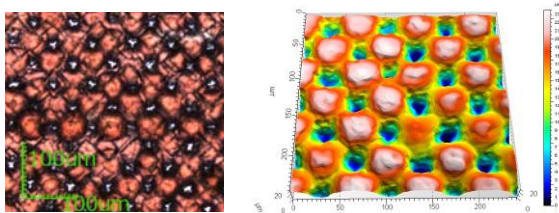


Figure 1: Images of the chessboard inkjet mask. (Left) Light microscope image of the printed mask. White openings (bare silicon) are visible between the red ink droplets. (Right) 3D-Image taken with a confocal microscope.

With the layout sketched in Figure 2, the hexagonal pattern can be realized. In this pattern each opening has 6 next neighbours at an average distance of 50.1 μm .

Due to the restrictions of the printer, droplets may only be placed within a bitmap. In the x-direction, the drop spacing has to be a multiple of the axis resolution of 5 μm , allowing only certain resolutions. In the y-direction, the spacing has to be a multiple of the distance between two nozzles. For the print head used, this limits the resolution to a multiple of 50 dpi.

The bitmap is inconsistent with the hexagonal array of droplets so a high resolution approach is used, which is shown in Figure 3. When covering a full wafer, this leads to stacking of the solidified drops in the y-direction. The bitmap is therefore prepared in a way that pixels remain white in between printed pixels. Different resolutions were chosen for the x- and y-directions in order to obtain the same distance between every droplet printed.

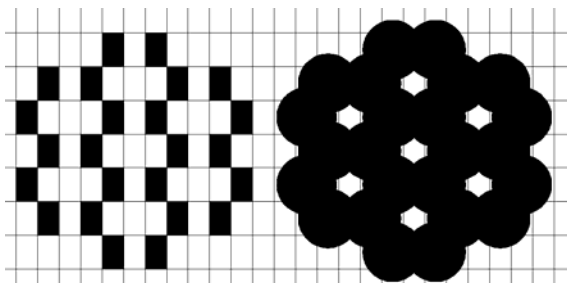


Figure 2: Bitmap mask with a resolution of 1016x1750 dpi (left); illustration of resulting printed structured with a droplet diameter of 44 μm (right)

The unique bitmap layout in **Figure 2** results in a printed structure with distances of 50 μm in the x-direction and 50.2 μm in the y-direction (diagonal) between the openings. When printed, the hexagonal pattern has an average opening of 21 μm diameter. It

differs slightly from Figure 2 due to non-uniform wetting of the surface and differing individual nozzle characteristics.

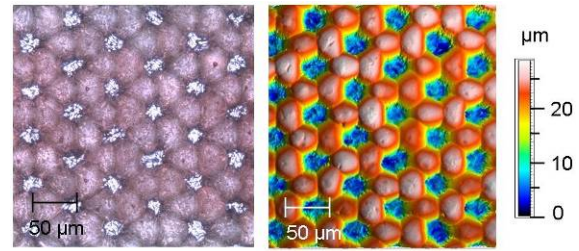


Figure 3: (Left) Light microscope image of the hexagonal mask. White openings (bare silicon) are visible between the red ink droplets. (Right) 3D-Image taken with a confocal microscope. A high regularity of the pattern can be seen.

3.2 Results after etching

An industrial etching environment has been simulated by choosing a relatively large etch solution volume (1 l) compared to the size of the wafers (30 mm edge length). As the etching solution is stable over a long period of time it can be used for industrial application. Furthermore the printing quality significantly influences the quality of the obtained honeycomb textures. Small printing irregularities already cause a much higher reflection because then the etch pits cannot grow together the way they should.

Figure 4 shows the results of the chessboard-like texture after etching. Well developed etch pits can be seen. They have a depth of 18 μm , a diameter of 44 μm and an average distance of 52 μm . Because the etch time was too short, they have not grown together yet. The weighted reflection of the chessboard-texture is 24.3% and its reflection graph is shown in Figure 6. The reason for this high reflection are the flat areas between the etch pits, which are caused by a too short etch time and by the design of the mask pattern.

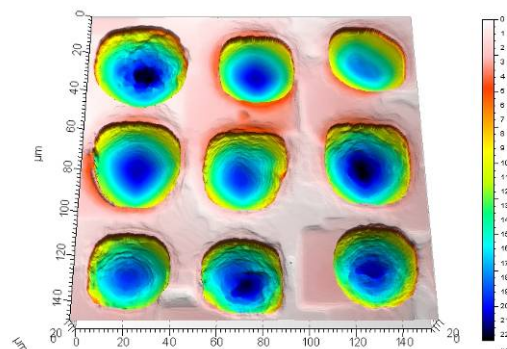


Figure 4: Topographical images of the texture created with the chessboard-mask. Etch pits have a depth of 18 μm , a diameter of 44 μm and an average distance of 52 μm .

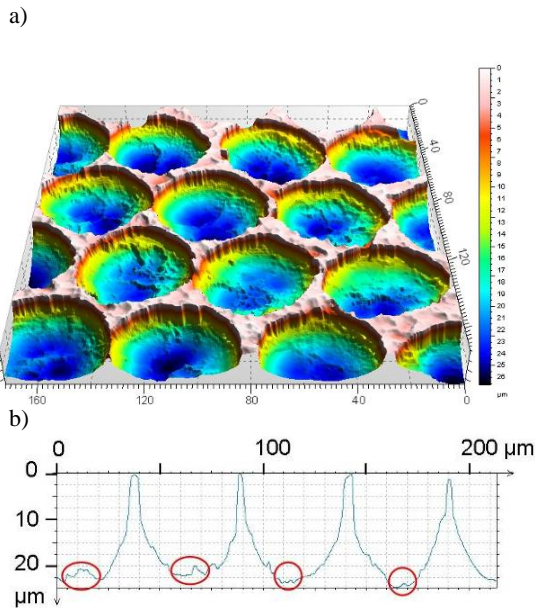


Figure 5: Topographical images of the texture created with the hexagonal mask. a) A 3D height image; b) a line scan through three typical honeycombs on image a). The flat bottom areas are encircled in red.

Figure 5 b illustrates a line scan through three typical honeycomb pits. A 15 μm wide flat area on the bottom of the pits can be seen. A smaller opening size, achievable with smaller droplet size or a higher stirring rate during etching could reduce the size of the flat areas. For the hexagonal HC texture, the reflection graph is plotted in Figure 6. The weighted reflection lies at 18.4 %, which is lower than the often measured value of 20% for other honeycomb textures [7]. The low reflection proves the good quality of the texture: There was a minimal amount of printing irregularities in the mask. Because of the optimal etching conditions only small flat areas between the etch pits have remained. Furthermore the saw damage removal before printing has been done with a standard acidic texturization process and hence the flat areas between the etch pits are not really flat but have the structure of an acidic texture and reflect less than a totally flat surface. However since these areas are not big, this reduction in reflection has only a weak influence on the total reflection.

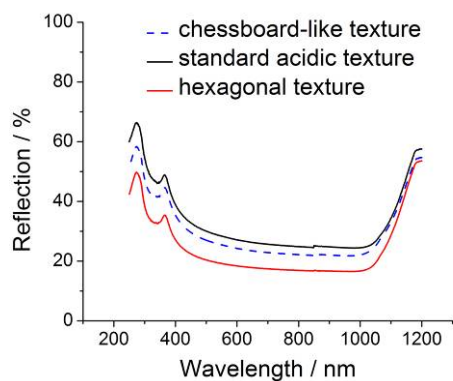


Figure 6: Reflection curves recorded with an integrating sphere. The hexagonal honeycomb texture (red line) reflects less (18.4 %) than the chessboard-like structure (24.3 %, dashed blue line) and less than the standard acidic texture at Fraunhofer ISE (27.1 %, black line).

4 CONCLUSIONS

A cost-effective and easy way to obtain a honeycomb texture for multicrystalline silicon solar cells has been found. This texture reflects only 18.4 % of the incident light and is hence better than most honeycomb textures in literature [3-5]. It is obtained by etching through an inkjet printed hotmelt mask which is resistant to the aggressive acidic etching solution consisting of HF, HNO₃ and HOAc. Two different mask patterns were examined. Both have the advantage that they create openings that are far smaller than the inkjet droplet size. In the chessboard-like pattern each opening has a size of 14 μm , four neighbors at a distance of 52 μm and a further set of neighbours at a distance of 79 μm . In the hexagonal pattern each opening is 21 μm wide and has six next neighbours at an average distance of 50.1 μm . After etching, a reflection of 18.4 % could be achieved with the hexagonal pattern whereas the chessboard-like structure only yielded 24.3 % reflection. The difference in reflection originates mainly from the superior mask design in case of the hexagonal structure.

As inkjet technology is already widely used, it is possible to use the new masking method for industrial wafer processing. With smaller droplet sizes in other inkjet printers the size of the pattern could be reduced so that less silicon has to be consumed by the etching step. Another advantage of the inkjet masking step is that it can also be used to create u-grooves for buried-contact metallization. Such a metallization is more effective than the standard metallization and would further increase solar cell efficiency.

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