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TMAH texturisation and etching of interdigitated back-contact solar cells

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In order to decrease reflectivity of silicon solar cells, NaOH or KOH texturisations are usually used leading to a pyramidal structure. However, these solutions are toxic and pollutant. Effectively, K^+ or Na^+ ions contaminate the passivation layer (SiO_2 or SiN) deposited on the surface of the cell after texturisation. An alternative to KOH and NaOH texturisation is tetramethyl ammonium hydroxyde $(CH_3)_4NOH)$ (TMAH). TMAH is not pollutant, not toxic and its use leads also to a pyramidal structure. Moreover, the etching rate and surface morphology can be controlled by the concentration of the solution, temperature and the addition of surfactant. Moreover, TMAH is selective with dielectrics and metals. It can therefore be used to produce self-aligned interdigitated back-contact solar cells (IBC). In this work, we have analysed the surface morphology and reflectivity after texturisation in TMAH in various experimental conditions. We have tested the possibility to use selective etching of the emitter of a back-contact solar cell by protecting the surface of the emitter with a metal grid. This new process permits to reduce the number of lithographic steps necessary to produce IBC solar cells.

Key words: *solar cell; texturing; TMAH*

1. Introduction

A key question in fabrication of photovoltaic cells is the cell cost. One of the promising ways of development is the reduction of material cost using thin film technologies [1, 2]. An interdigitated back-contact solar cell (IBC) is a very interesting technology for thin films because all contacts are at the back of the cell, hence the light absorption is increased. This absorption can be further improved by an optimised texturisation. Texturing of monocrystalline silicon is usually done in alkaline solutions. Such solutions are cheap but pollutant for passivation layers. In this paper, we investigate alternative solutions containing tetramethyl ammonium hydroxide ($(CH_3)_4NOH$, TMAH) [3]. TMAH solutions are widely used in microelectronic and micro-electro-mechanical systems (MEMS) because they combine high etching rates,

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good-quality anisotropic etching with full compatibility with microelectronic technologies. Moreover, they are clean room compatible, nontoxic and easy to handle [4, 5]. Iencinella [6] reported a recipe for random pyramidal texturing by TMAH solution containing dissolved silicon but this process was not easy to carry out. The first part of this study presents an alternative method to create uniform and reproductible pyramidal textures on silicon wafers with TMAH.

TMAH solutions also exhibit excellent selectivity to silicon oxide, silicon nitride and Al and Ag masks [7, 8]. In the second part of this paper, we present the optimization of the TMAH solution in order to develop a simplified technological process for fabrication of self-aligned interdigitated back-contact solar cells with only one lithographic step.

2. Optimization of the texturisation solution

2.1. Experiment

Texturing solutions were prepared using a 25% commercial TMAH solution, deionized water and standard isopropanol (IPA) used to avoid the formation of big hydrogen bubbles on the surface of silicon. All etching experiments were carried out

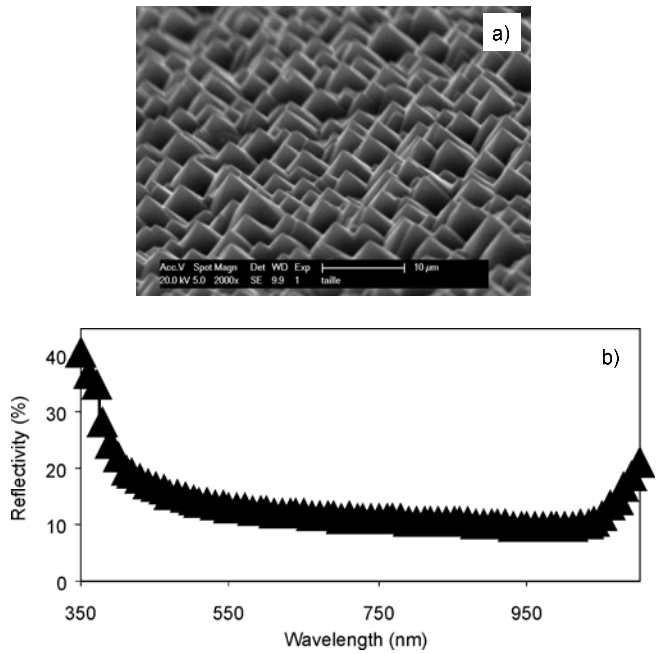

Fig. 1. SEM picture (a) of a TMAH textured wafer after optimized etching (30 min, 2% TMAH, 10% IPA, 80 °C). Hemispherical reflectance (b) of a TMAH textured silicon sample (30 min, 2% TMAH, 9% IPA, 90 °C)

using [100]-oriented, p-doped (1–10 Ω·cm) silicon wafer double-side polished. Before the etching process, the samples were dipped in a 5% HF solution for 10 seconds to remove the native oxide and rinsed in deionized water. The weighted reflectance (WR) is calculated by normalization of the hemispherical reflectance spectrum (350 –1100 nm) with the AM1.5D spectrum [9]. An example of the pyramidal structure and of the reflectivity obtained after the texturisation are presented in Fig. 1.

2.2. Results

First, we varied the TMAH concentration from 0 to 5%. In Table 1, one can see that the weighted reflectance decreases with increasing TMAH concentration to 2%. This result is explained by uniformity improvement. At 5%, the reflectivity is higher because pyramids are smaller but the uniformity is still obtained. TMAH solution is quite expensive, thus the concentration as low as only 2% needed to texture surface makes this method very cost competitive.

Table 1. Influence of temperature, TMAH and IPA concentration on weighted reflectance

[TMAH], % ([IPA]: 10%, 30 min, 80 °C	0	0.5	1	2	5
Weighted reflectance, %	41	18	15	13	20
Temperature, °C ([IPA]: 10%, [TMAH]: 2%, 30 min	60	70	80	90	
Weighted reflectance, %	15.2	14.4	13.5	13.3	
[IPA], % ([TMAH]: 2%, 30 min, 80 °C	0	6	9	14	23
Weighted reflectance, %	35	14.5	13	16	29

Isopropanol (IPA) is used as a surfactant diminishing the adherence of hydrogen bubbles to the etched surface. The dependence between IPA concentration and reflectivity is shown in Table 1. The reflectance decreases with IPA concentration up to 9% due to uniformity improvement. Beyond this concentration, the uniformity was always obtained but the surface reflectance increased. The pyramids were smaller thus we can make the assumption that the wettability was so important that bubbles stuck on silicon surface were too small to obtain high pyramids.

To determine the temperature influence, experiments were carried out at temperatures ranging between 60 °C and 90 °C. In Table 1, one can see that the surface reflectance decreases with temperature increasing. Sundaram [10] reported that on increasing temperature, the etch rate of the (100) and (110) crystallographic planes increased faster than the each rate of the (111) crystallographic plane. When temperature increases, this difference of etch rate results in higher pyramids and leads to a lower reflectance.

In order to analyse the reflectance with an antireflection coating (ARC), we covered the front surface of TMAH textured photovoltaic cells with a silicon nitride layer. The weighted reflectance diminishes from 10.2% (polished surface with an ARC) to 2.7% with TMAH pyramidal texture.

3. Fabrication of self-aligned interdigitated back-contact solar cells

In interdigitated solar cells, all contacts are placed at the back of the cell (Fig. 2), leading to an improved optical confinement and low series resistance compared to conventional p-n junction solar cells. However, this type of solar cells requires from two to six steps of lithography and alignment because their doped regions and contacts are on the same side of the cell.

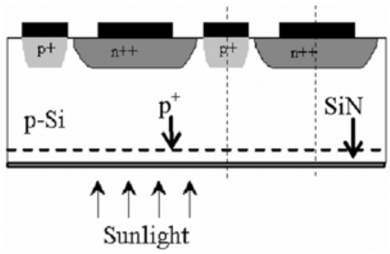

Fig. 2. Structure of an interdigitated back-contact solar cell

In order to reduce the number of technological steps, we tested the possibility of using a selective etching of the emitter by protecting the surface of the emitter with a metal grid. This process is self-aligned because only one lithographic step without alignment is necessary to fabricate the cell [11].

The following steps are used for the solar cell fabrication:

• Deposition of n^+ phosphorous doping glass on the whole surface of the wafer and drive-in.

• Formation of n-contact pattern by deposition of Ti/Pd/Ag followed by lift-off or by evaporation through the shading mask.

• Selective etching in TMAH solution. The Ti/Pd/Ag contacts act as masks during the etching and Ti/Pd/Ag cantilevers are formed. They are used as spacers to separate the metal contacts;

• Al deposition all over the surface of the cell and rapid thermal annealing (RTA) firing. After this step, p and n contacts are not short-circuited because of the particular n-contact profile obtained after the etching (Fig. 3).

One of the most critical steps in the process is the formation of Ti/Pd/Ag cantilevers; they have to be large enough to avoid short-circuit between n and p contacts. The advantage of using TMAH is a possibility to control the anisotropy of the etching (i.e,. the (100)/(111) etch ratio) by adding the surfactant [8]. In the latter part of this paper we present the optimisation of the TMAH solution (TMAH and IPA concentrations, temperature) in order to obtain the best ratio the etch width (under Ti/Pd/Ag contacts) to its depth (Fig. 3).

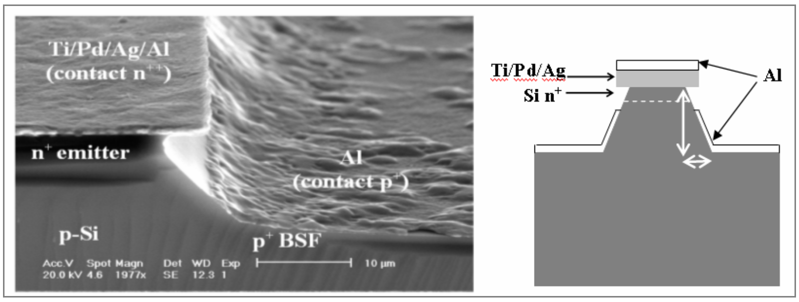

Fig. 3. Scanning electron microscopy picture (left) of a self-aligned interdigitated back-contact solar cell and of the Ti/Pd/Ag cantilever obtained by TMAH etching. Structure (right) of a self-aligned interdigitated back-contact solar cell (only one contact has been shown). The vertical white arrow corresponds to the etch depth ((100) planes) and the horizontal one to the etch width ((111) planes)

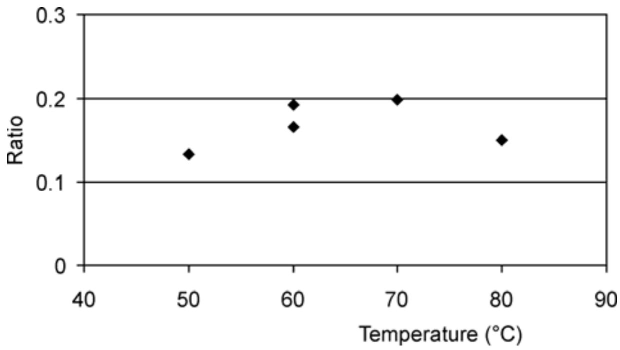

Fig. 4. The ratio of etching rates of (111) and (100) planes vs. temperature of solution: [TMAH] – 0.83%, [IPA] – 83%, duration – 3h

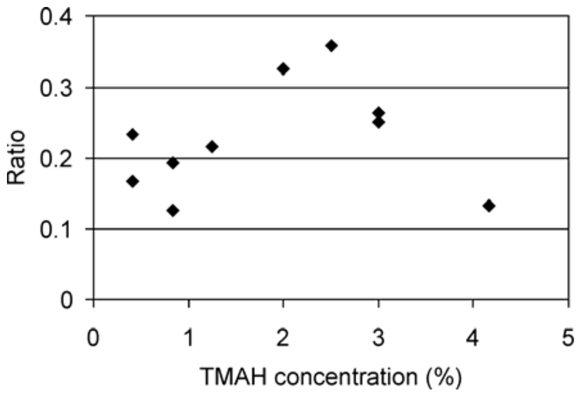

Fig. 5. The ratio of etching rates of (111) and (100) planes vs. TMAH concentration: [IPA] – 83%, 60 °C, 3h

The samples were dipped in TMAH solution during 3 h. The measurements of the etch widths and depths have been performed by the scanning electron microscopy (SEM). When temperature increases (TMAH and IPA concentrations are respectively 0.83% and 83%), the etching rates of both planes (100) and (111) increase, the ratio being almost stable (Fig. 4). When the TMAH concentration increases to about 2.5% (at 60 °C, IPA concentration – 83%), we observe an increase of the etch width and of the ratio of etching rates (Fig. 5). For TMAH concentrations higher than 2.5%, the ratio decreases drastically.

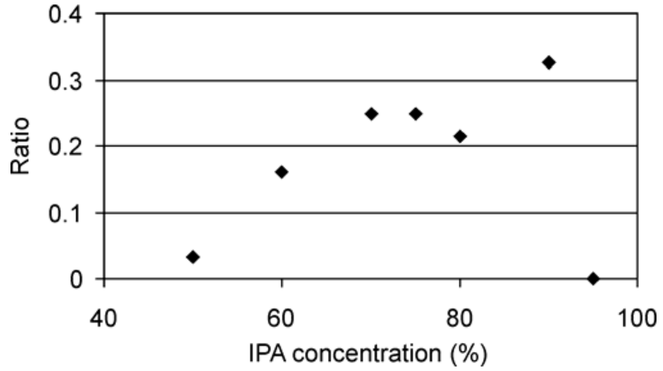

Fig. 6. The ratio of etching rates of (111) and (100) planes vs. [IPA] concentration: [TMAH] – 0.83%, 60 °C, 3h

Finally we have analysed the influence of IPA concentration on the ratio with an etching temperature of 60°C and a TMAH concentration of 1.25%. When the IPA concentration increases (Fig. 6), we observe a decrease of the etch depth and an increase of the etch width and of the ratio. For very high concentrations (95%), we cannot measure precisely the etch depth because the etch rate of the plane (100) is too slow, hence the ratio is difficult to determine. The optimised solution consists of 2.5% TMAH and an IPA in concentration of 85% with the application of a high temperature to have a higher etching rate.

4. Conclusions

In this paper, we have optimized the TMAH solution in order to texture the surface of silicon solar cells and to simplify the elaboration of interdigitated back-contact solar cell. The advantage of TMAH is that it is not pollutant for passivating layer unlike KOH, few toxic and clean room compatible.

Our best texturing solution contains 2% of TMAH and 9% of IPA and allows to realize optimized pyramidal texturing surfaces.

Concerning the use of TMAH in order to realize self-aligned interdigitated back contact solar cells, we have optimized the TMAH solution to obtain a higher ratio of

(111) and (100) planes etching rates. The best ratio corresponds to the solution with the concentration of TMAH of 2.5% and IPA concentration of 85 %.

In conclusion, TMAH is a very good candidate to replace KOH or NAOH solutions for the texturisation and the elaboration of solar cells.

Acknowledgements

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