THIN FILM SILICON FOR SOLAR CELL APPLICATION GROWN FROM LIQUID PHASE ON METALLURGICAL GRADE SILICON

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ABSTRACT: Liquid phase epitaxy was applied to grow roughly 10 μm thick n-type polycrystalline silicon film on p-type metallurgical grade (MG) silicon substrate at 900° C in gallium/indium solution. GaAs, dissolved in the melt, served as an arsenic donor source for the as-grown film. The carrier concentration of both the substrate and the as-grown film was 1 x 10^18 cm^-3 which is too high for practical photovoltaic applications. A post growth exposure to hydrogen plasma lowered the carrier concentration at the p-n junction by an order of magnitude, resulting in functional photovoltaic devices with an open circuit voltage V_{OC} of up to 480 mV. A morphology study, carried out by scanning electron microscope and atomic force microscope, revealed grain size in the range 1 – 3 mm, reflecting the grain size of the substrate. Our result indicates that usable solar-cells may be prepared from unmodified MG silicon without the costly need of recrystallisation for purification.

Keywords: Silicon solar cell, liquid phase epitaxy, metallurgical grade silicon, hydrogen passivation

1 INTRODUCTION

High purity silicon is by far the most important raw material for solar production today. As the world market for Si solar cell shows significant annual growth, a shortage of silicon will seriously constrain further increment. The existing photovoltaic technology is material intensive, as it uses relatively thick (~ 300 μm) wafers of expensive ultra-pure silicon. In recent years, the focus has been on the economical side of the solar cells fabrication instead of improving their performance, which is already relatively close to their optimum. Most of the crystalline Si material merely acts as a mechanical support for the solar cell device with most of the optical absorption taking place in the upper 30 μm [1]. Therefore the tendency is towards reducing material costs by using thinner wafers and by using cheaper and lower performance starting material [2, 3].

Thin film technology has been applied to create shallow and sharp p-n junction for photovoltaic application. One of the advantages of thin cells is that smaller diffusion lengths can be tolerated to maintain the same short-circuit currents than in the conventional solar cells [4] since the light-generated carriers have a shorter diffusion length in the spectral range where Si is photosensitive [12]. Therefore the surfaces of crystalline silicon solar cells are usually textured to reduce the surface reflectance which may increase the efficiency considerably. In some cases, production of thin film for solar cell application might incorporate such a texture and thereby lower or exclude the need for additional anti-reflection treatment.

Carrier concentration of 5 x 10^16 cm^-3 – 10^17 cm^-3 has been considered suitable for photovoltaic application [13] which is less than one tenth of the value for MG-Si. Hydrogen is known to passivate both donors and acceptors in virtually all semiconductors and has been used effectively to reduce the defect concentration in polycrystalline silicon film by 10^17 cm^-3 to a sub-micron depth [14]. Here we grow Si thin film on un-modified MG-Si and use hydrogen plasma to passivate the carriers to suitable levels.

2 SAMPLE PREPARATION AND EXPERIMENT

A polycrystalline MG silicon substrate was obtained by cutting and polishing raw MG silicon chunks of grade 441 (0.40% wt of Fe and Al and 0.10% of Ca), into 0.5 mm wafers. The MG silicon chunks were supplied by Bit Metals BV. A conventional horizontal graphite sliding crucible system [15] was used for the growth
p = 1 \times 10^{18} \text{ cm}^{-3},\) both in the MG-Si substrate and the as-grown film prior to hydrogenation which is roughly an order of magnitude higher value than desired. The \(I-V\) characteristics of the p-n junction before and after hydrogenation are shown in figure 1. As clearly visible, the hydrogenation has a significant influence on the electrical properties.

![Figure 1: I-V characteristics of a diode grown with LPE on MG-Si before and after hydrogenation](image)

Prior to hydrogenation almost no difference between forward- and reverse bias was seen and no photovoltaic response was observed during illumination with the red light source. After hydrogenation the \(I-V\) curve resembles more a diode-like behavior and the open circuit voltage \(V_{OC}\) was measured in the range of several tens of mV to a peak value of 480 mV under the same experimental conditions. Such a large variation in the voltage could be explained by structural imperfections in the MG-Si substrate, which consequently leads to an inhomogeneous film. The peak value of 480 mV does however indicate that hydrogen is able to passivate interface states at the p-n junction at the depth of several µm which is deeper than normally observed. This may be attributed to grain boundary diffusion in the polycrystalline film.

![Figure 2: SEM micrograph of Si grown in Ga/In solvent on MG-silicon substrate at 900°C.](image)

In the SEM micrograph in figure 2, cross sections of grains of the order of few mm² in size are seen. The wide boundaries between the grains are clearly visible. The reason is that non-crystalline silicon at the grain boundaries of the substrate is dissolved at much faster rate than the crystalline parts of the grains during the melt-back step. Growth does not occur in these depleted

3 RESULTS AND DISCUSSION

The Hall carrier concentration was measured as
areas and consequently, channels for hydrogen migration are left open. A porous nature of the substrate could also be a part of the explanation.

Figure 3: SEM micrographs of Si grown in Ga/In solvent on MG-silicon substrate at 900°C

Figure 3 depicts the relatively flat surface of the film. Contour of the film over an area of 40 × 40 µm² is shown in figure 3, giving the RMS roughness as approximately 30 nm. A value of roughness closer to the wavelength of visible light would have been desired in order for the fraction of reflectance to be low. Thus, an additional texturing process might be required for practical applications.

Figure 4: AFM micrographs of Si grown in Ga/In solvent on MG-silicon substrate at 900°C

4 CONCLUSION

A p-n junction in silicon was prepared by growing thin n-type film on un-modified MG-Si p-type substrate. A post-growth exposure to hydrogen plasma resulted in active photovoltaic device with $V_{OC}$ up to 480 mV. This indicates that hydrogen is able to passivate interface states at the p-n junction at the depth of as much as 10 µm which is deeper than normally observed. This may be attributed to grain boundary diffusion in the polycrystalline film. Our results strongly suggest that useable solar cell may be prepared from such inexpensive and low quality material as MG silicon.

REFERENCES