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Optimization of p^+ seeding layer for thin film silicon solar cell by liquid phase epitaxy

Eun-Joo Lee and Soo-Hong Lee†

Strategic Energy Research Institute, Department of Electronics Engineering, Sejong University, Seoul 143-747, Korea

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Abstract Thickness optimization of heavily doped p-type seeding layer was studied to improve performance of thin film silicon solar cell. We used liquid phase epitaxy (LPE) to grow active layer of 25 μm thickness on p^+ seeding layer. The cells with p^+ seeding layer of 10 μm to 50 μm thickness were fabricated. The highest efficiency of a cell is 12.95 %, with V_{OC} = 633 mV, J_{SC} = 26.5 mA/cm^2, FF = 77.15 %. The p^+ seeding layer of the cell is 20 μm thick. As thicker seeding layer than 20 μm, the performance of the cell was degraded. The results demonstrate that the part of the recombination current is due to the heavily doped seeding layer. Thickness of heavily doped p-type seeding layer was optimized to 20 μm. The performance of solar cell is expected to improve with the incorporation of light trapping as texturing and AR coating.

Key words LPE, Seed layer, Solar cell, Silicon, Thin film

1. Introduction

Crystalline silicon solar cells have the advantages of market dominance, non-toxicity, abundance, stability, high efficiency potential and the ability to share research and infrastructure costs with the integrated circuit industry. Currently wafers are produced by expensive silicon purification, ingot growth and dicing processes. The cost of the wafer is about half of the cost of the finished solar module. Thin film technologies reduce the amount of silicon used and hence the cost per watt of power output. Thin cells also allow the use of poorer-quality material for a given efficiency. In order to reduce these costs, various thin film solar cells are being developed [1-4].

Liquid phase epitaxy (LPE) is capable of producing high-quality layers. It has been found that mobilities in LPE layers are only slightly lower than those in similarly doped bulk Si [5]. Layers with high minority carrier lifetimes can be grown, so LPE layers are suitable for high-efficiency solar cells. LPE is an attractive growth method because the layers are grown close to thermal equilibrium so they generally show a low density of structural defects and a low recombination activity at grain boundaries. LPE can be used to deposit silicon on large areas.

We used LPE process to grow active silicon layer. LPE growth of silicon has many advantages over other thin film growth processes, including simplicity, low equipment cost and the ability to produce good film quality with low contamination levels at relatively low temperatures. LPE has been widely used for growing group III-V semiconductor films. This technique also was employed to grow epitaxial silicon. Basically this method results in the solute on the substrate from an molten saturated solution. The crystallographic orientation of the epitaxial layer is determined by that of the substrate. In this method, a substrate which generally of the same composition as the solute, is heated to a temperature approximately equal to that of the solution and then brought into contact with the solution. Usually the solution is in a saturated state. The temperature is normally raised 5~10°C to etch back a portion of the substrate surface to remove mechanical damage, to provide good wetting, and to produce a flat junction. Next, the temperature is lowered in a controlled manner and crystal growth occurs on the substrate. Epitaxial layer growth can be halted by separating the substrate and solution after a predetermined period of time.

The solar cell was fabricated on the LPE active layer that was grown on p^+ seeding layer with various thicknesses. Thickness optimization of heavily doped p-type seeding layer was studied to improve performance of thin film silicon solar cell.

2. Experiments

Solar cells with an area of 1 cm^2 were fabricated. The

†Corresponding author
Tel: +82-2-3408-3726
Fax: +82-2-3408-3329
E-mail: shl@sejong.ac.kr

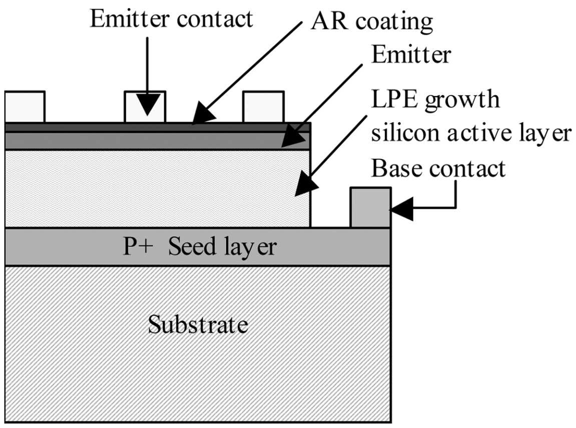

Fig. 1. The structure of the cell.

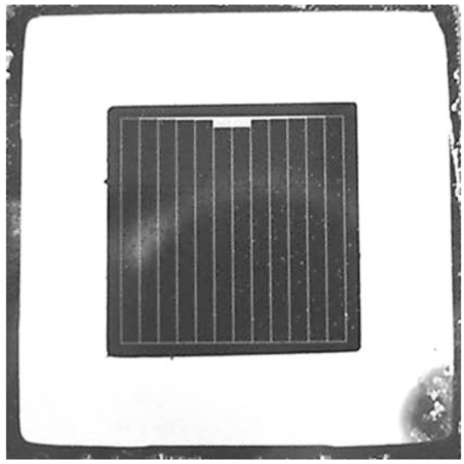

Fig. 2. The fabricated cell of 1 cm^2.

cells with p^+ seeding layer of 10 μm to 50 μm thickness were fabricated. We used LPE to grow active layer of 25~30 μm thickness on p^+ seeding layer. Indium was used as the solvent, and small amount of Ga were added to increase the p-type doping to levels between 10^{16} and 10^{17} cm^{-3}. Solar cells with an area of 1 cm^2 were then fabricated on the LPE active layer. To obtain a thin film single crystalline silicon layer, silicon-on-insulator (SOI) wafers formed by wafer bonding were used.

Cell processing was performed in a conventional manner. Masking oxide was grown by thermal oxidation. The n^+ emitter was formed by phosphorous diffusion at 910°C. The active cell area was defined by mesa etching. Processing was completed by deposition of metal on the top surface. By employing photolithography, e-beam evaporation, and lift-off techniques, the emitter metal (Ti/Pd) contact was produced. After the base contact metals (Al/Ti/Pd) were evaporated, the front Ag contact was plated and sintered. Figure 1 shows the schematic structure of a thin film silicon solar cell. This cell has a single-side contact structure of which both the emitter and base electrodes are at the front surface.

3. Results

Cells have been fabricated with epitaxial layers ranging from 25 to 30 μm in thickness. The fabricated cell of 1 cm^2 is shown in Fig. 2.

Performances of solar cell with LPE active layer were investigated by monitoring solar cell parameters as revealed by measurements of light I-V curves. The highest efficiency of a cell is 12.95 %, with V_{OC} (open circuit voltage) = 633 mV, J_{SC} (short circuit current density) = 26.5 mA/cm^2, FF (fill factor) = 77.15 %. The p^+ seeding layer of the cell is 20 μm thick. The I-V characteristics and the performance of the cell is presented in Fig. 3. Short circuit current is limited by no texturing and no anti-reflection (AR) coating.

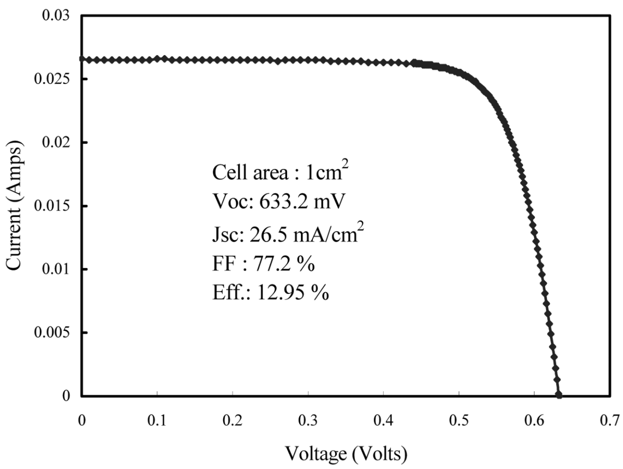

Fig. 3. The I-V curve for the cell with 20 μm seeding layer.

The efficiency of the cells as the thickness of seeding layer was shown in Fig. 4. As thicker seeding layer than 20 μm, the performance of the cell was degraded. The results demonstrate that the part of the recombination current is due to the heavily doped seeding layer. Thickness of heavily doped p-type seeding layer was optimized to 20 μm. The solar cell is expected to improve with the incorporation of light trapping as texturing and AR coating.

Light trapping is especially pertinent for silicon cells due to the low-absorption constant in the infra-red region. Thin silicon solar cells also require an enhanced optical path length to achieve high efficiencies. A 20 um thick device without light trapping can expect short circuit currents that are less than 70 % of that achievable from

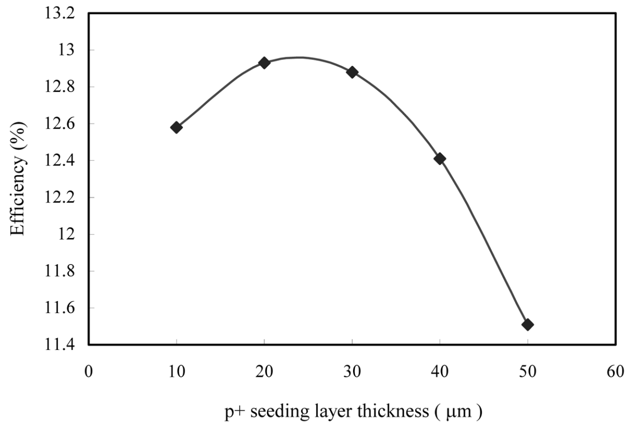

Fig. 4. The efficiency of the cells as the thickness of seeding layer.

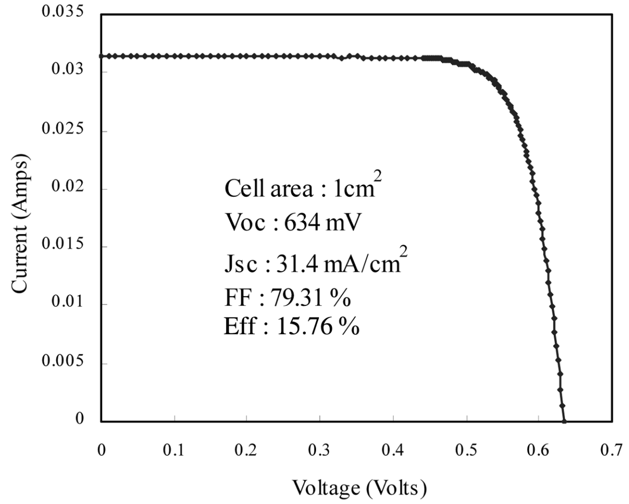

Fig. 5. The I-V curve of the cell with inverted pyramid.

standard thickness devices [6].

The performance of solar cell was expected to improve with the incorporation of light trapping as texturing. In order to reduce reflection losses of the cell, inverted pyramids are formed on the front side of the cells by oxidation, a standard lithography process and subsequent KOH etching. The major steps in fabricating the thin film solar cells are similar with process of the non-textured solar cell.

Therefore, the highest efficiency cell exhibits an open-circuit voltage of 634 mV, short circuit current density of 31.4 mA/cm^2, fill factor 79.31 %, and an energy conversion efficiency of 15.76 % based on a total cell area of 1 cm^2. Figure 5 shows the I-V characteristics and the performance of the cell.

4. Conclusion

Optimization of the seeding layer thickness and application of the surface texturing resulted in much improved a high cell efficiency. Thin film solar cells fabricated by the LPE process were investigated. The structure of a cell is a single-side contact structure of which both the emitter and base electrodes are at the front surface. The highest efficiency cell with texturing surface exhibits an energy conversion efficiency of 15.76 % based on a total cell area of 1 cm^2. This process will be applied to the fabrication of thin silicon solar cells on the ceramic substrate.

Acknowledgement

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