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Characterization of structural defects in the silicon crystal grown with various seeds

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ABSTRACT

To see the effect of the seeds on the crystallization of the silicon ingot, two types of seed were prepared and applied to the mono-like multi-crystalline silicon crystallization. One of them was conical shaped seed divided vertically into 4 pieces and the other one was chipped silicon seeds. Both of the seeds were placed at the bottom of the crucible before the growth of the multi-crystalline silicon material with a conventional directional solidification process. Compared to the conventional thin and flat seeds, conical shaped seed result in the larger single crystalline portion in the ingot although the gap of the seed division might act as source of dislocation generation during the crystal growth. This was expected to be due to the lateral growth of the silicon single crystalline grown from the conical seed which is taller than normal flat seeds. And also, comparison of the *Minority Carrier Life Time* (*MCLT*) between the silicon crystal grown from the chipped silicon seeds and the silicon crystal grown without any seed was conducted. It was found that the silicon crystal grown with chipped silicon seeds shows higher MCLT than the silicon crystal grown without seeds, although both crystals look similar as multi-crystalline silicon.

1. Introduction

Among the many materials of a solar cell, silicon still has a major share in the market. Two types of crystalline silicon have been used as substrates for solar cells, one of which is multi-crystalline silicon. This material has several advantages such as low production cost and no problem with light-induced degradation (LID). However, it has several defects including grain and twin boundaries, dislocations, and SiC inclusions [1,2].

Compared to multi-crystalline silicon, single crystalline silicon has no defects or contamination problems. However, still this material has drawbacks such as *light-induced degradation* and a high production cost [3,4].

For the compromise of these two materials, one suggestion has been mono-like crystalline silicon which has high productivity and quality. Vigorous trials have been carried out to establish this material as a major substrate for solar cells. However, this material still has some difficulties to be solved before it can be used as the best solar cell substrate. Much effort has been carried out to enlarge the single crystalline portion of the silicon ingot [5,6], as well as reducing the preparation cost of the seeds placed at the bottom of the crucible before melting. It was known that the gap between the seeds will generate several defects during the crystallization of the ingot [7]. In this investigation, several types of silicon seed will be applied to test the effects of seed materials on the quality of silicon.

2. Materials and methods

A silicon ingot of 12 kg was grown in a crucible of $180 \times 180 \times 150\ mm^3$ size. The inside surface of the crucible

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was coated with silicon nitride. The ingot was grown with a directional solidification (DS) method using silicon crystallization equipment manufactured by Insolteq Inc. The schematic of the equipment is shown in Fig. 1. Seeds for this experiment were prepared from the single crystalline shoulder produced using the Czochralski method. The polysilicon for melting was purchased from OCI Co., and was melted for 8 h and 30 min under the pressure of 17.4 Torr. Crystallization proceeded for 14 h with lowering of the crucible.

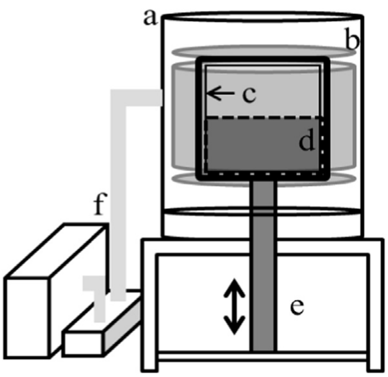

Fig. 1. Multi-crystalline silicon ingot growth equipment: (a) vacuum chamber, (b) graphite heater, (c) SiO_2 crucible, (d) molten silicon, (e) direction solidification guide, and (f) vacuum system.

The placement of the seeds is shown in Fig. 2. As can be seen in Fig. 2(a), the height of the conical seed is 7 cm and the remaining part of the crucible was filled with virgin polysilicon while the other part of the crucible was covered with chipped single crystalline silicon material. In this way, there are three dedicated areas in the crucible for chipped single crystalline silicon seeds (I), conical shaped seed divided vertically into 4 pieces (II), and no seeds (III) applied. Thus, we can compare the effects of seed materials on the crystallization of silicon ingots grown using the directional solidification method. For the characterization, the study employed μ-PCD in NewREC to measure the MCLT and an optical microscope to view the structural defects.

3. Results

Fig. 3 shows the MCLT map and related surface picture taken from specimen 1 in Fig. 2(c). This specimen was taken from the silicon ingot grown without any seeds at the bottom. As can be seen in the figure, a higher MCLT value was observed at the bottom and top part of the specimen and a lower MCLT value was observed in the middle part of it. Normally, the top part of the silicon ingot, which is the last part solidified in the DS method, has higher concentration of impurities or dopants which will lower the MCLT than the bottom or middle part of the ingot. However, as can be seen in the MCLT map, the top part has a higher MCLT value than MCLT value of the middle part and as expected, the bottom part of

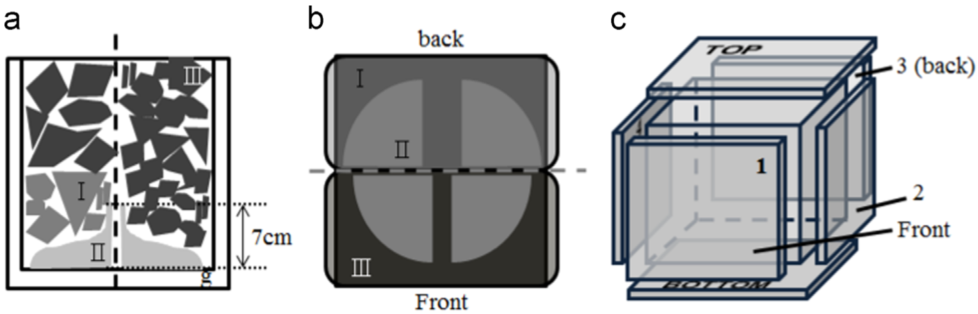

Fig. 2. (a) Side view of the crucible filled with seeds: (I) chipped single crystalline silicon seeds, (II) conical shaped single crystalline silicon seed, (III) virgin polysilicon, (b) top view of the bottom of the crucible after seeds placement, and (c) position of the specimens taken after crystallization.

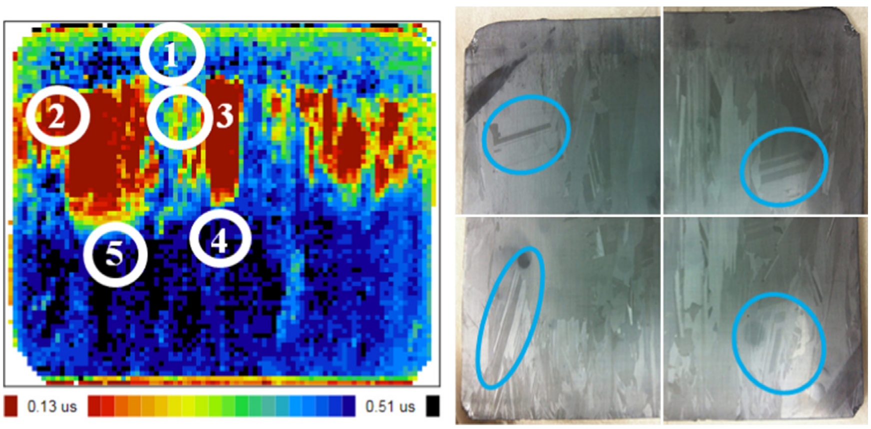

Fig. 3. MCLT map (left) and surface picture (right) of specimen 1 in Fig. 2(c): White circle with number is area that observed defects by optical microscopic. Blue circle in the right picture indicates twin boundaries.