Research on ingot casting of multicrystalline silicon miscellaneous materials for solar cell

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Abstract. Using multicrystalline silicon miscellaneous materials for ingot casting, optimizing the ingot casting process and charging formula, the utilization rate of silicon material is 66.15%, effectively improving the utilization of multicrystalline silicon miscellaneous materials. The minority carrier lifetime of the silicon block is 5.02us, which meets the requirements of solar cell products. The other electrical properties of the silicon block meet the needs of the product, and the miscellaneous ingots realize the reuse of resources, greatly reducing production costs and improving benefits.

1. Introduction
With the increasingly depletion of non renewable resources such as oil and coal, it has become the direction of people's efforts to seek green and environmentally friendly new energy. Solar energy occupies an important position in the development of new energy due to its inexhaustible and inexhaustible nature[1]. In the field of solar material application, multicrystalline silicon ingot plays an important role in solar cell application due to its low cost and high efficiency[2-4]. The impurities, dislocations and defects of ingot polysilicon play a decisive role in the conversion efficiency of solar cells[5]. Therefore, it is of great significance to study the growth of multicrystalline silicon to improve the conversion efficiency of solar cells, reduce the production cost and reduce the impact of the production process on the environment. In order to improve the efficiency and reduce the production cost, the quasi-crysta ingot technology is widely used[6]. The results show that about 30% of the edge, head and tail impurities are produced in the ingot by this method, which increases the utilization rate of silicon. In order to improve the utilization of materials, reduce the cost and improve the product performance, the edge skin, head and tail impurities produced by the similar quasi-crysta ingot are used to cast ingots again, study the performance of miscellaneous ingots.

2. experiment
The same GT ingot furnace and the same batch of products from the same manufacturer were used in the experiment. The multicrystalline silicon ingot was prepared by quasi-crysta process, and a layer of seed crystal was laid on the bottom layer of the crucible to induce the crystal. The silicon material is made of full edge, head and tail miscellaneous materials. The furnace feeding capacity of silicon material is 440kg. The charging formula is shown in Table 1. Considering the effect of ingot, it is necessary to reduce the proportion of head and tail and increase the amount of edge material.
Table 1. multicrystalline silicon miscellaneous material ingot charging formula

| Edge leather (kg) | Head stock (kg) | Tail material (kg) | Seed crystal (kg) |
|-------------------|-----------------|--------------------|------------------|
| 164               | 90              | 150                | 36               |

It is found that the growth rate has an important influence on the minority carrier lifetime of the crystal. Therefore, it is necessary to reduce the growth rate in the crystal growth stage in order to fully eliminate impurities and improve the minority carrier lifetime of the polycrystalline. The process optimization is mainly that the G5 time of the crystal growth stage is increased from 2h to 3.5h, and the temperature is unchanged, and the G6 time is increased from 2h to 3h, and the temperature is unchanged. After the ingot casting is completed, the silicon ingot is broken and squared to obtain 25 silicon blocks. The silicon blocks are sliced into 156mm×156mm silicon wafers with a thickness of about 0.18mm after infrared scanning and minority life detection.

3. Results and discussion

3.1 Utilization rate of multicrystalline silicon ingots

The silicon block is subjected to infrared scanning and minority birth life detection, cutting off the edges and head and tail materials that do not meet the production requirements, and the ratio of the remaining qualified part to the total weight of the silicon ingot is the silicon material utilization rate. Figure 1 shows the cutting length of the head and tail of the polysilicon miscellaneous ingot.

![Figure 1. Cut length of upper and lower part of silicon block](image)

The abscissa PV of figure 1 represents the average value of the same period of production, which is the same as the following figure. It can be seen from figure 1 that the average cutting length of the upper part of the silicon block of the full impurity ingot is 14.08mm, which is basically the same as that of the original polycrystalline silicon ingot and the mixed casting ingot. The average cutting length of the lower part of the ingot is 56.34mm, which is 5.02mm higher than that of the original multicrystalline silicon ingot and mixed silicon ingot.

The utilization rate of silicon material of polycrystalline silicon ingot is shown in figure 2. It can be seen from figure 2 that the utilization rate of five experimental ingots of miscellaneous silicon ingot is basically the same without abnormal fluctuation, and the average utilization rate is 66.15%, which indicates that the optimized ingot process is stable. The average utilization rate of experimental ingot is slightly lower than that of primary silicon ingot.
Combined with figure 1, it can be seen that the direct factor affecting the utilization rate of miscellaneous ingots is that the lower part of the silicon block is longer and the overall cutting weight is too much. In the process of ingot casting, it is inevitable to have a red region of minority carrier lifetime at the bottom of silicon ingot [7], which is cut off because the minority carrier lifetime is lower than the standard value. The cut length of the lower part of the silicon block is slightly longer, mainly because the bottom seed layer of the crucible only melts about half of the height, and the crystal grows to obtain a large-grained single crystal. The previous research table found that the initial growth rate of crystal growth was relatively large. At this time, because the seed crystal is not completely melted, the impurities near the solid-liquid interface are too late to segregate into the liquid phase and solidify as the crystal grows, forming impurity precipitation and reducing the minority carrier lifetime. The utilization rate of all miscellaneous ingots is only 1 percentage point lower than that of native polycrystalline and miscellaneous mixed ingots, indicating that miscellaneous ingots are effectively utilized.

3.2 Minority carrier lifetime of multicrystalline silicon ingots

After the multicrystalline silicon miscellaneous material is cast, the silicon block obtained by breaking the ingot is used to measure the minority carrier lifetime of the silicon block using the WT-2000 minority carrier lifetime tester. The average minority carrier lifetime of all silicon blocks in each silicon ingot is shown in figure 3.
The average minority carrier lifetime of polysilicon mixed ingot silicon block is 4.80us, which is lower than that of native polysilicon and mixed ingot silicon block by about 0.2us, which is within the range of product requirements.

Figure 4 shows the minority carrier lifetime distribution of silicon blocks. Figure 4(a) is a typical minority carrier lifetime distribution diagram of a silicon block with all-miscellaneous ingots. The lower part of the silicon block has a longer minority carrier lifetime red zone, mainly because the bottom seed crystal layer is not completely melted, that is, crystal growth and the bottom of the crucible caused by solid phase diffusion of impurities.

![Figure 4. Minority carrier lifetime distribution of silicon block](image)

Figure 4 (b) shows the typical minority carrier lifetime distribution of primary polycrystalline silicon and mixed ingots, and the red zone of minority carrier lifetime at the bottom of silicon block is short. The main reason is that there is primary polysilicon in the silicon material, which greatly reduces the impurity content. Impurities affect minority carrier lifetime through segregation. Impurities with segregation coefficient greater than 1 are concentrated at the bottom of the crystal, and impurities with segregation coefficient less than 1 are pushed to the top of the crystal [8-9].

Effective segregation coefficient of impurities [10]:

\[ K_{eff} = K_0 \left[ 1 - (1 - K_0)e^{-\frac{\sqrt{D \delta}}{V}} \right] \] (1)

In formula (1), \( V \) is the growth rate, \( D \) is the solute diffusion coefficient, and \( \delta \) is the thickness of the solute diffusion boundary layer. According to formula (1), the growth rate affects the segregation coefficient. At the initial stage of crystal growth, the growth rate is high and the effective segregation coefficient of impurities is large. At this time, impurities tend to accumulate at the solid-liquid interface and solidify with the crystal growth. Due to the enrichment of impurities at the bottom of silicon ingot, the minority carrier lifetime is greatly reduced.

4. Phase field simulation of multicrystalline silicon growth

The phase field method is used to simulate the growth of polycrystalline silicon, the anisotropy coefficient is 0.05, the mesh is 1200×1200, and the flow velocity is -1.0 and -2.0 respectively. The calculation results are shown in Figure 5.
Figure 5. Simulation results of phase field method

Figure 5(a) shows the simulation results of velocity-1.0. Figure 5(b) shows the simulation results of flow rate-1.5. The results show that the higher the flow rate is, the faster the growth of the nucleus tip is, and the more competitive growth is formed. Combined with the above analysis, it can be seen that the multicrystalline silicon ingot needs a young crystal layer to induce the crystal. The crystal growth is fast at the initial stage of the crystallization, and the impurities solidify with the rapid growth of the crystal, which affects the minority carrier lifetime and other properties, which is in good agreement with the simulation results.

5. Conclusion

This paper proposes a method of multicrystalline silicon all-miscellaneous ingot casting. By optimizing the casting process and charging formula, the impurity multicrystalline silicon ingot is obtained. The utilization rate of silicon material is 66.15%, which is 1% lower than the utilization rate of mixed ingots of miscellaneous materials and primary polysilicon materials. The minority carrier lifetime of the silicon block is 5.02us, which is lower than the 0.21us minority carrier lifetime of the mixed ingot of mixed materials and native polysilicon materials. The main reason for the slightly lower silicon utilization rate and minority carrier lifetime is that more impurities are introduced by the all-miscellaneous ingot, and the cut length of the lower part of the silicon block is slightly longer. The performance index of silicon ingot obtained in this study meets the requirements of solar cell products, realizes the reuse of miscellaneous materials and improves the efficiency.

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