Dislocation generation during Czochralski silicon growth

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Czochralski silicon ingots still dominate the photovoltaics market by their high efficiency and low defect density. In theory, growing a dislocation-free silicon ingot is possible if the growth process is kept stable and below the critical resolved shear stress value [1, 2]. However, in practice, a considerable proportion of the grown Si ingots are melted back due to the generation of dislocations or the so-called structure loss, reducing the productivity in the factory. The assessment of the failed ingots is a crucial step toward higher yield and productivity. Still, the characterization of Si ingots is challenging due to their high brittleness, which makes the cutting challenging, and the high concentration of dislocations related to slip.

In this work, we develop a non-destructive method to further study the ingots with structure loss and reveal the root causes of this failure. This study is performed on roughly 90 monocrystalline silicon ingots that are produced for solar cell applications. Most of these ingots have experienced a loss in the single crystal structure. In addition to the material characterization techniques that are used in this study, the growth process data are analyzed with a special focus on the temperature, crystal rotation, crucible rotation, and pulling speed to better understand the dislocation generation process.

Two types of dislocations are found: (i) growth dislocations: generated at the solid-liquid front and located at the growth ridge stop, (ii) post-growth dislocations: generated behind the solidification front and revealed on the surface by feather-like slip lines. Furthermore, many characteristic features have been found on the surface of Czochralski silicon ingots. Based on these features, the ingots are classified into major groups that could be related to the main causes of the structure loss. The careful measurements of the growth ridges' geometries reveal considerable information on the temperature gradient, pulling speed, and crystal rotation of these ingots. The measured parameters are compared with the logged data to further understand the thermal history of the ingots. Most of the structure loss ingots show a steep change in the temperature gradient and diameter.

Also, the transition from the mono-crystalline to the multi-crystalline structure is found to be different from one case to another. The time needed for this transition strongly depends on the cause of failure. A careful examination of these areas has been carried out in our study besides a characterization of the inclusion types that hit the solid-liquid interface and interrupt the single crystal growth. The chemical inspection of these foreign particles clarifies the major contamination sources during the growth.

References

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