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Thermal-stress induced dislocation distribution in seed-cast and CZ Si ingots

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Seeded directional solidification (seed-cast) is a promising method to improve the cost-efficiency of Si solar modules. Major drawback, however, is a high dislocation density that limits the device efficiency. Sources of dislocations are manifold and it is necessary to understand and reduce them by process control during the growth. Gao and Kakimoto have shown that reducing thermal stresses is essential for improving the dislocation densities [1].

In this work, Si ingots were grown using the seed-cast method. Fig. 1 shows the XRT image of such an ingot with an average dislocation density of 6×10^4 cm^{-2}. The dislocation density is high and several non-temperature related sources of dislocations, such as the seed interface or impurity precipitates, are apparent. Since already existing dislocations can multiply in the presence of thermal stress, another series of experiments was conducted where no grown-in dislocation sources exist to determine the places of high stresses and dislocation introduction. Dislocation-free CZ-Si was placed into the furnace and subjected to similar temperature gradients as the seed-cast grown ingots. A XRT image in slip direction after the experiment is shown in Fig. 2. The result gives a symmetric dislocation distribution with the highest values in the ingots periphery suggesting the highest thermal stresses in these areas. The dislocation density was found to be in the order of 2×10^2 cm^{-2} in the center to 8×10^3 cm^{-2} in the periphery. It can be concluded that the solely thermal stress related dislocation density is one to two orders of magnitude lower than the dislocation density measured in seed-cast grown Si ingots. This result suggests that dislocation densities as low as 10^2-10^3 cm^{-2} should be possible in the seed-cast method if impurities are reduced and the thermal stresses that lead to dislocation multiplication are minimized.

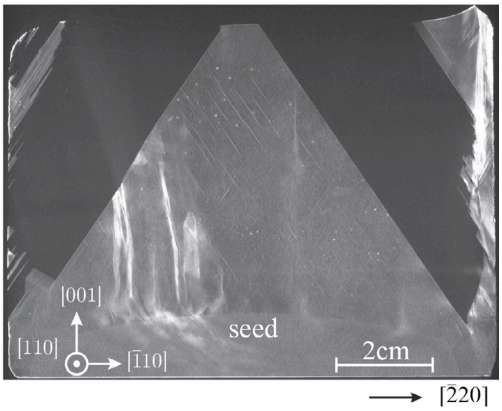

Fig. 1: XRT image of grown ingot

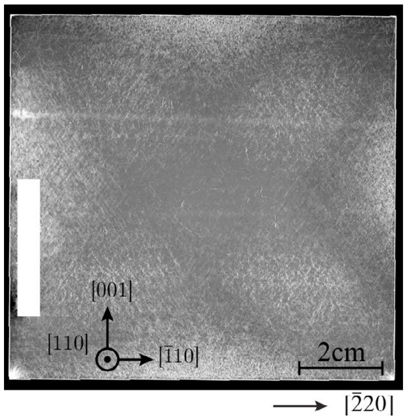

Fig. 2: XRT image of heated CZ crystal

[1] B. Gao and K. Kakimoto, J Cryst Growth, 384 (2013) 13-20

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