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# Emerging Technologies in Crystal Growth of Photovoltaic Silicon: Progress and Challenges

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**Abstract**

The Photovoltaic (PV) market is dominated by crystalline silicon materials in the form of high-quality high-cost Czochralski monocrystalline silicon (mono-Si) and lower-cost defect-prone crucible-cast multicrystalline silicon (mc-Si). Therefore, development and commercialization of materials offering high efficiency cells at low cost is necessary for wider deployment of photovoltaic systems. Several alternative crystallization techniques aimed at lowering material-cost and improving energy conversion efficiency are being developed. These include Mono-like Silicon aimed at producing monocrystalline silicon (mono-Si) wafers using mc-Si technology, Kerfless Epitaxial Silicon (KE-Si) and Liquid to Wafer aimed at reduction of some of the process steps such as ingot growth and wafering, and Non-contact Crucible Silicon (NOC-Si) aimed at quality improvement of crucible-cast silicon through reduction of stress and impurity contamination during ingot growth. In this contribution, we review some of the prospects and challenges of Mono-like Silicon, NOC-Si and KE-Si techniques, focusing on content and impact of impurities and structural defects and overall electrical performance.


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*Keywords:* Silicon; Non Contact Crucible Silicon; Kerfless epitaxial silicon; defects; impurities; minority carrier lifetime

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## 1. Introduction

The PV market is largely driven by crucible-cast silicon in the form of conventional or standard mc-Si and its derivative - High Performance mc-Si (HPMS), with >65% total world crystalline silicon market share [1]. This is because mc-Si technology is mature and offers lower manufacturing cost and tolerance to lower-quality feedstock [2]. However, solar cell and module efficiency of mc-Si materials is lower in comparison to those made from monocrystalline silicon (mono-Si) grown by the more-costly Czochralski method. In order to lower the cost/Wp of PV modules and increase competitiveness of PV in the energy market, both lowering of manufacturing cost, savings in silicon material and efficiency improvement are important [3].

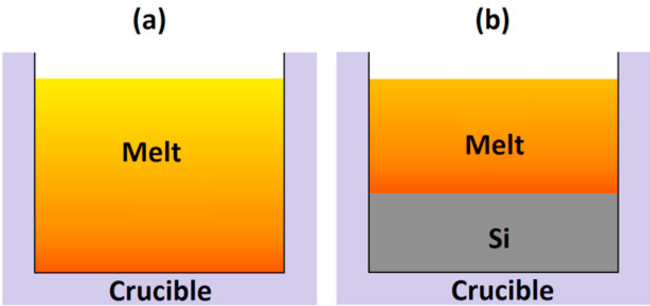


Fig. 1. Standard multicrystalline silicon ingot growth

Crystallization of standard mc-Si and HPMS involves ingot growth in a controlled directional solidification furnace, where the feedstock with dopant is melt in a crucible and solidified from the crucible bottom as shown in **Fig. 1**. Since the growing crystal is in direct contact with the crucible from the outset of crystallization, abundance of grain nucleation sites and confinement of the crystal to the crucible walls at high temperature, the density of structural defects i.e., grain boundaries, dislocations, stacking faults etc. and the concentration of deleterious metallic impurities is high. Defect engineering, such as gettering is therefore required for multicrystalline silicon solar cells to achieve acceptable efficiency levels. In a standard solar cell process, gettering is achieved during emitter diffusion and firing. However, since both defect density (due to dislocation growth and multiplication [4]) and impurity concentration (due to low segregation coefficient of most metallic impurity contaminants in silicon), increases with solidified fraction, gettering efficacy decreases with ingot height.

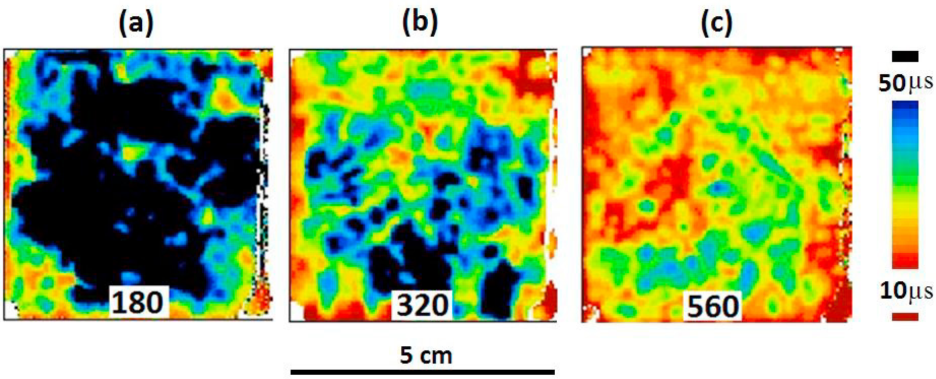


Fig. 2. µ-PCD minority carrier lifetime maps showing gettering efficacy with ingot height after phosphorus diffusion gettering. (a), (b) and (c) are wafer number 180, 320 and 560 respectively. Wafer number 560 is from near the ingot top.