Stress and temperature coupling effects on dislocation density reduction in multicrystalline silicon

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STRESS AND TEMPERATURE COUPLING EFFECTS ON DISLOCATION DENSITY REDUCTION IN MULTICRYSTALLINE SILICON

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ABSTRACT
In multicrystalline silicon (mc-Si), the presence of dislocation-rich areas limits solar cell conversion efficiencies [1-2]. Previous studies have demonstrated that dislocation densities higher than $10^{8}$ cm$^{-2}$ can dramatically decrease the minority carrier lifetime [3]. High dislocation densities, and their decoration with impurities, can limit minority carrier lifetime even after phosphorous diffusion or hydrogen passivation [4-5].

We previously proposed a method to remove dislocations from mc-Si by high-temperature annealing, demonstrating dislocation density reductions of 95% approximately [6]. We demonstrated that the dependence of dislocation density reduction on annealing temperature is much more pronounced that the dependence on annealing time [7]. In this contribution, we propose stress as an additional mechanism to enhance dislocation density reduction. We discuss the relationship between temperature, stresses and dislocation density in string ribbon.

NON-DESTRUCTIVE IMAGING OF DISLOCATION BANDS VIA INFRARED BIREFRINGENCE

Based on previous work by Buonassisi et al. [8] and Ganapati et al. [9] we probe local stresses surrounding dislocations using infrared birefringence imaging (IBI) [10]. Stress, either externally applied or internal (residual stress, defect-related stress), can induce birefringence in photoelastic cubic solids such as silicon. By measuring the birefringence of transmitted infrared light, Ganapati et al. [9] demonstrated that dislocation bands can be detected in mc-Si. IBI measurements in Figure 1 were taken on the same sample before and after annealing at 1300 °C for 6 hours.

![Before Annealing](image1.png)  ![After Annealing](image2.png)

Figure 1 Non-destructive imaging of dislocation bands: Infrared birefringence images of 2.5x8 cm$^{2}$ String Ribbon wafers before and after high-temperature annealing. Bright yellow/orange and light blue regions indicate higher stresses; dark red and blue regions indicate lower stresses. Dislocation bands visible before annealing disappear after treatment.

The highlighted region demonstrates high stresses around 45 degree angle lines, which chemical etching revealed to be dislocation bands. When comparing the two images, it is evident that annealing results in a considerable reduction of these diagonal dislocation bands.

DISLOCATION DENSITY REDUCTION VIA RELIEF OF RESIDUAL STRESS

During mc-Si growth, the crystal is subject to internal stresses due to thermal gradients and geometric constraints. Upon cooling, these stresses are fixed in place, resulting in residual stresses. When submitted to high temperatures, the mc-Si crystal can experience a considerable stress relief, resulting in dislocation density reduction. We demonstrated that samples with higher initial residual stresses present higher dislocation reductions upon annealing; detailed results will be published in an upcoming manuscript [11].

We further investigate the effect of externally applied loads at high temperatures. An experimental setup consisting of a three-point bending device was engineered. A String Ribbon sample was loaded as shown in Figure 2, to apply a tensile and compressive load simultaneously while annealing at high temperatures.

![Three-point-bending fixture](image3.png)

Figure 2 Stress Distribution Representation: Three-point-bending fixture showing highly localized stresses at the contact points and a gradual stress distribution: compression at the top part, and tension at the bottom end.
The sample under bending demonstrates a dislocation density gradient throughout its face, with some areas resulting in significant dislocation density reduction. While detailed results will be published in a peer-reviewed journal article [11], our preliminary results suggest that tailoring stress distributions in ingots, bricks, or wafers may present a promising path towards reducing dislocation densities.

REFERENCES


