INFRARED BIREFRINGENCE IMAGING OF RESIDUAL STRESS AND BULK DEFECTS IN MULTICRYSTALLINE SILICON

Vidya Ganapati[1], Stephan Schoenfelder[1,2,3], Sergio Castellanos[1], Sebastian Oener[1,4], Tonio Buonassisi[1]
[1]Massachusetts Institute of Technology, Cambridge, MA
[2]Fraunhofer Center for Silicon Photovoltaics, Halle, Germany
[3]Fraunhofer Institute for Mechanics of Materials, Halle, Germany
[4]University of Konstanz, Konstanz, Germany

ABSTRACT

We explore the potential of infrared birefringence imaging (IBI) to reveal a complete picture of macro- and microscopic internal stresses and their origins in multicrystalline silicon (mc-Si). We present a method to decouple macroscopic thermally induced residual stresses and microscopic bulk defect-related stresses, and validate this method in mc-Si wafers via microstructural analysis. We then describe the unique IR birefringence signatures, including stress magnitudes and directions, of common microdefects in mc-Si solar cell materials: β-SiC and β-Si_3N_4 microdefects, twin bands, non-twin grain boundaries, and dislocation bands. We relate observed stresses to other topics of interest in solar cell manufacturing, including wafer mechanical strength and minority carrier lifetime.

INTRODUCTION

Solar cell manufacturing yield is inversely related to the cost of photovoltaic power. The strength of wafers and cells is widely measured via bending tests using a continuum approach [1-3], assuming the material is homogeneous throughout. Fracture strength is evaluated using the Weibull distribution [4], since silicon is a brittle material exhibiting a large variation in fracture stress values. The resulting data is used industrially to improve manufacturing steps or investigate the influence of processing parameters on wafer strength. However, multicrystalline silicon (mc-Si) wafers exhibit a heterogeneous stress distribution due to defects, so the underlying cause of breakage is unclear with continuum investigations. As a result, PV technology pathways with cost reduction potential remain underdeveloped. For example, thinner wafers represent a promising path towards reduced materials costs, yet these benefits have been offset by lower production yields due to higher breakage.

In this contribution, we demonstrate the potential of *infrared birefringence imaging* (IBI), a high-throughput, non-invasive method, to characterize the spatial distributions of internal stresses in mc-Si solar cell wafers on the micron scale. We use the Grey-Field Polariscope (GFP) manufactured by Stress Photonics, as described in [5], to image our samples.

DISCUSSION

We observe two main causes of stress in our mc-Si samples: thermally induced residual stress, which arises from thermal gradients during the cooling of silicon down to room temperature, and stress originating from bulk microdefects. Thermally induced residual stress has a low spatial variation throughout the samples, as compared to the microdefect-related stress, which is highly localized around the defect. Thus, to differentiate the two causes of stress, we cleaved a sample in half and observed the stress relaxation near the free edge. This simple, albeit destructive technique for determining thermally induced residual stress is further detailed in the manuscript in [6].

We then decoupled and described the unique IR birefringence magnitudes, signatures, and origins of common microdefects in mc-Si solar cell materials, including silicon carbide (SiC) and silicon nitride (Si_3N_4) inclusions, dislocations, non-twinned grain boundaries, and twin bands. The full taxonomy of common microdefects and the correlation of the IR birefringence images to data obtained from other defect characterization techniques is given in [6].

CONCLUSION

We believe IBI may enable predictive yield analysis, as it shows the spatial distribution of internal stress, which is related to wafer mechanical strength. Additionally, we explore the relationship of minority carrier lifetime and IR birefringence in [6].

REFERENCES

1. Funke C, Kullig E, Kuna M, Möller HJ. Biaxial fracture test of silicon wafers. *Advanced Engineering Materials* 2004; **6**: 594.
2. Schoenfelder S, Ebert M, Landesberger C, Bock K, Bagdahn J. Investigations of the influence of dicing techniques on the strength properties of thin silicon. *Microelectronics Reliability* 2007; **47**: 168.
3. Rupnowski P, Sopori B. Strength of silicon wafers: fracture mechanics approach. *International Journal of Fracture* 2009; **155**: 67.
4. Weibull W. A statistical distribution function of wide applicability. *Journal of Applied Mechanics* 1951; **18**: 293.
5. Horn G, Lesniak J, Mackin T, Boyce B. Infrared grey-field polariscope: A tool for rapid stress analysis in microelectronic materials and

devices. *Review of Scientific Instruments* 2005; **76**: 045108.

6. Ganapati V, Schoenfelder S, Castellanos S, Oener S, Koepge R, Sampson A, Marcus MA, Lai B, Morhenn H, Hahn G, Bagdahn J, Buonassisi T. Infrared Birefringence Imaging of Residual Stress and Bulk Defects in Multicrystalline Silicon. *Submitted* 2010.