doi:10.1017/S1431927610056771
Microsc. Microanal. 16 (Suppl 2), 2010

Applications of Electron Microscopy in Crystalline Si Solar Cells

L. Liang

DuPont Central Research and Development, P.O. Box 80500, Wilmington, DE 19880-0500

Hundreds of millions of crystalline silicon cells with a planar *p-n* junction are produced annually to convert sunlight into electricity. In these cells, current collection is achieved using a low-cost Ag grid in contact with the Si emitter on the front, and full Al layer on the back. The Ag grid and Al layer are commonly screen-printed and fired with a belt furnace, which makes contacts. Typically, low-melting PbO or Bi_2O_3 glass is added to the Ag paste to chemically etch through the ~80 nm SiN_x:H anti-reflection (AR) coating on the Si emitter on the front-side. This etching chemistry can have a significant impact on the conversion efficiency of the resulting solar cells [1-2]. In this presentation, we will summarize the role that electron microscopy has played in the research and development of the contacts of solar cells.

In 1983, Nakajima et al. published the first microstructure study of interface between the front side and Si emitter by SEM [3]. Ballif and his co-workers later reported the formation of 200 nm to 500 nm Ag crystallites on the emitter surfaces [4]. These authors proposed a non-uniform conduction mechanism in which the "current flow occurs via a few isolated Ag crystallites that are directly connected or close to the Ag grains forming the contact bulk." Along with its variants, the "Ag-crystallite" mechanism is widely accepted [5] as the most likely explanation of the function of front side Ag contact in industrial crystalline Si solar cells. Li et al. used advanced electron microscopy to investigate the microstructure of front side contact in detail [2]. In under-fired cells, large variation in SiN_x:H thickness suggests that etching was highly non-uniform. A high density of nano-Ag colloids (size 5–100 nm) was seen in the glass layer in the under-fired cell. The optimally fired cell still had many nano-Ag colloids in the glass layer at the interface. The absence of Ag crystallites on the emitter of the best-performing cells revealed that Ag crystallites are not needed for efficient current collection. They therefore proposed that in these solar cells, current flow occurs via a tunneling mechanism (see figure 1).

The general mechanism for the formation of an alloyed aluminum back surface field (BSF) for the rear surface passivation and effective rear contacts during the rapid firing cycle in commercial belt furnaces was described [6]. Microstructure of the back-side was studied systematically by electron microscopy in top- and cross sectional views. Three layers in the backside, named, BSF, Al-Si alloy eutectic, and Al-Si particulate (see figure 2) have been characterized [7-11]. The relationship between performance, microstructure, and processing conditions, such as, aluminum paste loading, belt furnace firing profiles and peak temperatures will be summarized.

Currently, crystalline Si solar cells are still the most widely used in photovoltaic solar energy generation. Since the cost generated by solar cells is rapidly approaching that by fossil fuels, large-scale utilization of PV solar energy technology is becoming reality. Electron microscopy should play an increased role in the research and development of higher efficiency crystalline Si solar cells.

The author appreciates the stimulating discussion with colleagues in DuPont CR&D.

References:
1. R. Young, A. Carroll, *Proc. of the 16th European PVSEC* (2000) 1731.
2. Z. G. Li et al., *J. Applied Physics*, 105 (2009) 66102.
3. T. Nakajima et al., *Int. J. Hybrid Microelectron*, 6 (1983) 580.
4. C. Ballif et al., *Applied Physics Letter*, 82 (2003) 1878.
5. D. Pysch et al., *Proc. of the 22nd European PVSEC* (2007)1238.
6. Schubert et al., *Proc. of the 19th European PVSEC* (2004) 813.
7. M. Hilali et al., *J. Electrochem. Soc.*, 153, (2006) A5.
8. F. Huster, Proceedings. 20th PVSEC (2005) 635.
9. V. Meemongkolkiat et al, *J. Electrochem. Soc.*, 153 (2006) G53.
10. F. Huster and G. Schubert, *Proc. of the 20th European PVSEC* (2005) 1462.
11. W. Coulter et al., *Proc. of the 34th IEEE PVSC* (2009) 263.

Figure 1. Cross-sectional TEM image of front side contact (Ref. 2).

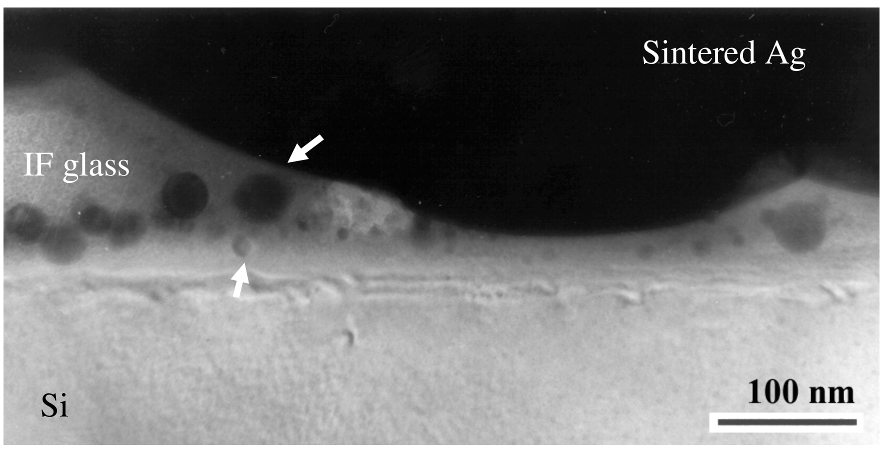
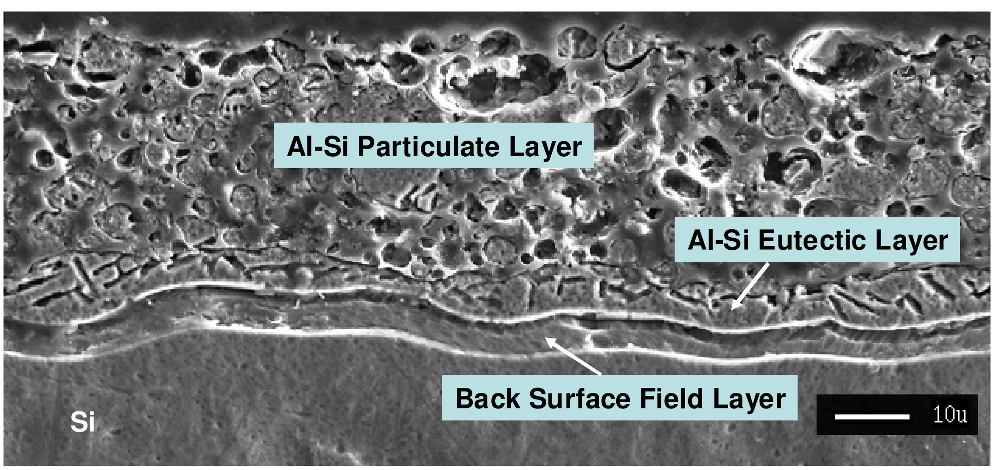


Figure 2. Cross-sectional SEM image of back-side contact (Ref. 11).



https://doi.org/10.1017/S1431927610056771 Published online by Cambridge University Press