A complete Transmission Electron Microscopy characterization of low temperature epitaxial Silicon film

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c-Si solar cells have a maximum efficiency of 26,7% and are the most economically competitive on the market, representing over 90% of commercial photovoltaic panels. Material investigation could lead to a better understanding of material properties and innovation in manufacturing processes to increase efficiency and stability and lower their cost.In crystalline silicon (c-Si) solar cell, low temperature epitaxy (LTE, <200°C) plasma-enhanced chemical vapor deposition (PECVD) is proposed in order to replace the standard boron rear emitter diffusion for n-PERT technology. LTE ensures a lower thermal budget and the formation of a sharper doping profile. More recently, it has also been investigated as a way to grow tunnel junctions for 2T perovskite/silicon tandem cells.

Transmission Electron Microscopy (TEM) is an advanced characterization technique that is not commonly used in solar industry, but could bring additional structural information, thanks to its atomic scale resolution. In this work, we studied an as-grown and a 350°C-annealed boron-doped c-Si:H:B films on n-type Si (100) substrates. The thicknesses of the films were measured by ellipsometry and verified by high resolution TEM to be 195 nm for the as-grown and 165 nm for the 350°C-annealed. In order to complete XRD, SIMS and elliosometry analysis which are already done by M. Chrostowski and *al* [1], different TEM techniques were used. For both as-grown-epi and 350°C-annealed-epi samples, cross-section and plan view lamella were prepared respectively by FIB and conventional grinding and ion milling.

In the images below, HRTEM (High Resolution TEM) show the microstructure of the interface c-Si/c-Si:H:B and around it. For the as-grown film, we can make out the interface because of the contrast difference between c-Si and the film. We can see an important density of structural defect in this film. Those defects form what is called a "leopard" contrast (alternating of black and white contrast clusters) in the image. The density of defects considerably decrease when the film is annealed at 350°C. This effect of the annealing can be seen on the related HRTEM image by completely different microstructure and interface. In the 350°C-annealed film, as-grown defects described above by "leopard" contrast completely disappear to give way to V-shaped defects which begin at the interface and can propagate until the surface of the film forming a column (observed at lower magnification). In the latter film a rougher interface can be observed. The defects in as-grown film are mostly related to hydrogen induced defects (platelets and molecular hydrogen) due to high hydrogen content which cause crystalline disorder and strain in the film [2,3]. While V-shaped defects which gave rise to streaking effects of the <111> spots in the Fast Fourier Transform (FFT) of the HRTEM images of the 350°C-annealed film are evidence of the presence of nanotwin in the film. Nanotwins are probably generated by the shear stressed induced by morphological change of the film (e.g. crystalline to microcrystalline) [4].

STEM-HAADF is a TEM technic which give chemical contrast images. As we can see in STEM-HAADF (chemical contrast) images, as-grown film shows a more diffusion interface (3.44 nm) than for the 350°C-annealed film (2.30 nm) which could be consistent with hydrogen desorption.

Thus annealing could both heal hydrogen defects and start early morphological change steps of the film.

In further work, to compare with XRD results, we plan to map strain in the epitaxial layers with Geometric Phase Analysis (GPA), which is an image processing technique capable of resolving lattice strain according to the analysis of local maxima (atoms) contrasts in the image. In our case, we will use

STEM-HAADF images because they are free of structural contrasts (unlike HRTEM images) which can interfere with GPA measurements.

References:

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