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Silicon Crystal Growth and Wafer Processing for High Efficiency Solar Cells and High Mechanical Yield

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Silicon Crystal Growth and Wafer Processing for High Efficiency Solar Cells and High Mechanical Yield

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ABSTRACT

We are studying the impact of nitrogen doping of FZ and Cz silicon on the minority carrier lifetime through the correlation of electrical and structural properties. Minority carrier lifetime of dislocated FZ Si is measured by laser-Microwave Photo-Conductance Decay (μPCD) and correlated with X-Ray Topography (XRT). Identification of dislocation related traps and their effect on minority carrier lifetime is carried out using Electron Beam Induced Current (EBIC) and Deep Level Transient Spectroscopy (DLTS). In addition, defects in heat treated nitrogen doped Cz Si wafers were delineated by Wright etching and the extended defect size distribution was measured by Oxygen Precipitate Profiler (OPP). SIMS profiles showed a strong coupling of oxygen with nitrogen.

Preliminary work on a novel process for external gettering by creating a band of silicon dioxide precipitation on top of a denuded zone via nitrogen doping is presented. The precipitate band is unique to N doping and is very shallow. When etched, it produces a uniform and efficient texture for light trapping and simultaneously eliminates the impurity sink, in essence the tailored gettering shallow region. The minimal specular reflectance reached is ~4%.

1. Introduction

Float zone (FZ) Si ingots grown in NREL are ultra pure and have the highest minority carrier lifetime [1]. Used for PV, this material can produce the highest efficiency planar solar cells for normal illumination as well as high concentration. However, it suffers high yield loss due to breakage and is expected to cause in-field performance degradation due to slip dislocations. Breakage and yield/performance improvements are key issues for future thin FZ wafers for PV. Therefore, it is necessary to study the basic mechanisms and interplay between nuclei and chemical clusters [2], oxygen precipitation and also the crystal response to the presence of metallic impurities. As a means to merge the benefits of both FZ and Cz crystals, it is planned to vary the oxygen content and/or dope FZ Si, grown in NREL, with nitrogen in order to maintain high minority carrier lifetime, by reducing carrier recombination at precipitates, while improving the hardness.

2. Main results

Longitudinally cut slugs from ingots grown at NREL were examined at NCSU in a non-destructive fashion by μPCD, see Fig. 1(a), and x-ray topography, see Fig. 1(b).

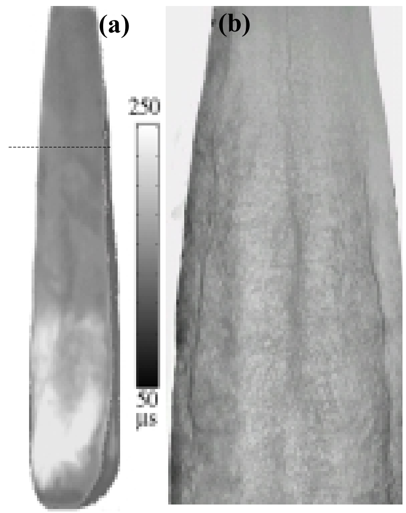

Fig. 1: (a) μPCD lifetime map of a dislocated FZ Si slug H=130 mm, W=28 mm.
(b) XRT of the upper portion.

One can immediately note that the average values of 70-80 μs in the heavily dislocated areas are in principle, still quite good for PV applications. This is attributed to the fact that the dislocations are “clean” in this high purity FZ crystal and relatively electrically inactive. Correlation of the lifetime variations in FZ Si with the dislocation density is made by EBIC after a very light defect decoration with Cu and Fe, this study will be detailed elsewhere [3].

Nitrogen doped Cz Si (N-Cz) wafers heat treated for denuded zone (DZ), with either Lo-Hi or Hi-Lo-Hi processes, exhibited a shallow defect band, limited to the first 1-2 μm of the traditional defect free denuded zone [4]. The defect density depth profiles were obtained by Oxygen Precipitate Profiler (OPP), see Fig. 2(a). The O and N SIMS profiles, shown in Fig. 2(b), demonstrate a clear coupling of the O and N in that shallow defect band; such a coupling goes further beyond the DZ [5]. The fact that it is nitrogen enhancing the nucleation of near-surface oxygen precipitation is evident from the SIMS N and O depth profiles. Although OPP and SIMS measurements were done on N-Cz Si materials grown in different conditions and the temperature of the nucleation step (Lo) had a 100 degrees difference, the defects appear clearly to be due to an interaction between N and O atoms while diffusing and clustering in the vicinity of the wafer surface [5].

The near surface defect band, which getters grown-in impurities, forms upon etching a textured surface that has very low reflectance. Typical texture produced by a 1 min preferential Wright etching is shown in Fig. 3(a). The reflectance, measured by a Filmetrics F20 Reflectometer with a detection solid angle of ~8°, is given in Fig. 3(b) for different wafer annealing conditions; i.e. different precipitate sizes in the near surface zone. A dramatic decrease of the in the specular reflectance is obtained mostly in the green region and extends to the near IR where the reflectance is reduced by a factor two.

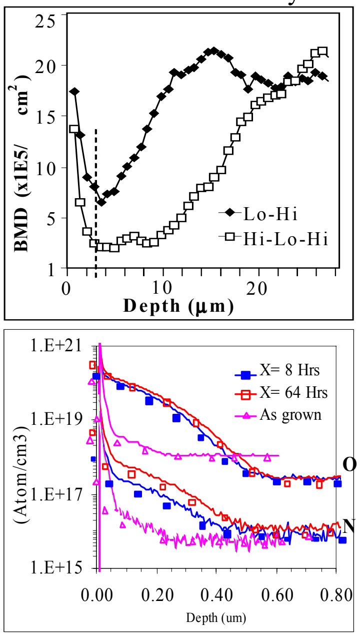

Fig.2:(a) OPP micro-defect distributions in Lo-Hi and Hi-Lo-Hi heat treated N-Cz Si samples (Hi at 1250C for 1 hr, Lo at 650C for 8 hrs, and Hi at 1050C for 16 hrs).
(b) O and N SIMS profiles at the surface of an as grown and heat treated N-Cz Si samples by Lo-Hi process (750C/ X hrs + 1050C/ 16hr) with X=8, 64 hrs.

A manufacturing compatible process is currently being studied which would generate a surface micro-structure suited for junction fabrication. This process consists of two simple etching steps (i) dense pit nucleation with Wright etching, a typical highly stress sensitive etching process by defect decoration, followed by (ii) pit growth using the highly anisotropic etching in an alkali solution. During the etching step, the impurity sink layer is removed along with any undesirable chemical traces from the Wright etching. Figure 4 provides the reflectance of an N-Cz wafer heat treated at 750C/8hrs and 1050C/16hrs for different KOH etching times. Figure 5 shows the structure of pits grown at O precipitates and SF sites, in connection to the reflectance curves reported in Fig. 4.

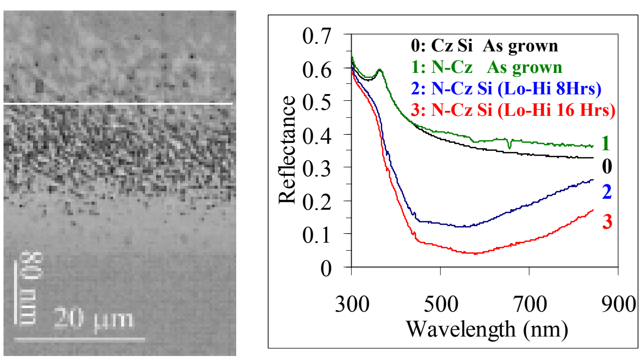

Fig. 3: (a) Etch pits on a bevel polished sample from a Lo-Hi annealed (750C/8hrs + 1050C/16hrs) N-CZ wafer.
(b) Specular reflectance at normal incidence of Wright etched N-CZ Si samples Lo-Hi annealed.

3. Conclusion

Nitrogen doping of FZ silicon is expected to provide a robust option for improving the mechanical properties of wafers, while preserving high minority carrier lifetime. In Cz Si, N doping reduces the strain around the precipitates thus decreases their gettering effects. A near-surface defect band found in N-Cz heat treated wafers can be used beneficially to getter grown-in impurities, to the wafer surface, and to simultaneously obtain a high quality surface texture, necessary for light trapping.

The goal of the NCSU-NREL joint project, which is partly supported by the SiWEDS [6], is to improve the FZ Si material via (i) N doping, (ii) control of O concentration and (iii) engineering the process induced extended defects. Also the integration of N doping beneficial features into a solar cell fabrication process will be considered. Study of external impurity gettering via the newly found N related shallow defect band and optimization of the reflectance are planned.

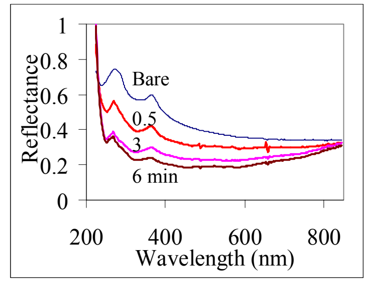

Fig. 4: Reflectance of N-CZ Si (111) samples etched for 0.5, 3 and 6 min with KOH. Wafers have received a prior Lo-Hi treatment.

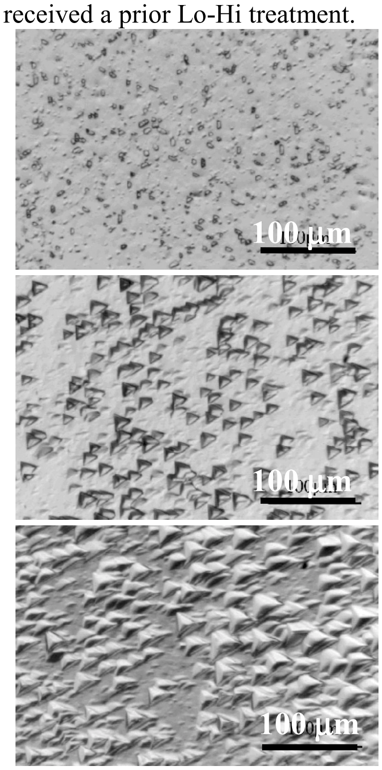

Fig. 5: Nomarski micrographs of samples cited in Fig. 4, after KOH etch for 0.5, 3 and 6 min.

Acknowledgements:
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[6] Silicon Wafer Engineering and Defect Science an NSF sponsored Industry/University consortium of silicon vendors and IC processing companies.