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Investigation of laser ablation induced defects in crystalline silicon solar cells

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Abstract

In this paper, the laser induced defects that result from a picosecond laser ablation (wavelength 355mm) of passivating SiO_2 and SiN_x layers on textured silicon surface are investigated for various laser fluence ranging from 0.48J/cm^2 to 1.43 J/cm^2. In the first part of this paper, we employ the Wright etching technique to identify and quantify thermally propagated dislocations as one of the resulting defects as a function of the laser fluence. Dislocations densities in the order of 4 - 13 x 10^6 cm^{-2} are measured. The second part of the paper takes a closer look at the impact of laser induced defects on the effective lifetime and surface recombination current. By comparing both parameters on structures with laser ablation and photo-lithography to pattern the dielectric, it is observed that dislocations formed during the laser ablation process do indeed enhance minority carrier recombination within the silicon wafers. The recombination current at the laser ablated area, for a moderate laser power, is shown to be four times larger than in the case of using lithography.

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Keywords: Laser ablation; laser damage; defects; dislocations; i-PERC

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1. Introduction

Laser processing is very useful and versatile tool for the fabrication of high efficiency solar cells. There are many opportunities laser processing offers, for example laser texturing [1], laser annealing [2], laser doping [3]. Among of them, laser ablation with ultra-shot pulses is a promising way to reduce the cost compare to photo-lithography and particularly suitable for industrial processing of high-efficiency solar cells, such as for laser opening of dielectrics on top of an emitter prior Ni/Cu plating [4]. However, the critical aspect is laser induced-damage. This damage can cause high saturation current densities in the emitter and increases the risk junction recombination or shunting. Therefore it is important to understand how laser ablation generates damage in the emitter and to quantify the impact on the electrical properties of the silicon wafer. There are several studies about the laser ablation induced damage in the silicon and its impact on the cell performance [5,6], however from our knowledge, there is still a lack in understanding what kind of damage occurs and how it is created.

In this work, laser ablation of SiN_x on p-type crystalline Si wafers was investigated. The effect of different laser fluence or energy density from a ps-laser was studied. We identify the laser–induced damage and also exam the electrical impact of this damage on Si wafers. A comparison between laser ablation and wet etching will be made.

2. Experimental details

In this work, large area (156x156mm^2) p-type, 1-3Ω.cm, magnetic CZ Si wafers, with starting thickness of 180µm, were used. After random pyramid texturing for the front and polishing of the rear side, the wafers were processed according the process sequence given in Fig.1a. The wafers were used with 2 separate aims: (i) defect visualization (Figure 1(a) left) and (ii) quantify recombination current (Figure 1(a) right).

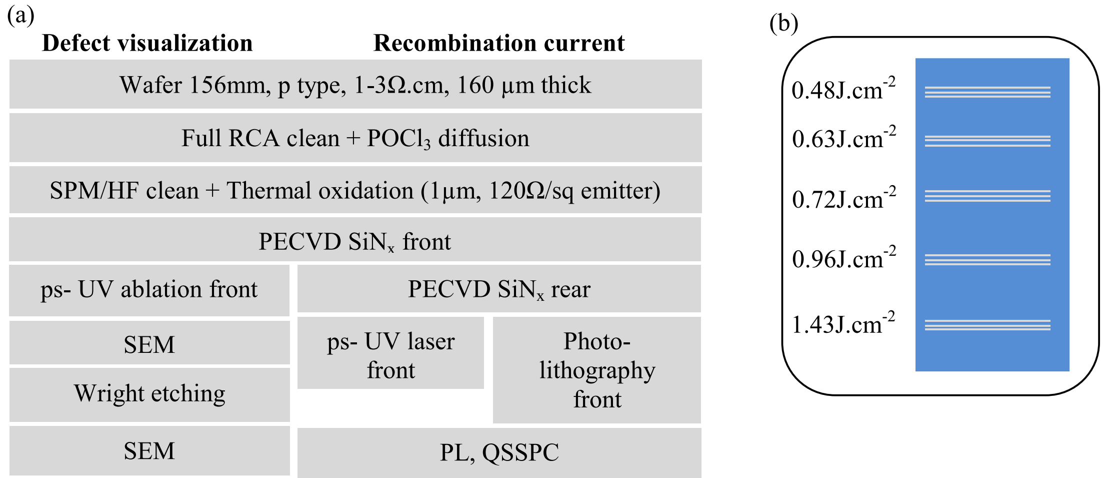

Fig. 1. (a) Process sequence of test samples for the defect characterization; (b) Schematic of the sample showing applied laser pulse energy density.

Prior to $POCl_3$ diffusion, the silicon wafers were subjected to a full RCA clean in order to remove organic and metallic contamination before the fabrication process. A HF 2% was applied to remove phosphorus silicate glass. Then the wafers were cleaned by SPM/HF before oxidation. After thermal oxidation, this resulted in a 1µm deep emitter with a sheet resistance of 120Ω/sq. Afterwards, the $POCl_3$ diffused emitter was passivated with a PECVD SiN_x:H layer. Subsequently, the wafers were processed in two separate experiments as following:

In a first experiment, the front laser ablation was performed by using a ps-laser (wavelength of 355mm) with various laser fluence: 0.48J/cm^2, 0.63J/cm^2, 0.72J/cm^2, 0.96J/cm^2 and 1.43J/cm^2. A schematic of the sample is shown in Fig.1b. A standard Wright [7] etch solution was used as defect etching chemical. This Wright etch