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Laser induced localised hydrogen passivation

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Abstract

Hydrogen passivation is considered as an effective way to reduce the recombination ability of low cost silicon wafer. In this paper, an innovative method to use laser to achieve localised hydrogen passivation is proposed. Laser induced localised hydrogen passivation is shown to be able to passivate localised high recombination sites, and therefore enhance the photoluminescence response and effective lifetime of the silicon wafer. In the experiment, various processing parameters on the effect of localised hydrogen passivation are investigated. It is found that the performance of localised hydrogen passivation increases with the laser induced peak temperature and laser illumination intensity until the critical value. The performance of localised hydrogen passivation is also found to increase with the decreased laser scan speeds, as reduced laser scan speeds lead to enhanced hydrogen passivation time.

Keywords: Silicon wafer; Localised hydrogen passivation; Laser; Peak temperature; Illumination intensity

1. Introduction

To date, intense research interest has been focused on hydrogen passivation. Hydrogen passivation has the ability to dramatically reduce recombination activities of various types of defects (Benton et al., 1980; Nickel et al., 1993; Pearton and Tavendale, 1982; Hanoka et al., 1983; Seager and Ginley, 1981; Bousbih et al., 2012), and is therefore considered an important technique in dealing with the recombination associated efficiency limit. Specifically, hydrogenation can passivate the surface and bulk regions by forming bonds with various impurities and intrinsic defects such as dislocation clusters and grain boundaries (GB) (Dubé and Hanoka, 1984; Seager and Ginley, 1979; Alnuaimi et al., 2013). However, conventional hydrogen passivation can only process silicon wafers as a whole, and therefore it is possible to reactivate other defects while passivating some defects within the silicon wafer (Devine, 1991; Glunz et al., 2003). Additionally, it is found that different defects respond differently to hydrogen passivation, therefore one step hydrogenation process such as co-firing process for the conventional hydrogen passivation scheme is not sufficient to passivation some high recombination centres (Duerinckx and Szlufcik, 2002; Morikawa et al., 2010).

Localised hydrogen passivation is required to passivate localised high recombination sites that significantly degrade the performance of the silicon solar cell. Laser technology, as an illumination and heating source, is an interesting option for performing localised hydrogen passivation (Lihui Song et al., 2015), as its localised nature enables it to achieve hydrogen passivation in specific areas. As previously discussed, lasers have been widely utilized for a variety of solar manufacturing processes including: edge junction isolation (Kray et al., 2007); buried contact groove formation (Wenham, 1993); selective doping (Sameshima et al., 1987); texturing (Abbott and Cotter, 2006); and for

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the ablation of dielectric layers (Ihlemann and Wolff-Rottke, 1995). However, in this paper, the focus is on the novel use of lasers to enhance hydrogen passivation. It will be shown that laser processes can be used to passivate localised high recombination centres, and the underlying mechanisms of hydrogen passivation will be investigated. An additional benefit of laser processing is that it allows hydrogen passivation to be performed subsequent to any processing step, which is favourable as it can help recover hydrogen passivation (for example after a high-temperature firing step).

2. Experimental method

Twenty 1 Ω cm p-type textured Cz samples were prepared for experiments. Firstly, 6 in. Cz samples were laser cleaved into 2 in. samples using a Lee laser. Those 2 in. samples were then RCA cleaned and had a 75 nm SiN_x:H layer ($n = 2$) deposited on both the front and rear of the wafers using a Roth & Rau AK400 PECVD System. Then different laser processing parameters such as different laser power densities, scan speeds and wafer substrate temperatures are used to process localised hydrogen passivation on these silicon wafers coated with double side SiN_x:H layers. The detailed processing parameters are listed in Table 1.

3. Results and discussion

3.1. Laser power density

First of all, a series of samples went through laser enhanced hydrogen passivation with different laser power densities tested. The impact of localised hydrogen passivation increased with the laser power density, up until the point when the sample broke up. As a new laser system was used for this experiment, no direct calibration had been built between the laser diode currents and laser power density; it is only known that laser power density increased with the laser diode currents. The PL images showing the variation of localised PL response as a function of laser power densities (8–13.5 A diode currents) are shown in Fig. 1.

It is evident that the PL response of the scanned region increased with the laser power density until a peak value. When the laser diode current was 14 A, the silicon wafer would break as a result of huge thermal stress. The laser scanned region become very bright when the laser diode current was 13.5 A, indicating that numerous recombination sites within this region has been passivated by hydrogen. The PL count ratio, which is defined as the average PL count of the laser scanned region over the average PL count of the wafer non-processed, is shown in Fig. 2 as a function of laser diode currents.

The lifetime variation is another important factor in evaluating the performance of localised hydrogen passivation, and is shown in Fig. 3.

Consistent with the variation of PL counts ratio, the lifetime of the sample after the localised hydrogen passivation increased with the laser diode currents, indicating that high diode current is good for localised hydrogen passivation. It is expected that high laser diode current leads to high laser induced peak temperature, such that hydrogen can diffuse deeper into the silicon wafer and react with defects with a higher rate at the high temperature. Therefore it could draw a conclusion that localised hydrogen passivation is better at higher laser induced temperature before forming laser damage within the silicon wafer.

3.2. Laser scan speed

The impact of laser scan speed ranging from 0.5 to 3.5 mm/s on the performance of localised hydrogen passivation is demonstrated in Fig. 4.

In Fig. 4, it is evident that better localised hydrogen passivation occurred at the low laser scan speed, as the laser scan speed is low, there will be more hydrogenation time for the localised area such that hydrogen can penetrate deep into the silicon wafer and passivate the silicon substrate. If the hydrogenation time is increased, more hydrogen-defect complex is expected to be formed.

The effective lifetime variation of the samples at the various laser scan speeds are shown in Fig. 5.

In Fig. 5, the low laser scan speed leads to higher effective lifetime of the sample that is better hydrogen passivation, as low scan speed is increasing the duration of hydrogenation time and thus more hydrogen can be incorporated into the silicon wafer and bond with defects.

3.3. Hot plate substrate temperature

The impact of hot plate substrate temperature ranging from 300 K to 823 K on the performance of localised hydrogen passivation is illustrated in Fig. 6.

In Fig. 6, it is evident that high hot plate temperature is good for hydrogen passivation, which is revealed as much brighter PL image for the samples after laser processing at high hot plate temperature. As at the high temperature, hydrogen has much faster diffusivity and defect bonding rate such that more hydrogen-defect complexes can be formed. However, localised hydrogen passivation effect is not evident at the high hot plate temperature as the laser induced temperature and illumination are not sufficient to induce evident localised hydrogen passivation impact.

Table 1
Laser processing parameters on the localised hydrogen passivation.

Laser power densities (A)	Laser scan speeds (mm/s)	Wafer substrate temperatures (K)
8–13.5	1	300
13.5	0.5–3.5	300
13	1	300–823