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# Nanosecond laser defects induced in crystalline silicon annealed: identification, localization and electrical impact.

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Laser Thermal Annealing (LTA) in conjunction with ion implantation has been demonstrated to be a very effective method to achieve heavily doped and localized regions needed in both advanced MOSFET and solar cells technology. In some cases, degradation of the electrical properties of the laser doped regions has been reported, including increased leakage current in p-n junctions, reduced carrier mobility and breakdown voltage shift in MOS transistors [1] or reduced carrier lifetime in solar cells [2], which are attributed to laser-induced damage, including impurity penetration during anneal [3] or point defect generation during melt recrystallization [4]. However, few works have been focused so far on the detailed investigation of laser induced damage.

In this work, we present a comprehensive investigation of laser induced damage by implementing a methodology allowing the identification and the localization of the defects as well as the investigation of their impact on the properties of the annealed regions. In order to avoid additional damage generated during an implant step, the investigations were conducted on *in-situ* doped Si substrates. Excimer LTA ( $\lambda=308$  nm, pulse duration=160 ns) was carried out with energy densities ranging from 1.7 to 8 J/cm<sup>2</sup> and with one more multiple pulse conditions. Several experimental parameters were analyzed, including the substrate temperature during LTA (300 or 448 K), the annealing ambient (air or N<sub>2</sub>) and the surface preparation (HF cleaning, thermal oxide). The annealed samples were analyzed by photoluminescence spectroscopy (PL) with several excitation wavelengths to probe different depths, secondary ion mass spectroscopy (SIMS) and transmission electron microscopy (TEM). Finally, p-n junction diodes were fabricated on selected samples to investigate the impact of LTA on the junction leakage current.

Typical PL spectra from annealed samples exhibit a broad band starting from 0.87 eV up to a very intense peak at 0.96 eV (G-line, related to the presence of carbon [5]), whose intensities increase with laser energy (cf. Fig. 1). Furthermore, a peak centered at 0.79 eV is also observed, identified as the C-line and attributed to the formation of interstitial carbon-interstitial oxygen pairs [5]. The intensity of the PL peaks is found to increase when decreasing the excitation wavelength, suggesting that the observed defects are mostly located close to the surface. The introduction of C and O during LTA is confirmed by SIMS analysis (cf Fig. 2). The observed increase of the oxygen dose with increasing laser energy as well as the corresponding diffusion profiles (reproduced by simulations based on a phase-field continuum model for the calculation of the temperature and phase transitions) suggest that the oxygen penetration originates from the oxygen atoms contained in the surface oxide layer (native or thermal) in contact with the melted Si during annealing. This is confirmed by the observed behavior of Carbon, which is typically contained only in native oxide. Indeed, C penetration was not observed in samples with a surface thermal oxide. Finally, leakage current in p-n diodes was found to increase with increasing number of pulses when the solid/liquid interface was located within the junction space charge region, suggesting that its origin is due to point defect generation during melt recrystallization.

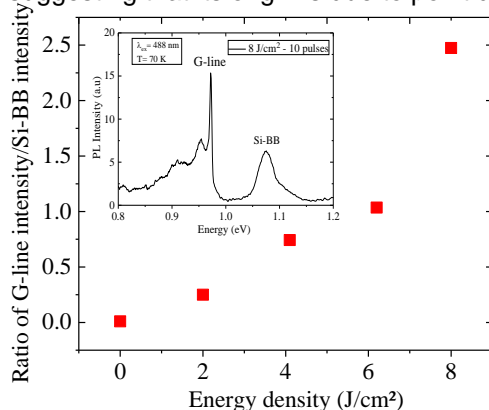


FIG. 1. Luminescence intensity ratio of G-line on Si band-band (Si-BB) obtained with  $\lambda_{ex}=488$  nm (penetration depth: 600 nm) at 70 K according to laser energy density. Inset: PL spectrum obtained on 8 J/cm<sup>2</sup>-10 pulses sample.

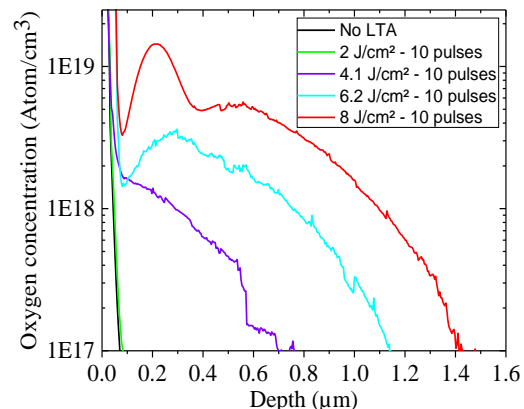


FIG. 2. SIMS profiles of oxygen concentration in depth generated by annealed laser for various laser energy (2 - 8 J/cm<sup>2</sup> with 10 pulses).

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