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Formation of highly doped and defect-free p-type junctions in SiC by using high temperature implants and UV-Laser Annealing

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Formation of highly doped and defect-free p-type junctions at reduced cost remains one of the important limitations for the manufacturing of high performance SiC devices. Today process of record presents some limitations in terms of defectivity, maximal implanted doses ($\sim 1E15$ at/cm²) and cost (carbon cap required during furnace annealing to avoid SiC dissociation) [1]. Indeed, if the implanted dose becomes too important ($>4E15$ at/cm²), basal stacking faults (BSF) are formed during the furnace annealing step [2].

To overcome these limitations, an alternative solution based on high-temperature ($>500^\circ\text{C}$) ion implantation and microsecond ultraviolet laser annealing (later referred as UV-LA) is proposed. This solution presents the advantages to enable implantation and activation of high doses of aluminum ($1E16$ at/cm²) while remaining defect-free. Moreover, the manufacturing costs with this solution are reduced since there is no need of any carbon cap during the laser annealing step.

UV-LA is an attractive solution for the activation of high-doses in SiC thanks to its short irradiation time (<100 μs) and the extremely high temperatures ($>2500^\circ\text{C}$) enabled by the use of UV wavelength in the range of 300 to 400 nm which provides a surface-localized anneal. Moreover, the common optimization of laser fluence (E_x) and irradiation time (τ_x) permits to have an accurate control of the temperature profile during the laser annealing as described in Fig. 1.

4H-SiC substrates with 4 μm of low doping epitaxy were implanted with a dose of $1E16$ at/cm² by using a multistep approach to form an Al box profile over 250 nm as shown in Fig. 2. Increasing temperature is expected to reduce crystal defectivity during the implantation step which later will help to boost dopants activation [3]. In this scope, two implant temperatures have been studied: 500°C and 800°C .

Then the two samples (500 and 800°C) have been cleaved. For each implant temperatures, one half has been directly laser annealed whereas the other half has been carbon capped and furnace annealed under standard conditions (1700°C during 30 min) [1]. Laser annealing conditions have been optimized to reach temperatures below the SiC melting point to avoid SiC dissociation as shown in Fig. 3.

To assess crystal quality before and after annealing, samples were measured by Raman spectroscopy (476 nm). Spectra were normalized to the E2T peak (776 cm^{-1}) [4]. Fig. 4 demonstrates that crystal recovers proportionally with laser irradiation times (dwell) until reaching the level of pristine SiC for the sample at 800°C . Same trend is observed for the 500°C implanted sample. This trend is later confirmed in Fig. 5 since the levels of ThermalWave (thermal emissions responses are directly proportional to implant induced damage density [5]) are almost similar between the laser annealed, furnace annealed and a pristine SiC samples which confirmed again that UV-LA can recover high-doses implanted SiC. TEM images are not shown here; however, we do not observe the presence of BSF on the laser annealed samples. Dopant activation has been later assessed by Sheet Resistance (4PP Rs) and SCM-SMM (not shown here). As shown in Fig. 6, the Rs of the laser annealed samples are up to 3 times lower than the reference one [1] annealed in furnace. Moreover, the Rs of the 800°C sample is 25% lower than the sample implanted at 500°C . This difference may be attributed to the better crystal quality during the implantation as shown in Fig. 5.

In summary, we have demonstrated that UV-LA is able to fully cure high-doses implanted SiC but also leads to higher activation ratio than the standard furnace anneal. This improvement can be attributed to the absence of BSF that can act as deep level traps [6]. This solution is also cost-effective since it does not

require the use of any carbon cap. Moreover, increasing the implantation temperature helps to boost the dopant activation by reducing the crystal damage during the implantation.

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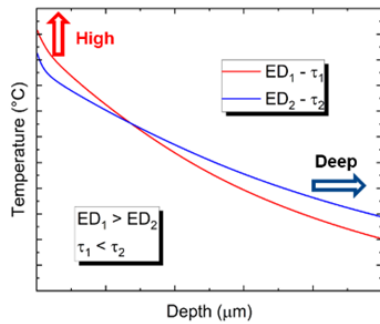


Fig. 1 : Thermal Simulations of UV-LA

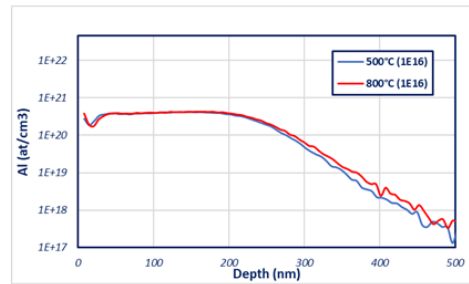


Fig. 2 : SIMS profiles of as-implanted samples at 500°C and 800°C (1E16 at/cm²)

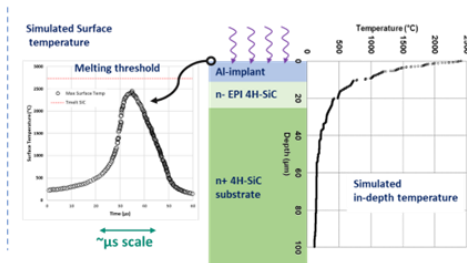


Fig. 3 : Thermal Simulations with optimized UV-LA conditions for SiC Activation

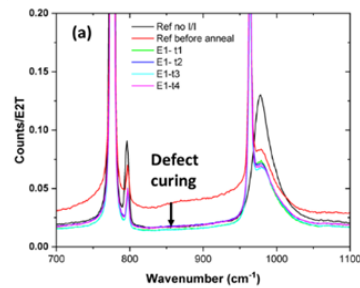


Fig. 4 : Normalized (ET2) Raman spectrums before and after UV-LA for the 800°C implanted sample

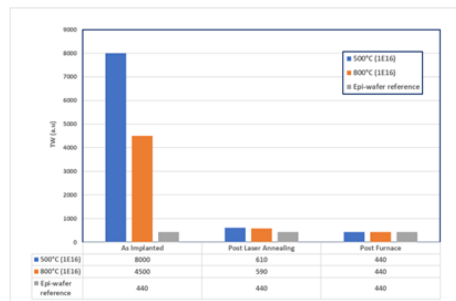


Fig. 5 : ThermalWave levels for pristine, as-implanted, furnace and laser annealed samples

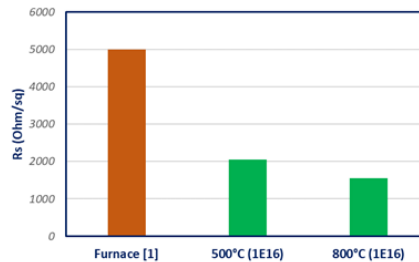


Fig. 6 : Sheet Resistances for furnace (500°C implanted, and laser annealed samples (respectively 500 and 800°C implanted)