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# Improved Annealing Process for 6H-SiC p<sup>+</sup>-n Junction Creation by Al Implantation

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**Abstract:** Five-fold Al implantations at both room temperature and 300°C ranging from 25 keV to 300 keV and a total fluence of  $1.75 \times 10^{15} \text{ cm}^{-2}$ , have been performed in 6H-SiC epilayers to create p<sup>+</sup>-n junctions. The samples have been annealed at 1700°C during 30 mn in an inductively heated furnace especially configured. Surface effects, recrystallization, dopant distribution and electrical activation are investigated by XPS, RBS, SIMS and sheet resistance measurements. For both RT and 300°C-implanted samples, good recrystallization and surface stoichiometry are found as well as no dopant loosing and an interesting electrical activation (46% and 99%, respectively).

## Introduction

p<sup>+</sup>-n junctions in SiC power devices must be realized by ion implantation due to very low diffusion coefficients of dopants in silicon carbide. SiC high density and its structural crystallinity involve a delicate post-implantation annealing. The implantation temperature, annealing environment, time and temperature of annealing and the heating rate are the essential parameters to reorder the crystal damage induced by ion implantation and to activate the dopants by migrating in SiC atomic sites. Initially, after ion implantation, almost all Al dopants are distributed in interstitial sites, where they are not electrically active.

We utilized a JIPELEC<sup>TM</sup> rf induction furnace. This technique of annealing has significant advantages such as the very high rising slope in temperature and the very localized zone of heating (the suscepter). But this one implies high temperature variations, vertically in the enclosure and laterally on the surface of the SiC wafers. These temperature gradients may cause an etching of, or a layer deposition on the SiC surface. Moreover, Si is known to volatilize towards 1400°C at one atmosphere pressure, and in lack of a Si supersaturating vapor the carbonization of the surface is inevitable. This paper presents the results of an optimized thermal rf annealing, which avoids these problems.

## Experiment

Aluminum, a p-type impurity with a low activation energy (0.20-0.25 eV above the valence band), was chosen to be implanted in a  $5 \times 10^{15} \text{ cm}^{-3}$  6H-SiC n-type epilayer purchased from Cree Research. Five implantations were realized at both room temperature (RT) and 300°C with energies ranging from 25 keV to 300 keV, and a total fluence of  $1.75 \times 10^{15} \text{ cm}^{-2}$ , which correspond in TRIM theoretical simulations to a  $4 \times 10^{19} \text{ cm}^{-3}$  dopant box profile and a 0.5 μm p<sup>+</sup>-n junction depth [Table 1]. Both RT and 300°C implanted samples were annealed during 30 mn at 1700°C in argon atmosphere and silicon partial pressure, in a rf heating furnace. The heating slope was 60°C per second.

The samples were investigated using physico-chemical analysis after each step in dopant incorporation and redistribution. These results were compared to other heating furnace configurations previously published [1-3]. Ion-induced damage in the as-implanted material, residual damage after post-implantation annealing and SiC recrystallization were evaluated by Rutherford Backscattering Spectrometry in the Channeling mode (RBS/C) technique. The dopant

Energy (keV)	Fluence (cm <sup>-2</sup> )	R <sub>p</sub> (nm)	ΔR <sub>p</sub> (nm)
300	8x10 <sup>14</sup>	335	77.9
190	3.9x10 <sup>14</sup>	211	56.6
115	2.8x10 <sup>14</sup>	127	38.5
60	1.9x10 <sup>14</sup>	66	22.8
25	9x10 <sup>13</sup>	29	11.0

Table 1: Energy and fluence implantation parameters of experiments, and projected range R<sub>p</sub> and standard deviation Δ R<sub>p</sub> TRIM simulation results

profiles in the as-implanted and annealed samples were obtained by Secondary Ion Mass Spectroscopy (SIMS) measurements with a 10 keV O<sub>2</sub><sup>+</sup> primary ion beam. Surface stoichiometry of the implanted faces were determined by X-Ray Photoelectron Spectroscopy (XPS), employing AlK<sub>α</sub> radiation(1486.7eV). Electrical activation and dopant incorporation in SiC lattice, were inferred from sheet resistance electrical measurements

## Results

### ◆ XPS measurements

X-Ray Photoelectron Spectroscopy measurements were undertaken for both 25°C and 300°C implanted samples on the polished surface. The XPS results reveal a good surface stoichiometry for the two sample faces, since a yield Si/C=1 was found at 200 Å depth. This shows a non silicon sublimation in spite of our high annealing temperature. We also observe that the energetic shifts reveal a large proportion of C-C/C-H bonds from surface to 8 nm, which must be related to some carbon deposition.

### ◆ RBS/Channeling measurements

After Al RT implantation, the RBS/C spectrum presents an increased backscattering yield, which approaches random value from the surface to a depth of 0.25 μm. This is due to the high fluence used exceeding the critical value at which amorphization of the SiC crystal occurs (about 10<sup>15</sup> cm<sup>-3</sup> [4]). For the 300°C implanted samples, the RBS/C spectrum shows a strongly reduced crystalline defect density and no amorphization zone [Figure 1]. The backscattering yield after

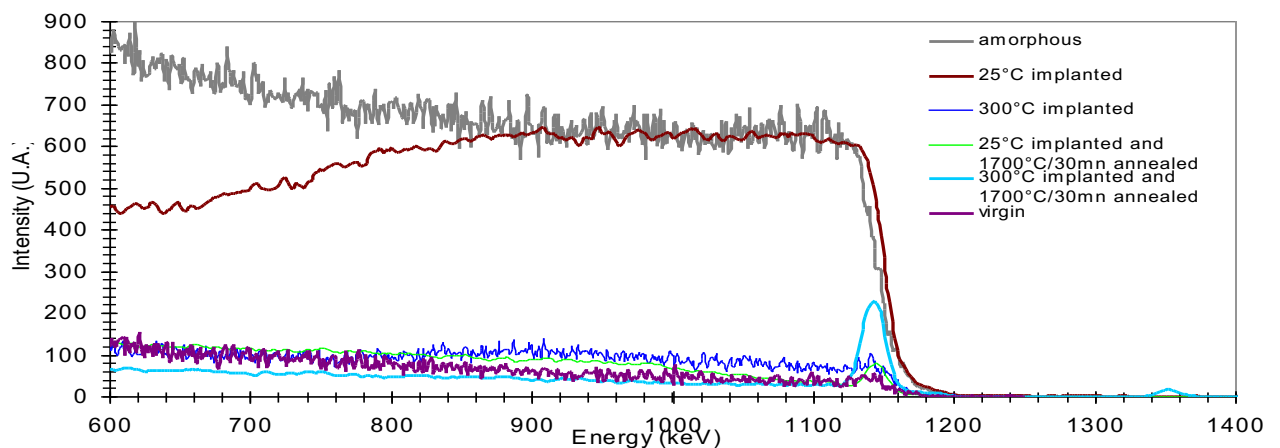


Fig.1 RBS/C signals

annealing is 4.4% for the RT implanted and 4.2% for the 300°C-implanted sample, that proves the sample good crystallinity after annealing for both samples. For the RT-implanted one, a residual damage arising with depth denotes the presence of some extended defects, probably related to the end-of-range defects.

### ◆ SIMS measurements

SIMS profiles of both type-implanted samples agree with the TRIM simulations except the channeled part [Figure 2&3]. For the 25°C-implanted samples there is a lightly stronger channeling effect. After annealing a fluence of more than  $1.6 \times 10^{15} \text{ cm}^{-2}$  is found for the RT and 300°C-implanted samples, which denotes no dopant losing by silicon carbide etching or Al exodiffusion and no layer deposited on implanted surface, in the species and thickness ranges detectable by SIMS. These values compared to other furnace configurations, with other sample ambients, show a clear improvement of our annealing.

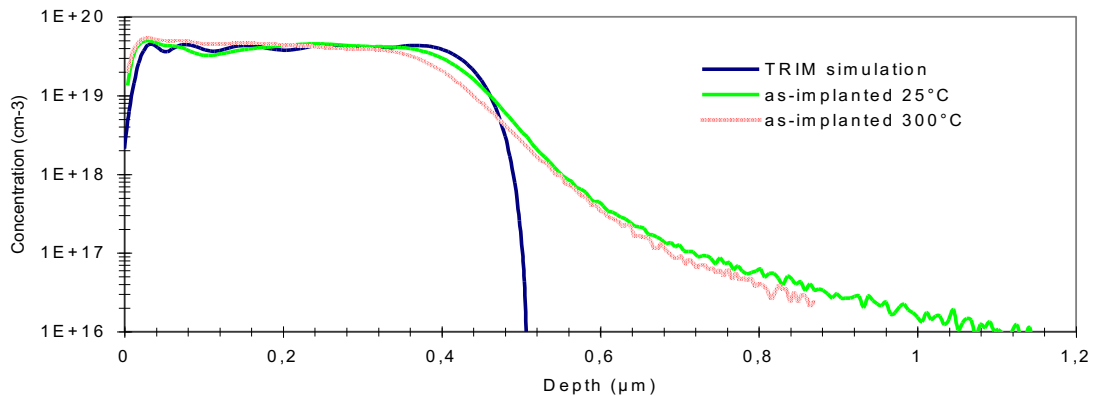


Fig.2 Impurity SIMS profiles before annealing

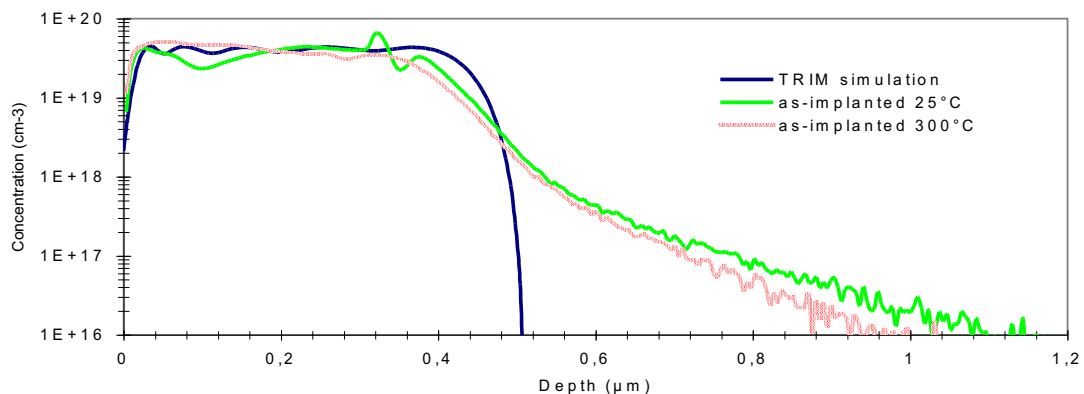


Fig.3 Impurity SIMS profiles after annealing

We can notice that in the case of 300°C-implanted samples a box profile at  $4 \times 10^{19} \text{ cm}^{-3}$  is found, like for the as-implanted sample, in contrast with the RT-implanted sample profile where we have some dopant peaks due to the stabilization of Al atoms on end-of-range defects. These defects appear when an amorphous layer is formed. They are localized below the amorphous/crystalline interface and are produced by the coalescence of interstitial impurities into small diameter dislocation loops during the annealing [5].

### ◆ Sheet resistance measurements

A four point probe technique at 25°C was used to measure the sheet resistance of Al p-implanted layers, in order to determine the electrical active center density. Before four point measurements, 40 nm of the SiC implanted layer was removed from surface by a reactive ion etching (RIE) in  $\text{SF}_6/\text{O}_2$  plasma, to contact the Al box profile.

For the RT-implanted samples, the measured acceptor activation (incorporation of Al in SiC lattice sites) is in the 35%-46% range, and for the samples implanted at 300°C we find a higher activation between 48% and 99%. An ionization coefficient of 0.9% for Al dopant and a mobility of  $40 \text{ cm}^2/\text{V/s}$  for hall carriers have been undertaken.

We can remark disparities in the electrical activation results probably due to the measurements method, the little size of our samples and surface non uniformity. Nevertheless, satisfactory electrical results were obtained, in agreement with SiC microstructure post-annealing quality noticed by physico-chemical analyses.

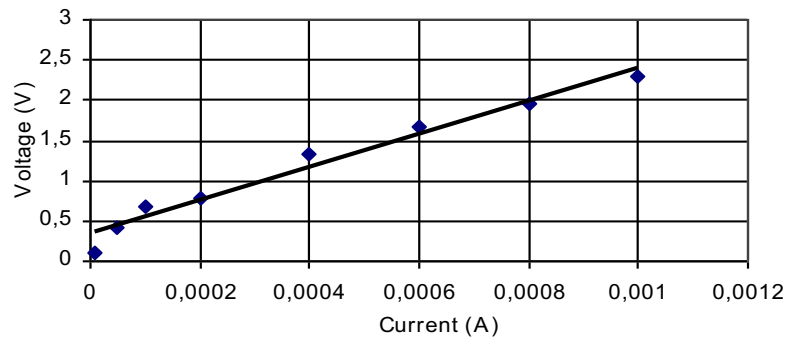


Fig.4 Four point measurements data for a 300°C-implanted sample,  $R_{\square}=9.3 \text{ k}\Omega$  which corresponds to 99% electrical activation

### Conclusion

RBS/C measurements reveal that the virgin level is attained after annealing for both RT and 300°C-implanted samples. No great surface carbonization, deposited layer or dopant losing are found. Elevated implantation temperatures produce higher dopant electrical activation, but the values for RT-implantations are not negligible in the perspective of industrial applications. Additional and various electrical investigations will be carried out on p<sup>+</sup>-n diodes and Hall effect devices, which are in fabrication process.

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