High Electrical Activation of Aluminium and Nitrogen Implanted in 6H-SiC at Room Temperature by RF Annealing

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Abstract. Al and N implantations were carried out in 6H-SiC n-type epitaxial layers at room temperature. RBS/C analysis confirms the presence of an amorphous layer up to the surface in the as-implanted samples. The samples rf-annealed at 1700°C during 30 mn with a preliminary 40°C per second heating slope are recrystallised in RBS/C analysis terms. SIMS measurements show no dopant loosing after the annealing and dopant profile distributions are in agreement with CNM Monte-Carlo simulation. A good surface stoichiometry is revealed by XPS after annealing but AFM surface measurements reveal a relatively high rms roughness (14 nm) on annealed samples. High electrical activation of dopants was found, 19 kΩ/□ sheet resistance, which corresponds to 50 % electrical dopant activation for Al implanted layer, and 6.7 kΩ/□ sheet resistance and 100% electrical activation for N-implanted layer.

Introduction

Ion implantation in SiC, an indispensable technique for the p-n junction creation, due to very weak dopant diffusion coefficients, generates an important density of defects which involve high temperature annealing and particular conditions on ramp temperatures and environment partial pressures. High temperature and/or high energy ion implantations were used to reduce the material damage [1-4], however, these implant conditions remain not interesting in an immediate perspective of industrial applications. In this paper we present room temperature (RT) aluminium (Al) and nitrogen (N) ion implanted and rf-annealed samples with viable physico-chemical and electrical properties.

Experiment

Aluminium implantations were performed at RT in 6H-SiC n-type epitaxial layer samples purchased from Cree Research ($3x10^{15}cm^{-3}$ epitaxial doping) with energies ranging from 25 up to 300 keV and 100 to 400 keV with a total dose of $1.75x10^{15}cm^{-2}$ and $1x10^{15}cm^{-2}$ respectively. A thin aluminium mask (1500 Å) was used for the second implant series to avoid the channeling of Al ions, a major effect in 6H-SiC. Nitrogen was implanted in similar SiC samples at RT with energies ranging from 30 to 190 keV and a $1x10^{13}$ cm^{-2} total dose, following an Al 350 keV high dose implantation in order to realise a n-p junction in surface.

All these samples were annealed at 1700°C during 30 mn with a preliminary heating slope of 40°C/s in argon atmosphere with a silicon carbide partial pressure, in a J.I.P.ELEC™ rf-induction heating furnace. The decreasing of the temperature at the end of the annealing is governed by thermal inertia.

SiC annealing in a rf induction furnace presents important advantages such as very high heating slope. This can allow the recrystallization of amorphised layers. Specially 4H and 6H-SiC samples need a very high heating slope in temperature to preserve the polytype from cubic inclusions, which may be generated during the solid phase epitaxy at too low temperature [5,6].

An inhomogeneous temperature in the heated wafer support is a drawback of the induction technique. Lateral and vertical thermal variations can induce SiC etching if appropriate environments and configurations rich in silicon and carbon are not provided. Silicon volatilizes at temperatures above 1300°C at one atmosphere pressure [3].

Dopant distributions before and after annealing have been investigated by Secondary Ion Mass Spectroscopy (SIMS) measurements, and have been compared to CNM-Monte Carlo simulations [7] of Al implantations in 6H-SiC. Damage induced in materials and recrystallization have been analyzed by Rutherford Backscattering Spectrometry in the Channeling mode (RBS/C). Concerning the surface its stoichiometry has been examined by X-Ray Photoelectron Spectroscopy (XPS) and its roughness by Atomic Force Microscopy (AFM). Finally electrical activation of dopants, i.e. incorporation of Al and N in substitutional SiC lattice sites, has been evaluated by sheet resistance measurements with a four point probe technique at RT.

Results

SIMS measurements

In order to examine the dopant profile distribution, CNM Monte-Carlo simulations were carried out as well as SIMS analyses before and after rf-annealing (Figure 1). The CNM Monte-Carlo simulation of Al ions implanted in 6H-SiC allows us to quantify the point defect generation and their effects in impurities distribution after annealing. We remark a good agreement between simulation and SIMS before annealing measurements

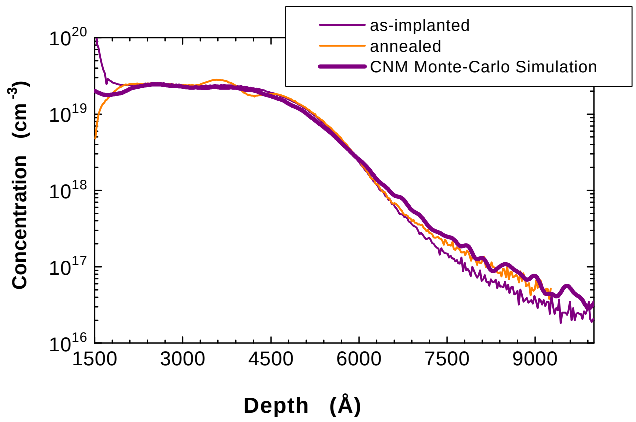

Fig1. *CNM Monte-Carlo simulation and SIMS analysis for the 100 to 400 keV Al-implanted layer*

SIMS profiles after annealing are not flat, Al dopant peaks are formed in high defect concentration zones due to an amorphous layer formation (Al peak at 3580 Å depth in Figure 1). We notice no dopant loosing after annealing.

RBS/Channeling measurements

Residual damage before and after annealing, SiC recrystallisation were evaluated by RBS/C technique. RBS spectra before and after annealing have been compared to a complete disoriented analyzed sample (amorphous) and a not implanted one (virgin). RBS/C analyses confirm the presence of an amorphous layer up to the surface in the implanted samples. Despite that, after a rf-annealing a satisfactory recrystallisation is found, the backscattering yield for the 1700°C/30 mn nearly coincides to the virgin one.

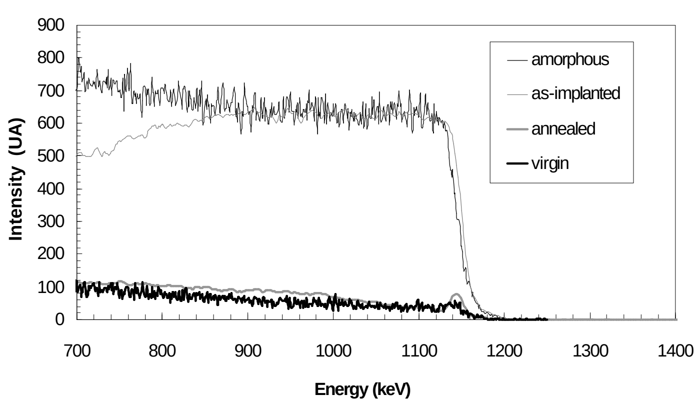

Fig2. *RBS/C measurements for the 25 to 300keV Al implanted samples before and after annealing*

To understand silicon carbide recrystallisation in RBS/C terms the heating slope during annealing was varied from 10°C per second to 40°C per second for samples implanted with the same dose or higher (18 times). RBS/C analyses showed that the layer remains amorphous in this latter case, and there is no influence of the heating slope on recrystallisation rate. It is possible, that there are at least two amorphous states depending on the implantation dose. Above a given deposited nuclear energy threshold, the layer may loose all bulk crystallinity information, and epitaxial recrystallisation may then become impossible even in optimized annealing conditions.

Surface analyses

A good surface stoichiometry is obtained by XPS after annealing. In Table 1 are presented the atomic ratio [Si/C] in surface and after thin layers Ar^+ sputtering. The thickness values correspond to a silica reference material. Two samples have been analyzed. Sample (A) placed in the suscepteur during annealing and sample (B) at the periphery. We remark that the surface of the sample (B) shows a carbonic layer deposited probably due to a lateral temperature gradient evaluated to be about 50°C.

	Depth (Å)	% C	% O	% Si	Si/C
Sample A	*surface*	*44.4*	*16.0*	*39.6*	*0.89*
	10	*46.6*	*4.6*	*48.8*	*1.04*
	70	*48.3*	*2.1*	*49.6*	*1.03*
Sample B	*surface*	*84.3*	*3.6*	*12.1*	*0.14*
	10	*75.8*	*0.8*	*23.4*	*0.31*
	70	*56.2*	*1.6*	*42.2*	*0.75*
	200	*51.6*	*2.0*	*46.4*	*0.9*

Table 1 *Atomic ratio determined by XPS for two samples annealed in the center (A) and the periphery of the suscepteur (B).*

C_{1s} XPS energetic shifts are more related to a deposited layer rich in C-C/C-H bonds than a Si volatilization process. At 20 nm depth, sample B looks like sample A.

AFM surface measurements reveal a relatively high rms roughness (14nm) on annealed samples. Many samples have been analyzed to discern if either the recrystallization of the amorphized layer or either the rf-annealing is responsible for this roughness. For the virgin sample (Figure 3) a rms roughness of 0.31 nm before annealing denotes a good initial surface quality.

After annealing we found very close values: 13.5 nm rms roughness for the virgin annealed and 14.4 nm rms roughness for the 100 to 400 keV Al implanted and annealed sample. Surface morphologies are nearly similar, the annealed virgin sample presents furrows much more parallel which is normal seeing the initial surface before the annealing of the implanted sample. These results are completely different, compared to an anneal in a resistive heating furnace with very similar time

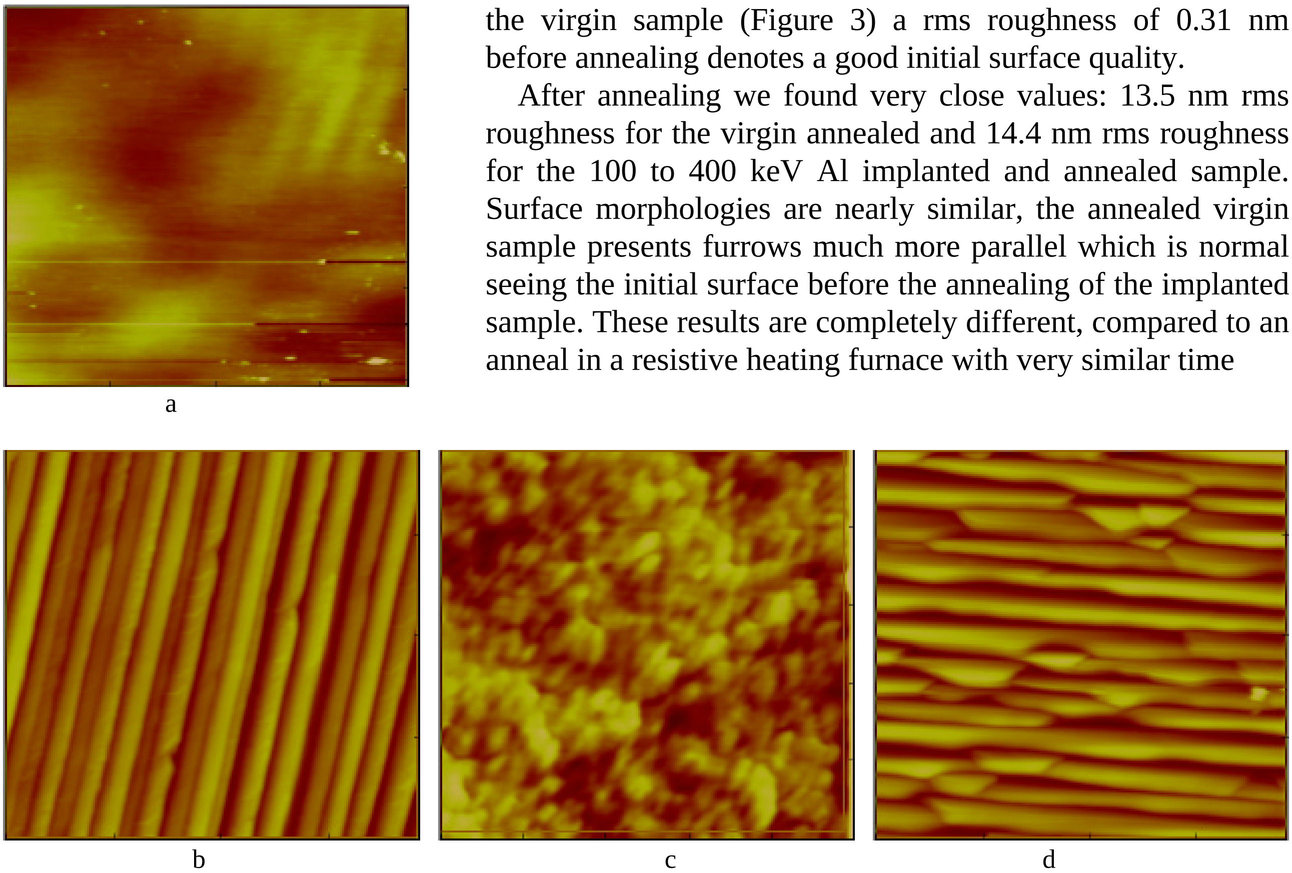

Fig3. *Atomic force micrographs of (a) a virgin sample, (b) a virgin sample 1700°C/30 mn rf-annealed, (c) Al as-implanted sample and (d) Al implanted and 1700°C/30 mn rf-annealed sample. Edge length of images correspond to 5µm for non annealed samples and 19µm for annealed ones.*

and temperature parameters (1700°C / 40 min) [8]. In these experiments indeed, the implantation step was responsible for an increase of the surface roughness.

Electrical measurements

Sheet resistance measurements by a RT four point probe technique on Al and N implanted and rf-annealed samples prove a high electrical dopant activation for RT implanted samples, in terms of Al and N incorporation in SiC lattice sites (Si and C respectively). For Al-implanted samples a 19 kΩ/□ sheet resistance at 300K has been found which corresponds to an electrical dopant activation of 50%. Better results are found for N-implanted samples (Figure 4): 6.7 kΩ/□ sheet resistance and 100% electrical dopant activation.

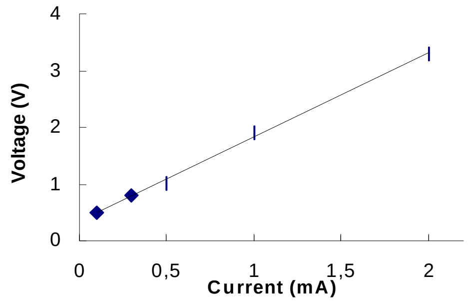

Fig4. *Sheet resistance measurements at 300K on a RT N-implanted layer*

Conclusion

Al and N room temperature implantations were realized in 6H-SiC. Rf-annealing at 1700°C during 30 mn in a special silicon and carbon rich configuration performs satisfactory physico-chemical properties. Amorphous layers are recrystalized, dopants are not loosed during the heating process. If a good stoichiometry are obtained in surface a relatively high roughness is created at 1700°C. Reasonable electrical properties are attained, 50% activation for Al implanted dopants and 100% for N.

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References

[1] T. Troffer, M. Shadt, T. Frank, H. Itoh, G. Pensl, J. Heindl, H.P. Strunk and M. Maier: Phys. Stat. Sol. (a) 162 (1997), 277.

[2] M. Lazar, L. Ottaviani, M.L. Locatelli, D. Planson, B. Canut and J.P. Chante: Mater. Sci. Forum 338-342 (1999), 921.

[3] M.Ghezzo, M.Brawn, E.Downey, J.Kretchmer, W.Hennessy, D.L. Polla and H.Bakhru: IEEE Electron Device Letters, 13 (1992), 639.

[4] O. Takemura, T. Kimoto, H. Matsunami, T. Nakata, M. Watanabe, M. Inoue: Mater. Sci. Forum 264-268 (1998), 701.

[5] J.Pezoldt, A.A. Kalnin, D.R. Moskwina and W.D. Savelyev:: Nuclear Instruments and Methods in Physics Research B80/81 (1993), 943.

[6] Ye.N. Potapov and F. Neubert, Prikl. Vopr. Fiz. Tverd. Tela 1 (1987), 88.

[7] E.Morvan, P. Godignon, J. Montserrat, J. Fernandez, D. Flores, J. Milan and J.P. Chante: Mater. Sci. Engin. B46 (1997), 218

[8] M.A. Capano, S. Ryu, M.R. Meloch, J.A. Cooper, JR., and M.R. Buss: J. Electron. Mater., 27, 4 (1998), 370.

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