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Shuttle Activation Annealing of Implanted Al in 4H-SiC

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Introduction

SiC is an attractive material for high power, high temperature, and high frequency switching devices because of its superior properties such as wide band gap, high breakdown field, high thermal conductivity and high saturation drift electron velocity[1]. Extensive research on SiC devices has been conducted to date[2,3,4]. However, there still remain several problems to realize practical SiC devices. On selective area impurity doping for fabricating devices on SiC, an ion implantation and a subsequent high temperature annealing are indispensable, because of its small impurity diffusion coefficient[5]. Especially, cure of implantation damage is one of the most serious subjects to realize the reliable device process for the actual application[6,7].

For activation of implanted impurities in SiC crystal, the implanted wafers need to be heated at high temperatures more than 1,600˚C[8]. The conventional activation annealing is carried out by the inductively heated carbon crucible containing wafers in inert Ar gas or vacuum[9]. However, it takes several hours for the process cycle, and the surface of wafers becomes rough during the process. In order to establish the high throughput annealing process, several techniques have been tried, such as flash lamp heating[10], electron beam heating[11], or laser heating[12]. In this paper, we investigate the shuttle annealing process as a possible high-throughput technique, and examine activation and surface roughness of the Al-implanted 4H-SiC under various annealing conditions, including RTA process.

Shuttle type Annealing system

Figure 1 shows the schematic diagram of the cross sectional view of the shuttle type annealing system. A quartz-rod-supported carbon holder carries implanted wafers (up to Φ4") to the furnace heated at around 1,700˚C, stays for fixed annealing time, and carries it back. The furnace temperature and the carbon holder temperature are monitored directly by radiation sensors. Figure 2 shows monitored temperature during RTA and thermally equilibrium annealing (TEA) using the system. With specially designed our carbon holder, it takes 8sec. to increase the holder temperature from 1,500˚C to 1,700˚C, and 12sec. to decrease the temperature from 1,700˚C to 1,500˚C. The recorded temperature demonstrates that ~1sec. RTA at 1,700˚C is possible using the system.

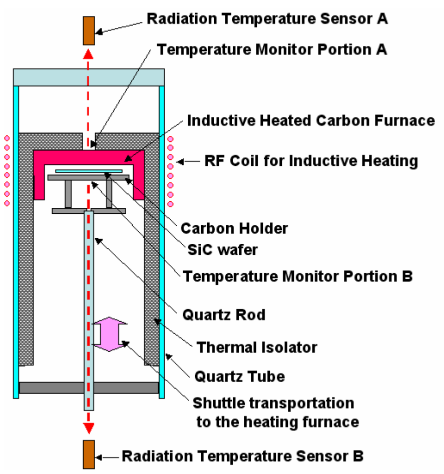

Fig. 1 Schematic diagram of shuttle type annealing system.

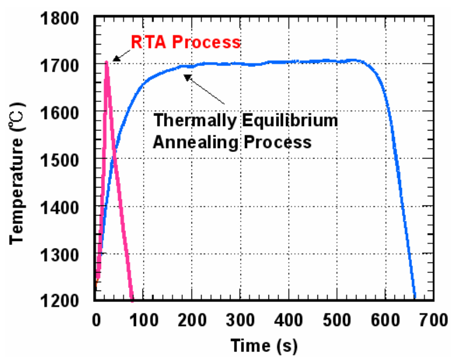

Fig. 2 Holder temperature during shuttle annealing.

Activation annealing of Al implanted 4H-SiC

P type Al doping is a key process for SiC power MOSFETs. We examined the shuttle annealing of 4H-SiC implanted with Al. Concentration of the multi-step-implanted Al was about 2×10^{18} cm^{-3} and the depth was about 0.8μm. Figure 3 shows the annealing temperature dependence of Na-Nd obtained from C-V measurement and acceptor activation ratio calculated by (Na-Nd)/2×10^{18}. Circles show the TEA results of several annealing time, and triangles RTA results of 1 sec. annealing. This indicates the critical temperature for implanted Al activation is 1700˚C. Activation ratio strongly depends on the annealing temperature and time for annealing at temperatures lower than 1700˚C. On the other hand, for annealing conditions at temperatures higher than 1700˚C, the activation ratio becomes around 85% irrespective of the length of annealing time.

Figure 4 shows the annealing temperature dependence of sheet resistance of Al-implanted p type region measured at room temperature. Circles and triangles present the 10min. TEA results and the 1sec. RTA results. From Hall measurement, the hole concentration is only 1.0~2.3 % of Na-Nd, indicating the existence of high concentration deep levels. Even with the similar level of Al activation, there is a significant difference between RTA and TEA. This discrepancy indicates the existence of hole traps in the annealed materials and the trap density depends on the annealing time.

Surface roughness after annealing of TEA of 1700˚C,10min. and RTA of 1800˚C,1sec. was inspected by AFM as shown in Fig. 5. TEA processed surface(A) shows the obvious step bunching with r.m.s. 10-25nm. On the other hand, RTA processed surface(B) is very smooth and the r.m.s. is less than 5nm. The surface decomposition proceeds during the 10min. TEA and the surface becomes rough.

The acceptor activation uniformity in Φ2" wafer was inspected at 13 points by C-V measurement. The averaged activation ratio is 80.2% with 1.6% standard deviation. For larger wafer process, the carbon wafer holder and the heating procedure should be optimized to achieve the uniform annealing results.

Conclusion

As a result of the comparison between RTA and TEA process using the same shuttle annealing system, more hole traps may remain after RTA process compared to TEA process, although the RTA process is very effective to reduce the surface roughness. Mechanism of generation and extinction of deep levels in the implanted region during the annealing process needs to be cleared for further improvement of the annealing process.

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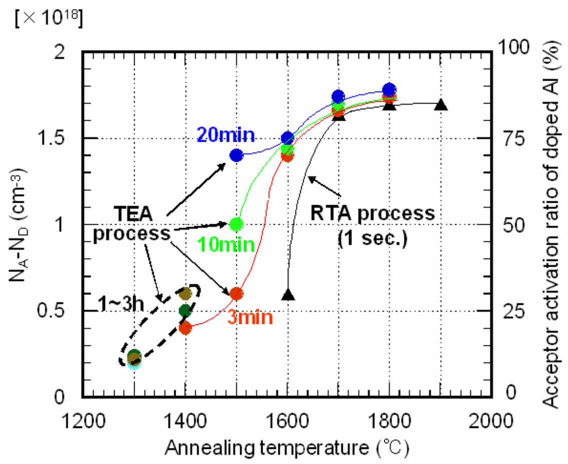


Fig. 3 Temperature dependence of acceptor activation of Al in 4H-SiC by RTA and thermally equilibrium annealing (TEA).

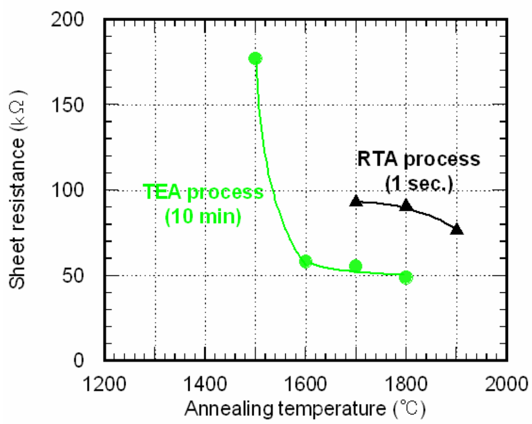
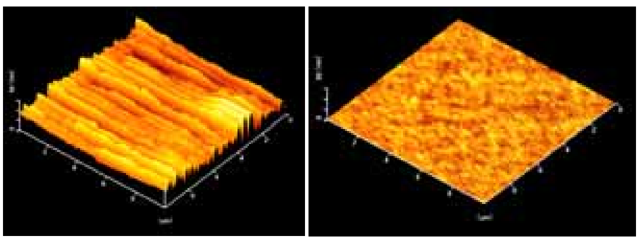


Fig. 4 Temperature dependence of sheet resistance of Al-implanted p type region.



(A) TEA (1,700,10min.) r.m.s.:10~25nm (B) RTA (1,800,1sec.) r.m.s.:<5nm

Fig. 5 AFM inspection of annealed surface of (A) TEA (1,700˚C ,10min.), and (B) RTA (1800˚C ,1sec.).