Ion implanter and Activation Annealing for SiC devices

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***Abstract*—Ion implanter process for SiC devices needs much longer time compared with Si process. Therefore implantation process optimization is important to reduce cost. In this paper, implantation temperature that affects process time is discussed. And activation conditions after implantation is also discussed.**

Keywords—box profile, high temperature implantation, room temperature implantation, activation annealing, capping

I. INTRODUCTION

Ion implantation process time for SiC devices is long, because it needs several times implantation to create box-profile due to dopant hardly move even if activation annealing.

Figure 1. is the 300nm depth box-profile. To get this profile, Four(4) times Al+ implantations are carried out at the beam energy 30keV, 70keV, 150keV and 300keV respectively (Table 1.). Figure 2. is the SIMS profile after activation annealing, it shows SIMS profile does not be affected by the annealing temperature so much, it means implanted dopants hardly move in SiC.

In order to optimize implantation temperature, fundamental experimental results are discussed.

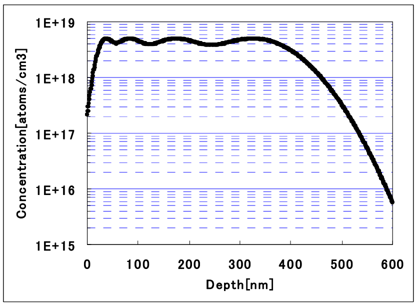

Fig. 1. Depth profile of implanted Al

Table1. Al doping condition (Doping level 5E18/cm^3)

Energy (keV)	Dose (atoms/cm^2)
300	9.28E13
150	5.29E13
70	2.74E13
30	1.23E13

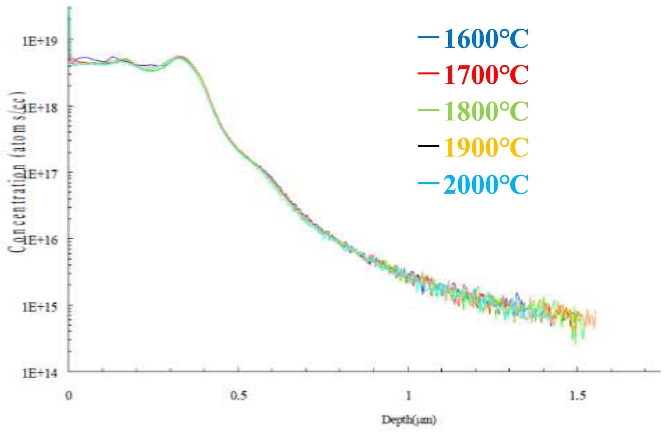

Fig. 2. SIMS depth profile of Al after 3minute annealing

After ion implantation, activation annealing is carried out. Annealing conditions are also important for device characteristics. So the annealing temperature and time dependency is also evaluated.

II. IMPLANTATION TEMPERATURE

Mr. Watanabe et al., investigated the effects of implantation temperature on electrical properties of heavily Al-doped 4H-SiC layer formed with Al implantation [1]. The multi-step-implanted Al had a box profile with a concentration of about 2E20/cm^3. They said that the implantation temperature above 175deg.C. is needed.

This implies the possibility of reducing the implantation temperature to about 200-250deg.C. from 500deg.C. Therefore ion implanters are required to operate these temperature range. Ion implanter throughput improves with a decrease of implantation temperature. Because wafer pre-heating time is also can be decreased.

We investigated the implantation temperature dependence at the Al concentration 5E18 cm^{-3} and 2E20 cm^{-3} respectively.

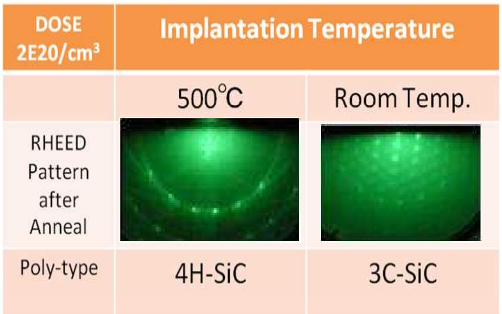

Fig. 2. Implantation temperature dependency at Al concentration 2E20/cm^3

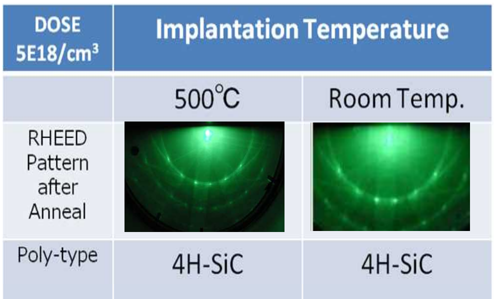

Fig. 3. Implantation temperature dependence at a Al concentration 5E18/cm^3

4H-SiC epiwafers were used. Fig. 2, Al concentration 2E20/cm^3, shows amorphous layer (3C poly-type) after annealing in RHEED pattern at the room temperature implantation condition. It means that high temperature implantation is necessary at the relatively high Al concentration.

Fig.3, Al concentration 5E18/cm^3, shows 4H poly-type after annealing in RHEED pattern at the even room temperature implantation.

Fig. 4. Implantation temperature dependency at Al concentration 2E20/cm^3

Fig. 4 is the more detail results for implantation temperature dependency. If temperature is room temperature or 200deg.C., 3C poly-type were observed. So, it shows more than 200 deg.C. implantation temperature is necessary at least.

Summary is following based on these results above.

(1) High temperature is necessary at the Al concentration is 2E20/cm^3 (Relatively high dose).
(2) Room temperature implantation is possible at the Al concentration is 5E18/cm^3 (Relatively low dose).
(3) 200-250deg.C. not 500 deg.C. may be possible for high temperature implantation.
(4) Room temperature implantation or reducing implantation temperature have benefits of improving throughput.

On the other hand, the device electrical properties improvement is reported when implantation temperature is increased to 600deg.C. [2].

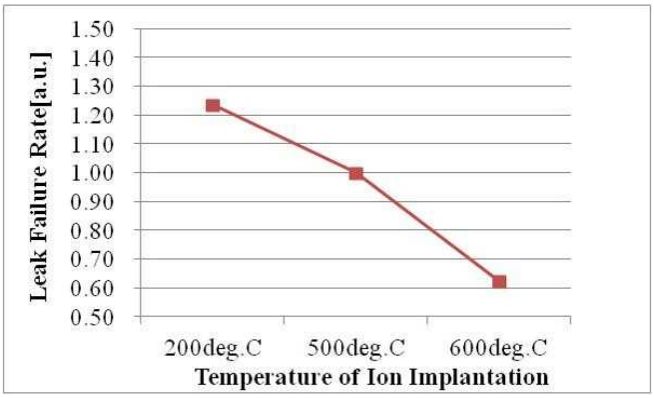

Fig. 5. The leak failure rate of the PN diodes which were annealed at 1600deg.C. The leak failure rate is normalized with that using PN diodes prepared with 500deg.C. ion implantation. [2].

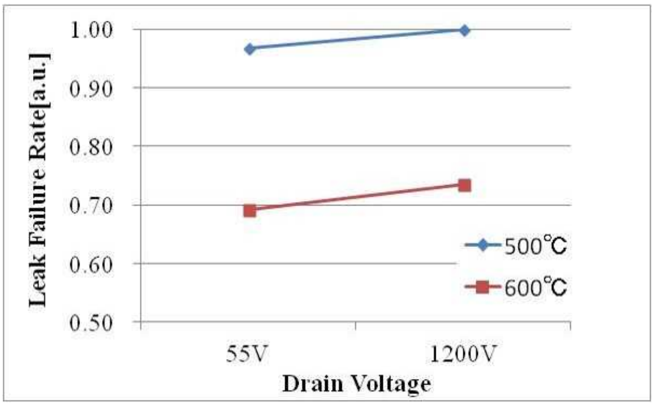

Fig. 6. The leak failure rate of the IEMOS which was fabricated by ion implantation at 500deg.C. (Blue line) and 600deg.C. (Red line). The leak failure is normalized with that measured at 1200V using IEMOSs prepared with 500deg.C. [2].

III. ACTIVATION ANNEALING

Activation annealing after ion implantation is important, because high annealing temperature causes SiC surface's roughness that leads to deterioration of the electrical characteristics.

We investigated the surface roughness dependency on annealing temperature and time. We also compared the difference between carbon cap and photo resist cap as a protect film during annealing.

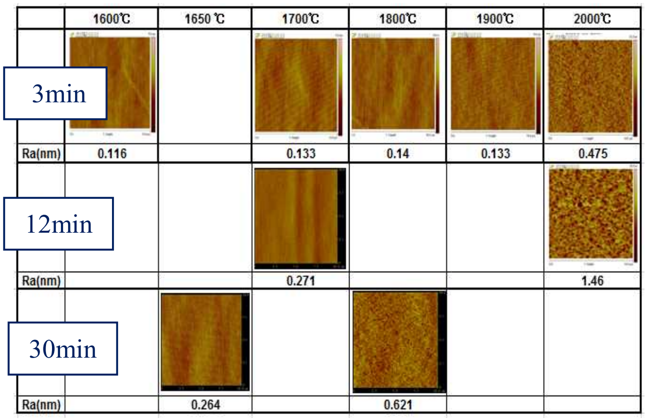

Fig. 7. Surface roughness dependency on annealing temperature and time (STM image)

Fig. 7 shows the surface roughness deteriorates with the increase of annealing temperature and time.

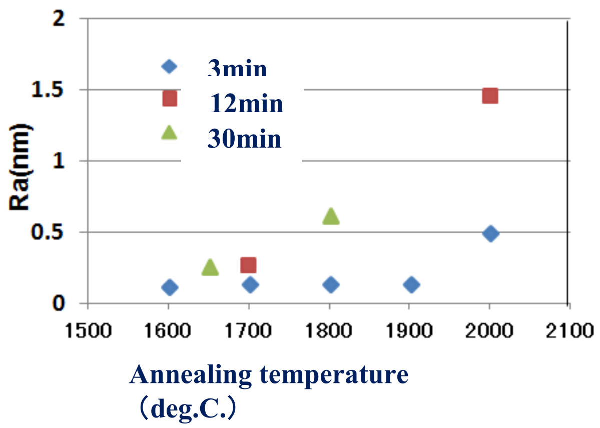

Fig. 8. Surface roughness dependency on annealing temperature and time

The surface roughness in Fig. 8 is described by Ra (nm). It shows that the annealing time less than three(3) minutes, less than twelve(12) minutes, and less than thirty (30) minutes are necessary at the annealing temperature 1900 deg.C., 1700 deg.C., and 1650 deg.C. respectively.

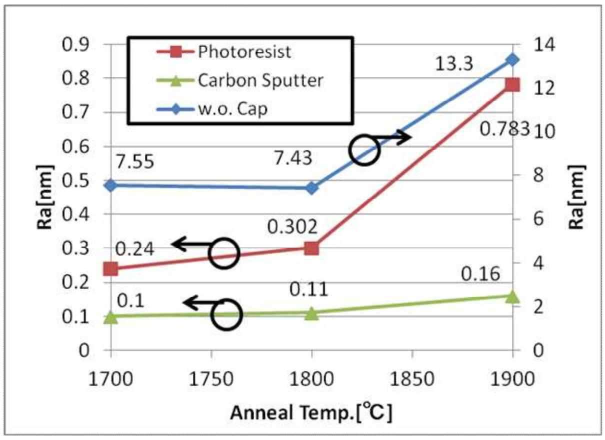

Fig. 9. The comparison between carbon cap and photo resist cap as annealing protection film

Fig. 9 shows

(1) The roughness using carbon cap is better than photo resist cap.

(2) Especially if annealing temperature exceeds more than 1800 deg.C., the surface using photo resist deteriorates seriously.

(3) If no use of protection film, the roughness is about ten times than using protection film. (See blue line and the scale is right side.)

IV. SUMMARY

The implantation temperature conditions for SiC devices are discussed. To improve throughput for implantation process, it is important to optimize the implantation temperature.

Activation conditions after implantation is also discussed.

ACKNOWLEDGMENT

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