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Kinetics of Boron Activation by Flash Lamp Annealing

K. Yamashita, M. Noguchi, H. Nishimori, T. Ida, M. Yoshioka[1], T. Kusuda[2], T. Arikado and K. Okumura[3]

Semiconductor Leading Edge Technologies, Inc.
16-1, Onogawa, Tsukuba, Ibaraki 305-8569, Japan,
phone:+81-29-849-1659, fax:+81-29-849-1185 yamashita3@selete.co.jp
[1]Research and Development Center, Lamp Company, Ushio Inc.
[2]Research and Development Center, Dainippon Screen MFG. Co. Ltd.
[3]Research Center for Advanced Science and Technology, The University of Tokyo

1. Introduction

A thermal budget reduction is essential not only to make an ultra shallow junction, but also to suppress an interfacial reaction of a high-k film with an underlying SiO_2 during the activation. There are two approaches: to lower the temperature and to shorter the heating time.

A flash lamp annealing (FLA) is one of the promising technologies to accomplish the ultra rapid thermal process [1-3]. However, ultra rapid heating up (>10^5 ℃/sec) and cooling down (>10^3 ℃/sec) induce stress that could generate defects in a wafer. In the worst case, a wafer breaks down.

We have examined the relation between the energy density supplied by flash lamps, dopants activation, and defects generation. This paper reports the kinetics of an activation of boron and a recrystallization.

2. Experimental

The experimental apparatus has a similar structure to that previously reported [1], except for a wafer size of 300 mm. The pulse width (FWHM in a flash pulse) was changed between 0.55 and 0.9 msec. The peak power of the flash was controlled by a capacitor charging voltage. The irradiation energy was measured by a calorie meter. The substrate was pre-heated at 300-400℃, prior to flash lamp irradiation.

3. Results and Discussion

3.1. Activation of boron

Fig. 1 shows the variation in sheet resistances as a function of irradiation energy density with the pulse width as a parameter. The pre-heating temperature of FLA is 400℃. The ion implantation conditions are BF_2^+ 40keV and dose of $5\times10^{15}cm^{-2}$. The sheet resistances drastically decrease with increasing the energy density. Since any traces suggesting melting on the patterned wafer are not observed within this experimental condition, the ultimate temperature must be under 1420℃. Comparing the sheet resistance at the same energy density, a shorter flash pulse gives a lower sheet resistance.

A flash lamp irradiates the white light, which contains various wavelengths, through a discharge of capacitors. The ultimate surface temperature of Si is given by the following equation [4],

$$T_s - T_0 = \frac{K \cdot J}{\sqrt{\pi}\sqrt{D\tau}} \qquad (1)$$

where notations are as follows: Ts = ultimate surface temperature, T_0 = pre-heating temperature, K = a constant, J = energy density, D = a heat diffusion constant, τ = a pulse width. As shown in equation (1), a shorter pulse gives a higher temperature if the energy density J is constant. This is due to the characteristics that the peak power becomes higher with decreasing the pulse width, as schematically illustrated in Fig. 2. Table 1 summarizes the charging voltage, which gives the energy density of 21 J/cm^2 as an example. It is evident that the charging voltage becomes higher with decreasing width. The higher charging voltage gives a higher discharging current, leading to irradiation with a higher intensity.

Fig. 3 shows the variation in sheet resistances as a function of irradiation energy density with the pulse width as a parameter. The pre-heating temperature of FLA is 350℃. The ion implantation conditions are B^+ 800eV and dose of $1\times10^{15}cm^{-2,}$ with Ge^+ pre-amorphization implantation (PAI) 2keV and dose of $5\times10^{14}cm^{-2}$. Comparing the sheet resistances at the same energy density, the shorter pulse width gives the lower resistance as the same case as BF_2 without Ge PAI. The distribution of the sheet resistances, in the case of 0.8 msec in Fig. 3, is accomplished uniformly within a 300 mm wafer as shown in Fig. 4.

Fig. 5 shows the cross-sectional TEM photograph after FLA. The pre-heating temperature of FLA is 400℃, the energy density is 27.8 J/cm^2, and the pulse width is 0.8 msec. The ion implantation condition is the same as in Fig. 3. The amorphous layer made by Ge PAI has recrystallized completely, when the boron in Si is sufficiently activated. However, defects still remain in the position of about 10 nm from the substrate surface. These results suggest that the recovery of defects requires not only a surface temperature, but also a certain level of time, although the activation is a momentary phenomenon that strongly depends on an ultimate temperature.

3.2. Junction Leakage

Fig. 6 shows that there is P^+ junction leakage current after some FLA. The ion implantation conditions are BF_2^+ 20keV and dose of $3\times10^{15}cm^{-2}$. The area of the junction is 0.25 mm^2 and the peripheral length is 11 mm. These leakage currents of FLA are about one order larger than that of the spike annealing. Significant differences between these results of FLA are not seen in this experiment range. Since there is no peripheral length dependence, the

leakage current is mainly caused through the plane region of the vicinity of the junction. The insufficient recovery of defects induces a relatively large leakage current. The further optimization of the pulse width and energy density is expected to recovery the defects successfully.

4. Conclusion

Using a flash lamp technology, the activation of boron with and without Ge PAI is accomplished uniformly within a 300 mm wafer. By changing the pulse width, it is found that the activation was greatly dependent on the peak power determining an ultimate surface temperature, rather than the irradiation energy density of a flash pulse. However, a certain level of time is required in order to recover the defects that cause leakage current. Optimizing the pulse width and the energy density is expected to recovery the defects successfully.

References

[1] T. Ito, *et.al.*, *Extended Abstract of SSDM 2001*, (2001) pp. 187-188

[2] T. Ito, *et.al.*, *Jpn. J. Appl. Phys. 41*, (2002) pp. 2394-2398

[3] A. Mokhberi, *et.al.*, *Technical Digest of IEDM 2002*, (2002) pp. 879-880

[4] H. S. Carslaw and J. C. Jaeger, *Conduction of Heat in Solids*, Oxford at the Clarendon Press

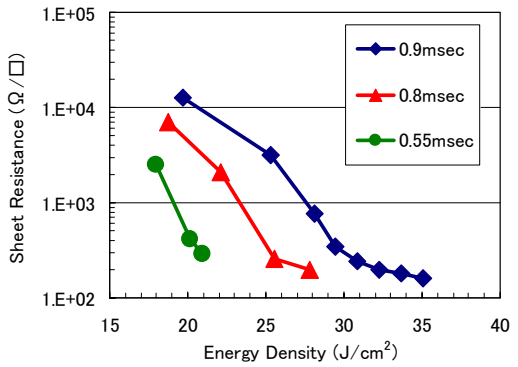

Fig. 1 Variation in sheet resistances of BF2 as a function of irradiation energy density.

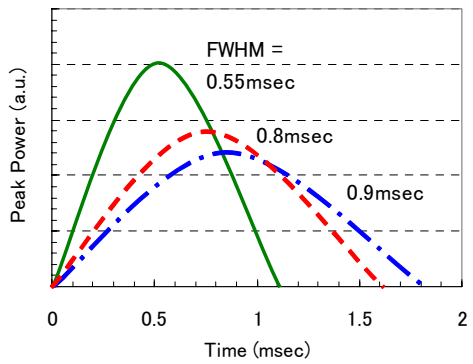

Fig. 2 Schematic illustration of the relation of the peak power and the pulse width under a constant energy density.

Table 1 Charging voltage of 21 J/cm^2 energy density.

Pulse Width (msec)	0.55	0.8	0.9
Charging Voltage (V)	4400	3200	2800

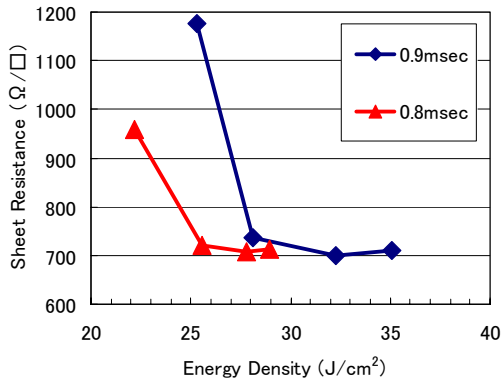

Fig. 3 Variation in sheet resistances of B with Ge PAI as a function of irradiation energy density.

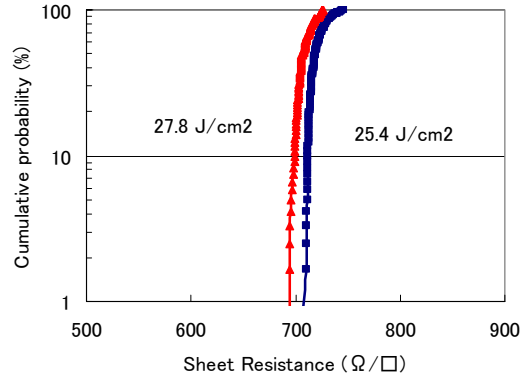

Fig. 4 Distribution of sheet resistance of B with Ge PAI.

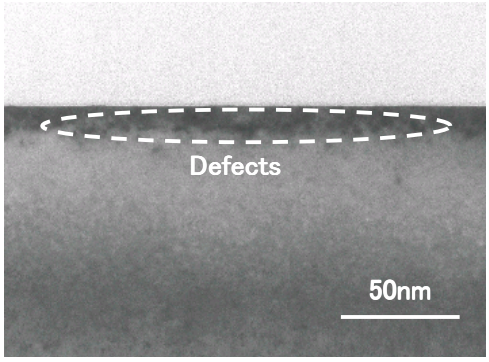

Fig. 5 Cross-sectional TEM photograph of B with Ge PAI.

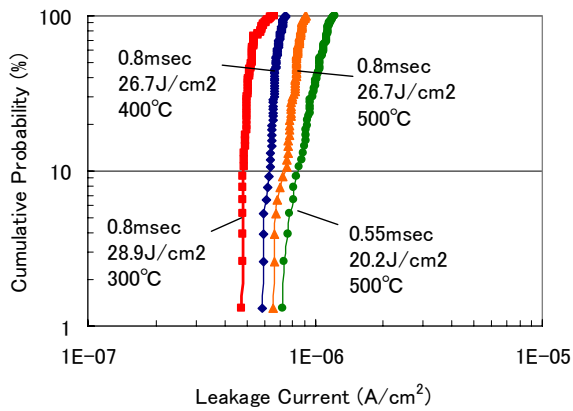

Fig. 6 P^+ Junction Leakage Current after FLA.