Low-Resistive and Low Leak Current Ultra-Shallow n^+/p Junction Formed by Heat-Assisted Excimer Laser Annealing

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1. Introduction

Low-resistive ultra-shallow junctions with well-controlled dopant profile and low leak current is required at source/drain extension to improve performance of MOSFETs [1]. Conventional RTA has the difficulty to keep the dopant profiles due to TED [2]. We have reported heat-assisted laser annealing (LA) technique, which can reduce laser irradiation energy density (E_L) as keeping low sheet resistance (R_s) [3, 4].

In this paper, effects of E_L to R_s and I-V characteristics were studied. The role of substrate temperature (T_{sub}) was also discussed.

2. Experimental

Ion implantation (Sb^+, 10 keV, 6×10^{14}cm^{-2}) was carried out into p-type Si (100) substrates through a 5-nm-thick screen oxide. The X_j as implanted was 21 nm (1×10^{18}cm^{-3} of Sb concentration). XTEM images indicate that the a-Si layer by the implantation was 11 nm.

T_{sub} is 250 to 525°C and RT in N_2 atmosphere. Heating procedure is shown in Fig.1. KrF excimer laser (□ ≈ 248 nm) was used for irradiation. The E_L was varied in the range of 200 to 600 mJ/cm^2, laser pulse number was 1 to 100, and FWHM of the pulse was 38 ns. Diodes with n^+/p junctions were fabricated. Carrier concentration of p-region is 2×10^{17} cm^{-3}. I-V curve for reverse direction was measured.

3. Results and Discussion

Figure 2 shows Sb depth profiles before and after the heat assisted LA (1 pulse) at T_{sub} of 450°C. The same profile as implanted was obtained when only the Si substrate was heated. (1) E_L = 300 mJ/cm^2: the profile retained almost the same profile as implanted, while weak pileup of Sb was observed. (2) E_L = 400 mJ/cm^2: strong pileup into the SiO_2/Si interface occurred within the a-Si layer as implanted. (3) E_L = 500 mJ/cm^2: not only a-Si but also c-Si region were melted. Figure 3 shows E_L dependence of R_s at RT, 250°C, and 450°C. Heat assist realize low R_s at small E_L. Constant low values of R_s are obtained on condition that X_js are not spread at E_L of 300 to 400 mJ/cm^2 when T_{sub} is 450°C. Therefore, we can regard the R_s-constant region as process window about E_L at T_{sub} of 450°C.

To clarify effects of T_{sub}, XTEM observation was carried out. Figures 4(a), (b), and (c) are the XTEM images before and after LA. From Fig. 4(a) and (b), (11 – 5) = 6 nm of residual a-Si layer was recrystallized by LA, though rapid recrystallization generates many defects. On the contrary, Fig. 4(c) obviously indicates that 11-nm-thick a-Si was recrystallized with few defects after LA (E_L: 300 mJ/cm^2, T_{sub}: 525°C). Because recrystallization velocity is so fast [5, 6], entire a-Si layer was recrystallized in the dwell time, that means non-melted LA process was carried out.

Effects of pre-recrystallization before LA were investigated. Figures 5 shows Sb depth profiles with linear scale (E_L: 300 mJ/cm^2 1 pulse, T_{sub}: 450 and 525°C). Distinct pileup at T_{sub} of 450°C is due to the melting of residual a-Si. Figure 6 shows laser pulse number dependence of R_s (E_L: 300 mJ/cm^2, T_{sub}: 525°C). Almost the same R_ss indicate that the recrystallized layers are hardly melted by multi-pulse laser irradiation.

Figure 7 shows I-V curves for reverse direction. Large leak current was obtained by only substrate heating. On the other hand, LA or RTA can fabricate diodes with low leak current. Diodes with heat-assisted LA, however, have slightly larger leak current than those with RTA, which is probably due to remained defects which are not removed by LA.

4. Summary

The heat-assisted LA process was evaluated for low-resistive ultra-shallow junction formation. The E_L to activate Sb was reduced by the heat assist. Non-melted process by heat assist enhances solid phase regrowth, which can form low R_s junction with few defects. Low-leak-current junction was formed by heat-assisted LA.

Acknowledgement

This work was partly supported by NEDO/MIRAI Project. The authors thank Komatsu Ltd. for cooperation.

References

[1] T. Yamamoto et al., VLSI Symp. Tech. p.138 (2002).
[2] P. A. Stolk et al., J. Appl. Phys., **35**, p. 6031 (1997).
[3] K. Kurobe, et al., Ext. Abst. of IWJT 2002, p.35.
[4] A. Matsuno et al., Proc. the 2nd Int. Semiconductor Tech. Conf. (ISTC), **2002-17**, p. 148 (2002).
[5] L. Csepregi et al., J. Appl. Phys., **49**, p. 3906 (1978).
[6] J. S. Williams et al., Phys. Rev. Lett. **51**, p.1069 (1983).

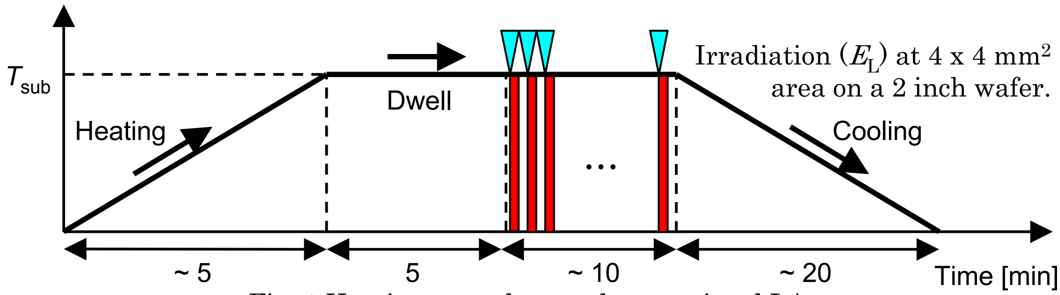


Fig. 1 Heating procedure on heat-assisted LA.

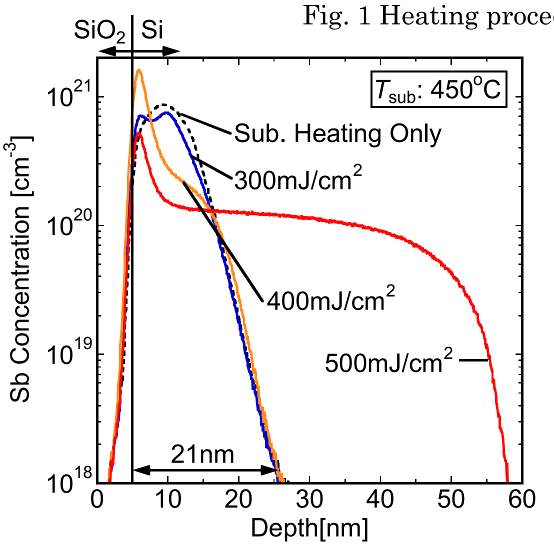


Fig. 2 Sb depth profiles before and after heat assisted LA (1 pulse) at T_{sub} of 450°C.

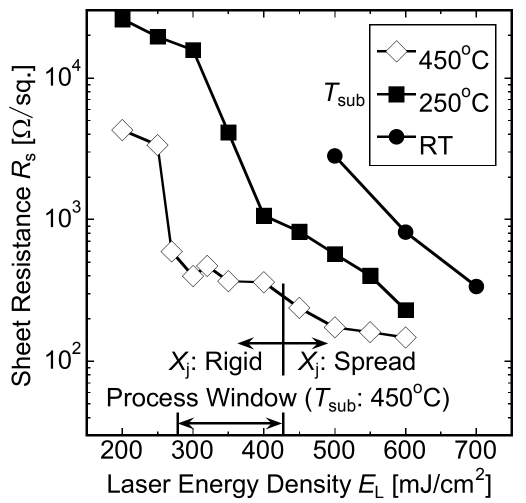
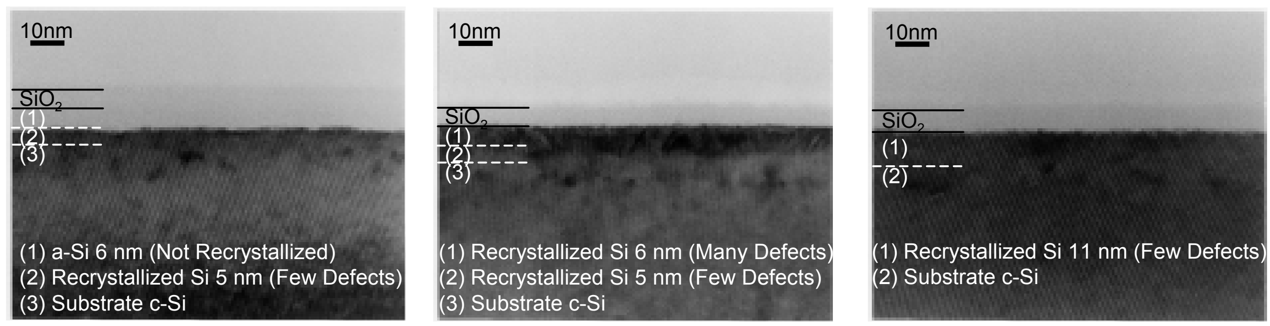


Fig. 3 E_L dependence of R_s at RT, 250°C, and 450°C.



(a) T_{sub}: 450°C holding for 8 min before LA

(b) T_{sub}: 450°C after LA (E_L: 300 mJ/cm² 1 pulse)

(c) T_{sub}: 525°C after LA (E_L: 300 mJ/cm² 1 pulse)

Fig. 4 XTEM images before and after LA.

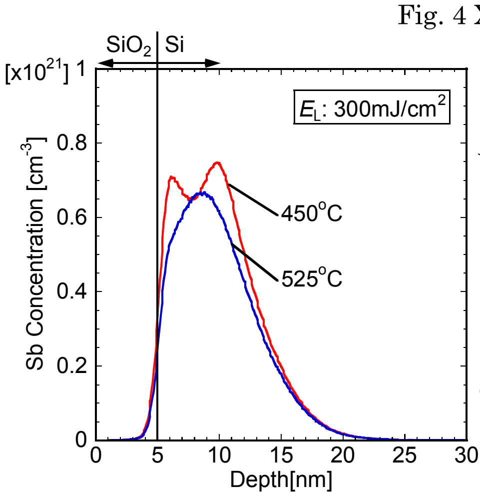


Fig. 5 Sb depth profiles with linear scale (E_L: 300 mJ/cm² 1 pulse, T_{sub}: 450 and 525°C).

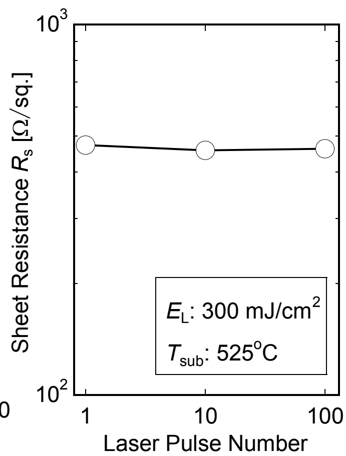


Fig. 6 Laser pulse number dependence of R_s (E_L: 300 mJ/cm², T_{sub}: 525°C).

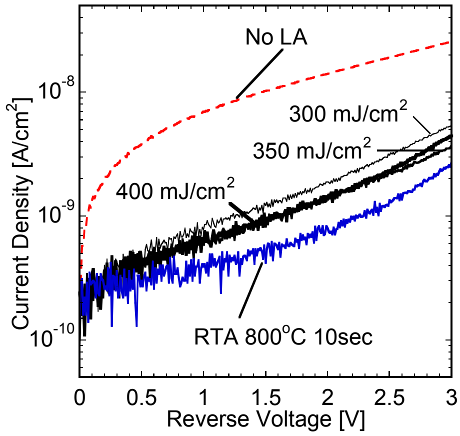


Fig. 7 *I-V* curves for reverse direction. Sub. heating only, heat-assisted LA (T_{sub}: 525°C), and RTA are compared with one another.

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Introduction

Laser Annealing (LA) is favoring for formation of MOSFET S/D Extension.

Advantages of KrF excimer LA:
1. Localized heating to the surface due to large absorption (λ=248 nm, Penetration depth: 10nm)
2. Activation over thermal equilibrium limit

Heat-assisted LA can realize reduction of sheet resistance (R_s) as keeping junction depth (X_j)

K. Kurobe, et al., Ext. Abst. of IWJT 2002, p.35.

Necessary to clarify and characterize

- Mechanism of Heat-assisted LA
- Effects to device property (particularly leak current)

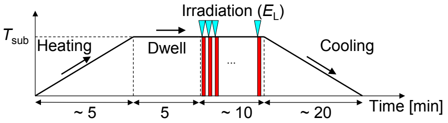
Experimental

- Wafers: p-type, 2 inches, 8 – 12 Ωcm
- Formation of screen oxide: 5 nm
- Sb^+ ion implantation: 10 keV, 6×10^{14} cm^{-2}
- Substrate temperature (T_{sub}): **250 – 525°C**
- Laser irradiation energy density (E_L): **200 – 600 mJ/cm²**

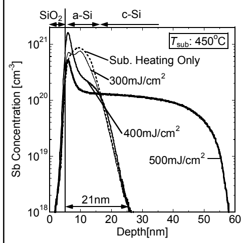
FWHM of pulse: 38 ns
Pulse number: 1 – 100
Irradiation area: 4-mm sq.

Characterization

Heating procedure



SIMS Profiles (against E_L)



300 mJ/cm²
Almost the same profile as I/I
No region melted

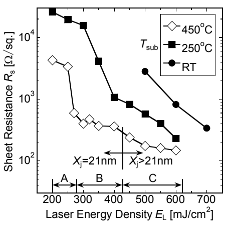
400 mJ/cm²
Strong pileup into SiO_2/Si interface
Melted: only the a-Si layer

500 mJ/cm²
Melted: a-Si and c-Si region

E_L increase:
X_j spreads by melting of c-Si sub.

E_L Dependence of R_s

R_s: measured by 4-point probe method.



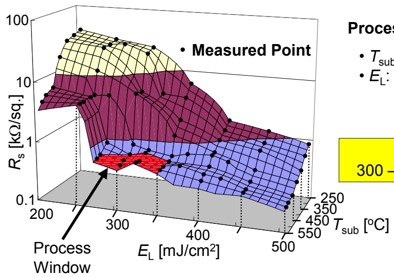
300 – 400 mJ/cm²
Low R_s and the same X_j as implanted

T_{sub}: 450°C

Region	R_s[Ω/sq.]
A	> 3000
B	300 – 400
C	< 300

Region B:
Process window for E_L

R_s Mapping (against E_L & T_{sub})



Process Window

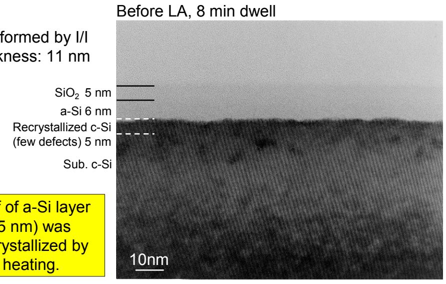
- T_{sub}: 450°C –
- E_L: 270 – 350 mJ/cm²

R_s:
300 – 400 Ω/sq.

Recrystallization of a-Si Layer (T_{sub}: 450°C): Before LA

Before LA, 8 min dwell

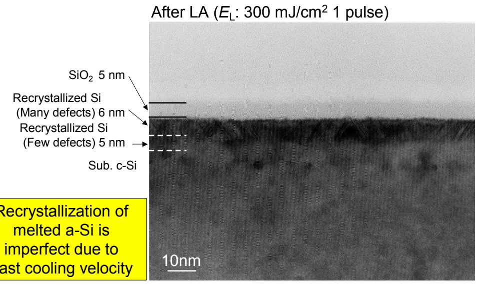
a-Si formed by I/I
Thickness: 11 nm



Half of a-Si layer (5 nm) was recrystallized by heating.

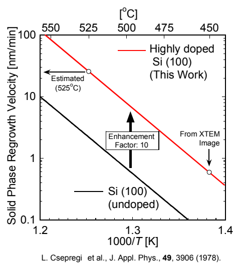
Recrystallization of a-Si Layer (T_{sub}: 450°C): After LA

After LA (E_L: 300 mJ/cm² 1 pulse)



Recrystallization of melted a-Si is imperfect due to fast cooling velocity

Recrystallization Velocity of a-Si Layer



L. Csepregi et al., J. Appl. Phys., 49, 3906 (1978).

Compare recrystallization velocity v_R(T_{sub}=450°C) with that from the reference

Highly doped Si has 10 times v_R of undoped Si.

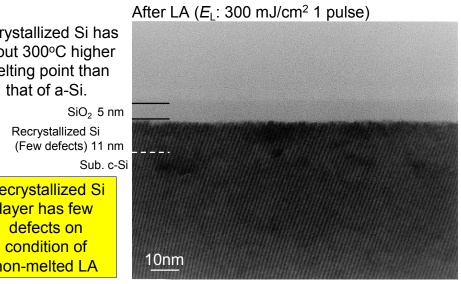
v_R (T_{sub}=525°C): 20 nm/min (by estimate)

Heating at the temperature of 525°C before LA will make a-Si layer fully crystallized in the dwell time.

Recrystallization of a-Si Layer (T_{sub}: 525°C): After LA

After LA (E_L: 300 mJ/cm² 1 pulse)

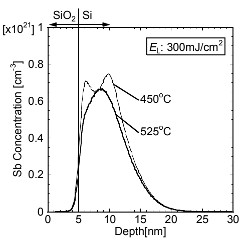
Recrystallized Si has about 300°C higher melting point than that of a-Si.



Recrystallized Si layer has few defects on condition of non-melted LA

Effect of Residual a-Si Layer to SIMS Profiles after LA

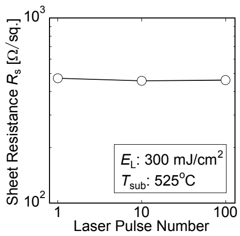
SIMS profiles for different T_{sub}



T_{sub}: 450°C
Pileup was strong at both SiO_2/Si interface and original a/c interface.
T_{sub}: 525°C
Little pileup was observed.

T_{sub}: 450°C
Dopants are diffused in melted a-Si layer.
T_{sub}: 525°C
Few dopants are diffused in recrystallized Si layer.

Pulse Number Dependence of R_s



R_s hardly changes by increase of pulse number.

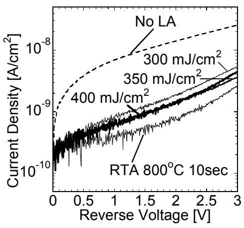
Recrystallized layers are hardly melted by multi-pulse laser irradiation.

n^+/p Diode Fabrication

- Wafers: p-type, 2 inches, 8 – 12 Ωcm
- B^+ ion implantation: Carrier concentration 2×10^{17} cm^{-3}
- Formation of screen Oxide: 5 nm
- Sb^+ ion implantation: 10 keV, 6×10^{14} cm^{-2}
- T_{sub} : **525°C**
  E_L : **270 – 400 mJ/cm²**
  For control: RTA 800°C 10 sec

- Reverse I–V characterization
- Hall effect measurement (for estimation of activation ratio)

Reverse I-V characteristics of n^+/p Diode



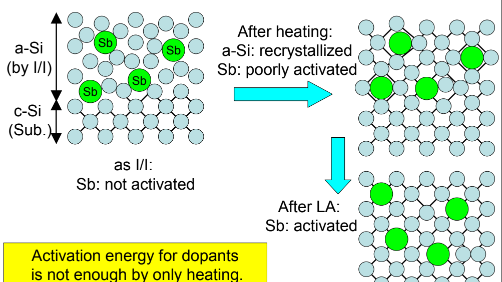
Diode without LA has large leak current.

E_L	Activation ratio
No LA	16 %
300 mJ/cm²	36 %

Many dopants are activated by LA.
Leak current: small

Good reverse I-V curve with LA
Slightly larger leak current than that with RTA (residual defects by LA may affect)

Mechanism of Heat-Assisted LA



Activation energy for dopants is not enough by only heating.
LA is needed for further activation.

Conclusions

n^+/p shallow junctions were formed by heat-assisted LA, and electrical characterization was carried out.

- Process window for E_L and T_{sub} was found; low-resistive ultra-shallow junction can be formed.
- The role of heat assist was clarified by XTEM observation.
- Mechanism of heat-assisted LA was speculated; non-melted LA after heating can form low R_s junction with few defects.
- Low-leak- current junction was formed by heat-assisted LA.

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