Formation of Low-resistive Ultra-shallow n⁺/p Junction by Heat-assisted Excimer Laser Annealing

Ken-ichi Kurobe1, Yoshinori Ishikawa1, Kazuhiro Kagawa2, Yoshiyuki Niwatsukino2, Akira Matusno2, and Kentaro Shibahara1
1Research Center for Nanodevices and Systems, Hiroshima University
2Komatsu Ltd., Research Division
1-4-2 Kagamiyama, Higashi-Hiroshima, Hiroshima, 739-8527 Japan
Tel: +81-824-24-6265, Fax: +81-824-22-7185, e-mail: kurobe@sxsys.hiroshima-u.ac.jp

Abstract
Low-resistive ultra-shallow n⁺/p junctions were formed with Sb by a heat-assisted laser annealing method. A wide process window for laser energy density and heating temperature was obtained. Under that condition, Sb diffusion was small and did not affect junction depth. The obtained sheet resistance was about 540 Ω/S for junction depth of 21 nm.

Introduction
Laser annealing (LA) is expected to replace rapid thermal annealing (RTA) for fabrication of sub-100 nm-MOSFETs [1]. Especially, high absorption coefficient in Si and short pulse duration of KrF excimer laser (λ=248 nm) is suitable to realize non-equilibrium annealing.

In this work, we have evaluated heat-assisted LA technique, that is, LA with Si substrate heating. Based on one-dimensional heat flow analysis, it is predicted that laser energy density necessary for dopant activation can be reduced [2]. This will be helpful to suppress laser induced gate poly-Si damage [3] and make development of LA equipment easier.

Using antimony as a dopant, influences of substrate temperature (Tsub) and the laser energy density on its depth profile and sheet resistance (Rs) were evaluated.

Experiment
Sb was implanted into p-type Si (100) substrates through a 5 nm screen oxide at a dose of 6×10¹⁴ cm⁻² and implantation energy of 10 keV. The Si surface is amorphized by this implantation [4]. Each wafer was heated to Tsub from 250 to 525°C in a nitrogen atmosphere. The KrF excimer laser energy density for LA was varied in the range of 200 to 525 mJ/cm². Full width at half maximum (FWHM) of the laser pulse was 38 ns.

A laser-exposed area was 4 mm square. The sheet resistances of Sb implanted layers were measured by a four-point probe method. Because of relatively long probe intervals, Rs values obtained by the four-point probes were overestimated by a factor of about 1.6 compared with the values obtained by a two-point probe method with a short interval. All Rs values in this paper are as measured and not corrected with this knowledge.

Sb depth profiles were evaluated with secondary ion mass spectrometry (SIMS). Primary ions were Cs⁺ and the screen oxide was not removed before SIMS measurement.

Results and discussion
Figure 1 shows Sb depth profiles before and after the heat assisted LA at 450°C. Large diffusion due to the crystalline-Si melting [4] is observed for the laser energy density of 500 mJ/cm². In the case of non-heat assisted LA, the crystalline-Si melting was found for 800 mJ/cm² and above. This is the clear evidence for reduction in practical laser energy density for LA by the heat assist. Except for 800 mJ/cm², diffusion at distribution tail is very small and junction depth defined at 1×10¹⁸ cm⁻³ is nearly constant at 21 nm.

For the laser energy density of 400 and 500 mJ/cm² in the same figure, Sb pileup at the SiO₂/Si interface attributed to its segregation tendency to melt phase [4] is observed. On the other hand, pileup for 300 mJ/cm² is very small. Figure 2 shows laser energy dependence of Rs at the same Tsub. In spite of the difference in re-distribution behavior described above, Rs has a plateau around 300 to 400 mJ/cm² at about 550 Ω/S that corresponds to region-B in Fig. 2. In region-A, much higher Rs was obtained, which implies insufficient activation of Sb. Lower Rs in region-C is attributed to increase in junction depth shown in Fig. 1. Figure 3 shows an Rs contour map against the laser energy density and Tsub. A process window for low-resistive and ultra-shallow n⁺/p junction formation is indicated as a shaded area. The window includes the region-B in Fig. 2. In the window region, junction depth was almost constant. In the case of so-called laser thermal process, a process window is attributed to a-Si melting [1]. However, because of solid phase re-growth, the heat-assisted LA cannot be understood simply by the a-Si melting. Further discussion should be done with information on recovery in crystallinity by the heat assist.

Summary
The heat-assisted LA was evaluated for low-resistive ultra-shallow junction formation. The laser energy density to activate Sb was reduced by the heat assist. The process window was found against laser energy density and Tsub.

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References

Fig. 1 Sb depth profiles before and after LA.

Fig. 2: $R_s$ against laser energy density at $T_{sub} = 450^\circ C$.

Fig. 3: Contour map of $R_s$ against laser energy density and $T_{sub}$. 