Mo Gate Deformation Induced by Laser Annealing Process

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Abstract

Laser annealing is a promising candidate for ultra-shallow junction formation. However, melt-annealing that utilizes fast recrystallization to achieve non-equilibrium activation tends to accompany undesirable melting at portions other than junction areas. In this paper, deformation of Mo gate is discussed through experimental and simulation work.

1. Introduction

Currently, post-spike annealing methods, such as flash lamp annealing [1-3], solid phase re-growth [4] and laser annealing (LA) [5], are actively investigated for the scaling of source and drain (S/D) junctions and MOSFET performance improvements. We have reported Heat-Assisted Laser Annealing (HALA) [6, 7] that is a combination of substrate heating and laser irradiation showing 20-nm depth ultra-shallow Sb-doped junction formation. The heat-assist at around 450-525°C led to good dopant activation with a relatively wide process window against laser energy density (E_L) and the heat-assist temperature.

In this paper, an issue associated with LA such as a gate deformation due to melting and a countermeasure for it are discussed.

2. Experimental Conditions

KrF excimer laser (λ ∼ 248 nm) was used for LA. Laser light pulse width was about 38 ns. A single laser pulse was irradiated to each point on specimens. In the case of HALA, Si wafers were heated to 450°C or 525°C prior to laser irradiation in a nitrogen atmosphere. Sheet resistance values shown in this paper was obtained with Sb doped n/p junctions [6, 7]. Sb was implanted at 10 keV through 5 nm screen oxides for this purpose. Mo was used as a gate material. Because of its very high melting point, 2620°C, robustness against laser irradiation was expected. In addition, it is one of the interesting candidates for the CMOS metal gate, since its workfunction is tunable by nitrogen incorporation [8].

3. Results and Discussions

Laser irradiation for S/D activation sometimes gives rise to melting or deformation of device structures [9]. Especially this problem is very severe for gate pads which are usually located on a field oxide, since the thick field oxide works as a heat insulator, as explained in Fig. 1. Figure 2 shows an example of the 50-nm thick Mo gate electrode deformation by laser irradiation whose laser energy density (E_L) was moderate one for dopant activation.

To relieve this problem, E_L necessary for sufficient activation should be reduced. HALA can reduce the necessary E_L to about the half of that for the non-heat-assist case, as shown in Fig. 4 [6, 7]. Figure 5 shows optical microphotographs taken after laser irradiation. Assuming the same E_L, HALA deteriorates the gate pad deformation. However, as indicated in this figure, sheet resistance lower than 500 Ω/sq. was obtained by HALA at 350 mJ/ cm². In the case of non-heat-assist LA, that is R.T. LA, this E_L was too low to activate dopants. As a results, HALA can relieve the gate deformation problem. The deformation was affected by Mo thickness, as shown in Fig. 6. Thicker Mo film showed better robustness against laser irradiation. In Fig. 6, Mo lines located on the gate oxide are also shown. Because of good heat conduction through the thin gate oxide, the Mo gate in active regions did not deform.

To discuss the gate deformation mechanism one-dimensional thermal diffusion simulation [10] was carried out. Figure 7 shows temporal temperatures profiles at the Mo surface and the field oxide bottom. E_L for HALA and the non-heat-assist cases were 300 mJ/cm² and 60 mJ/cm². In spite that HALA provided better activation as described above, temperature rising at the gate pad was reduced. Therefore, results shown in Fig. 5 was qualitatively explained by the simulation. However, the highest Mo temperature obtained by the simulation was too low to give rise to melt. Table I shows simulated highest temperatures for various Mo and oxide thicknesses. The difference between the highest temperatures for thin 50 nm and thick 100 nm Mo films, was too small to explain clear difference shown in Fig. 6. Two mechanisms which were not included in the simulation were possible candidates to explain these quantitative disagreement between experiments and the simulation. One is the Gibbs-Thomson effect [11], that is, lowering of melting point at structures with nano-meter scale small curvature. Another one is irradiation from backside as a results of diffraction of incident light at gate edges and its reflection at the field oxide/Si interface (Fig. 8). The latter is considered to result in effective E_L increase at the gate edge.

4. Summary

Gate deformation by laser irradiation for junction formation was evaluated. In the case of R.T. LA, Mo that has very high melting point easily melted. HALA that utilizes low temperature substrate heating was helpful to relieve the problem. The mechanism of the gate deformation was discussed with one-dimensional thermal diffusion simulation.

Acknowledgements

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References

Fig. 1 Schematic cross section of MOSFET along gate electrode. Gate pad on a thick field oxide is heated to higher temperature because of low thermal flow through the field oxide.

Fig. 2 Plan-view optical microphotograph of Mo gate pad after laser irradiation to activate dopants and schematic illustration to indicate the position of gate pad.

Fig. 3 SEM cross sectional image of Mo L/S formed on thick SiO₂. Mo lines deformed because of melting by laser heating. Initial Mo thickness was 50 nm.

Fig. 4 Relationships between sheet resistance and laser energy density. HALA provides good dopant activation by weaker laser irradiation.

Fig. 5 Plan-view optical microphotographs of Mo gate pad after laser irradiation. Dashed lines indicate original figure of the gate pad.

Mo: 50 nm, Field Oxide 300 nm

<table>
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<tr>
<th>Laser Energy Density $E_L$ [mJ/cm²]</th>
<th>Sheet Resistance $R_s$ [Ω/sq]</th>
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<tr>
<td>200</td>
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HALA 525°C

R.T. LA

525°C

Mo 50 nm

Mo Surface

525°C

Eₚ 600 mJ/cm²

Mo Gate Pad

Field Oxide

Si Substrate

R.T.

300 mJ/cm²

500 mJ/cm²

Mo Thickness

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Oxide Thickness

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Fig. 6 Plan-view SEM microphotographs of Mo L/S formed on the border of active and isolation regions. Thin 50 nm Mo showed serious deformation. The gate oxide thickness and field oxide thickness were 5 nm and 300 nm, respectively.

Fig. 7 Simulated temperature at the Mo gate surface and the field oxide bottom.

Fig. 8 Model to explain additional heating at the gate edge. Laser light diffracted at the edge and reflected at the field oxide/Si interface heats up the gate edge from its bottom side.