Rapid Thermal Scanning for Dopant Activation for Advanced Junction Technology

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1. Introduction

The formation of abrupt ultra-shallow junctions (USJ) is required to fabricate high performance advanced devices with design rules below 65 nm. Higher electrical activation of heavily implanted Si, above the solid solubility limit, without dopant diffusion and residual crystalline damage is one of the principal challenges facing process engineers today [1].

Combinations of “soak” and “spike” rapid thermal anneal (RTA) are generally used for implant activation applications. The annealing time for typical “soak” anneal is in the range of 10~30 s between 950°C~1100°C. The “spike” annealing duration is typically less than 1.5 s within +/- 50°C from the programmed peak temperature. For further improvement of the dopant activation rate with minimal dopant diffusion, a very rapid surface anneal (<10 ms) at a very high temperature (>1100°C) is considered the most promising solution to maximize electrical activation of dopants without causing diffusion [1 - 4]. Flash lamp and laser annealing techniques have been actively investigated and promising results have been demonstrated. [1 - 2, 5 - 10]

As an alternative electrical activation technique, solid phase epitaxy (SPE) at lower temperatures (< 700°C) after USJ implantation and epitaxial chemical vapor deposition (CVD) growth of highly doped layers are also being investigated [1, 4].

In this study, a new dopant activation technique using focused light beam scanning is proposed. [9 - 13] Medium energy $^{31}P^+$ and $^{75}As^+$ implanted wafers were electrically activated at room temperature by the proposed technique. Very low energy ion ($^{11}B^+$ and $^{49}BF_2^+$) implanted Si wafers, with and without Ge PAI (pre-amorphization implantation), were also activated by the same technique for electrical activation without significant dopant diffusion.

2. Experiment

Medium energy $^{31}P^+$ and $^{75}As^+$ implanted wafers and low energy $^{11}B^+$ and $^{49}BF_2^+$ implanted n-type silicon wafers were electrically activated at room temperature by scanning a focused light beam. A fixed dose of (1.0 x 10^{15} cm^{-2}) $^{31}P^+$ and $^{75}As^+$ ions were implanted at 20keV and 50keV to verify the extent of dopant activation by focused light beam scanning at room temperature. Typical implant energies and doses for shallow junctions are $^{11}B^+$ 0.5~1.0 keV, 1.0 x 10^{15} cm^{-2} and $^{49}BF_2^+$ 0.6~3.0 keV, 1.0 x 10^{15} cm^{-2}. Approximately one half of the wafers were pre-amorphized by Ge implantation ($^{72}Ge^+$ 30.0 keV, 1.0 x 10^{15} cm^{-2}). Light intensity and scanning speed were changed over a very wide range. Sheet resistance (Rs) of implanted wafers was measured using a four point probe after scanning the focused light beam for dopant activation. The B depth profile was measured using secondary ion mass spectroscopy (SIMS). The junction depth, xj (at a B concentration of 1.0 x 10^{18} cm^{-3}) and movement of implanted species after scanning activation was estimated from the SIMS B depth profiles.

3. Results and Discussions

The Rs values from the medium energy $^{31}P^+$ and $^{75}As^+$ implanted (20keV and 70keV, 1.0 x 10^{15} cm^{-2}) wafers after the scanning dopant activation process are summarized in Figs 1 and 2. As the light intensity increases (effective temperature of implanted layer increases), a higher dopant activation was observed. The effect of scanning speed was also investigated. Slower scanning resulted in higher dopant activation (Fig. 3 (a) and (b)). The dopant activation trends are consistent with our previous study on USJ implant anneal using the Xe arc lamp flash annealing method.

The as-implanted junction depth of $^{11}B^+$ (0.5 keV, 1.0 x 10^{15} cm^{-2}) implanted wafers with Ge pre-amorphization (30 keV, 1.0 x 10^{15} cm^{-2}) was 25.0 nm. The Rs range of 360~880 ohm/sq. is achieved after various scanning activation conditions at room temperature without significant B diffusion. For the $^{11}B^+$ (0.5 keV, 1.0 x 10^{15} cm^{-2}) implanted wafers without Ge pre-amorphization, the as-implanted junction depth was ~28.0 nm. Under the same scanning conditions, the Rs range of 1500~1750 ohm/sq. is achieved from the $^{11}B^+$ (0.5 keV, 1.0 x 10^{15} cm^{-2}) implanted wafers without Ge pre-amorphization. For both wafers, the average Rs values were reduced as the light intensity was increased indicating an increase of dopant activation without significant B diffusion.

For $^{49}BF_2^+$ (0.6~3.0 keV, 1.0 x 10^{15} cm^{-2}) implanted wafers, with or without Ge pre-amorphization, similar activation was observed with negligible dopant redistribution (diffusion). Wafers with Ge pre-amorphization required less light energy for dopant activation compared to those without Ge pre-amorphization.

4. Summary

Rapid thermal scanning for activation of dopants is proposed for applications in advanced junction formation. The proposed rapid thermal scanning dopant activation technique was found to be very effective for both deep and shallow implanted junctions while providing enhanced activation parameter control capability.

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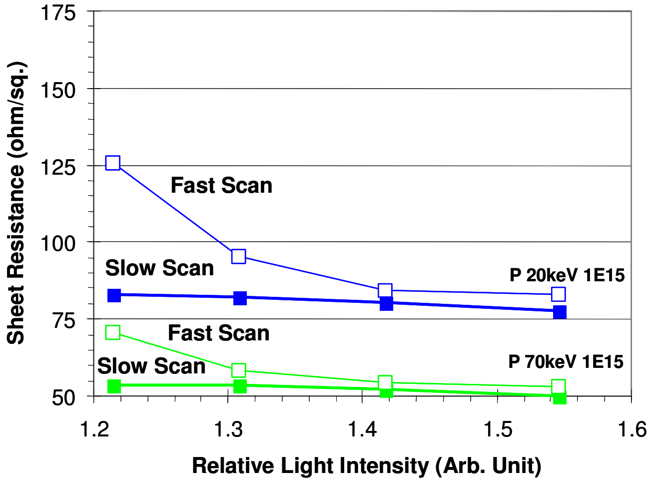


Fig. 1. Rs values from the medium energy $^{31}P^+$ implanted (20keV and 70keV, 1.0 x 10^{15} cm^{-2}) wafers after scanning focused beams of various intensity at different scanning speeds.

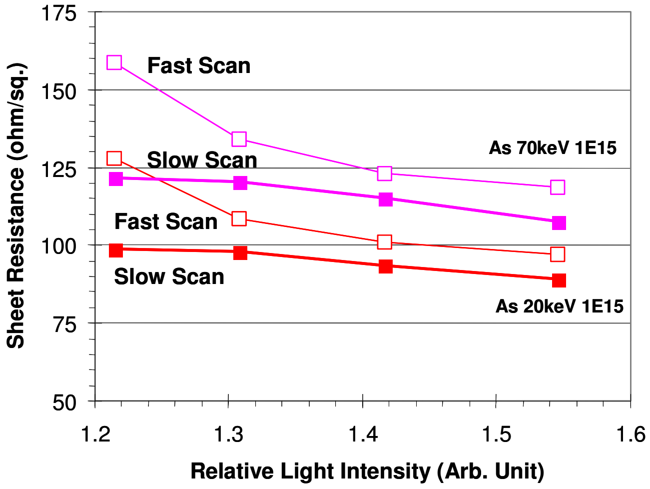
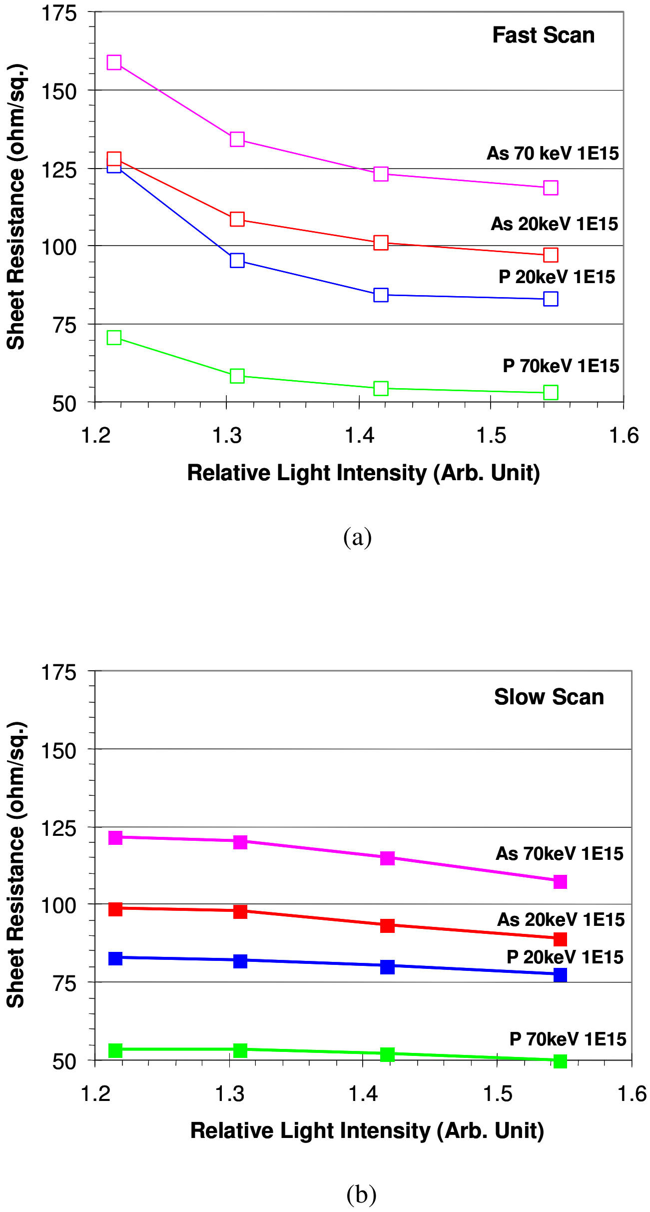


Fig. 2. Rs values from the medium energy $^{75}As^+$ implanted (20keV and 70keV, 1.0 x 10^{15} cm^{-2}) wafers after scanning focused beams of various intensity at different scanning speeds.



(a)

(b)

Fig. 3. The effect of scanning speed on dopant activation. (a) fast scan and (b) slow scan.