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Pulsed Focused-Laser Beam Annealing of Ultra-Shallow Implanted Silicon and *In Situ* Dopant Activation Monitoring

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1. Introduction

Higher electrical activation of heavily implanted Si, above the solid solubility limit, without significant dopant diffusion and residual crystalline damage is one of the key challenges in fabricating abrupt ultra-shallow junctions (USJ) for high performance advanced devices [1].

Numerous dopant activation methods seek to maximize electrical activation of dopants without causing diffusion. Some of these are: combinations of conventional "soak" and "spike" rapid thermal anneal (RTA), millisecond flash lamp anneal, pulsed excimer laser anneal, solid phase epitaxy (SPE) at lower temperatures and epitaxial chemical vapor deposition (CVD) growth of highly doped layers to [1-6].

In this study, a new dopant activation technique using pulsed focused-laser beam scanning is proposed [7]. This approach has the advantage of allowing much greater control of the energy flow through controlling the laser pulse spot size, peak power, pulse width, rep rate and step size. In addition, a novel approach which can directly observe activation during the annealing process is demonstrated.

2. Experiment

Low energy $^{11}B^+$ and $^{49}BF_2^+$ implanted n-type silicon wafers were electrically activated by pulsed focused-laser beam scanning at room temperature. Typical implant energies and doses are $^{11}B^+$ 0.5~1.0 keV, 1.0 ~ 2.0 x 10^{15} cm^{-2} and $^{49}BF_2^+$ 2.0~3.0 keV, 0.5~1.0 x 10^{15} cm^{-2}. Pre-amorphization implantation (PAI: $^{72}Ge^+$ 5.0~30.0 keV, 0.5~1.0 x 10^{15} cm^{-2}) was done to approximately one half of the wafers. A schematic of the pulsed focused-laser beam annealing system is shown in Fig. 1. A diode pumped, continuous wave (CW) yttrium aluminium garnet (YAG) laser beam (1064 nm) was focused and optically modulated to deliver a high intensity, pulsed laser beam. The pulse width and repetition rate were varied from 5 to 10 ns and from 20 to 40 kHz with a spot size on the order of tens of micrometers. The system is capable of varying the scanning area of the focused-laser beam without moving the wafer merely by controlling the galvanometric x- and y-axis mirrors. Pulsed laser peak power and scanning speed were varied over a wide range. Sheet resistance (Rs) of the implanted wafers was measured using a four point probe after annealing. The B depth profile was measured using secondary ion mass spectroscopy (SIMS). A new i*n situ* dopant activation monitoring technique was incorporated into the system to facilitate optimization of the annealing parameters.

3. Results and Discussions

The Rs values from the ultra-shallow $^{11}B^+$ (1.0 keV, 2.0 x 10^{15} cm^{-2}) implanted wafers with or without $^{72}Ge^+$ (5.0keV, 0.5 x 10^{15} cm^{-2}) PAI after pulsed focused-laser beam annealing under various peak pulse power conditions are summarized in Fig 2. As the peak pulse power is increased, effectively increasing the temperature of the implanted layer, higher dopant activation was initially observed. As the peak pulse power is increased further, the Rs values start to decrease. The B SIMS depth profiles of B implanted wafers with or without Ge PAI are plotted in Fig. 3. The relative peak pulse power and Rs values are also shown with B profiles. All the wafers annealed in this work show significant dopant diffusion. As the relative peak pulse power increases, the dopant diffusion is deeper. For simplicity, only the experimental results from $^{11}B^+$ (1.0 keV, 2.0 x 10^{15} cm^{-2}) implanted wafers, with or without Ge PAI, are described.

The wafers with Ge PAI absorb photon energy more efficiently than the ones without Ge PAI. Thus, dopant activation occurs at much lower photon density irradiation. This dopant activation trend is consistent with our previous study on USJ implant anneal using the Xe arc lamp flash annealing method [4-5]. Whenever the Rs value increases with the increasing annealing temperature, the possibility of dopant deactivation is often discussed. The increasing Rs values with higher annealing temperature (peak power ≥1.33 in Fig. 2) in this case is due to the lowering of the average dopant concentration as seen in the SIMS profiles.

The typical signature of dopant activation was monitored electrically, *in situ,* by observing the voltage drop in a series voltage divider circuit during the pulsed focused-laser beam annealing. This is shown in Fig. 4. As dopants become electrically activated, the resistance (R2) and voltage (V2) across the probes drops. By monitoring the voltage drop, the degree of dopant activation can be monitored *in situ*.

Annealing process optimization for USJ formation and the effect of laser wavelength on annealing characteristics are being investigated.

4. Summary

A pulsed focused-laser beam annealing technique was proposed as an alternative dopant activation technique and preliminary process results are demonstrated. A method for *in situ* monitoring of dopant activation and its application are introduced.

References

[1] J.O. Borland, Semiconductor International, **29** (13) (2006). 49.

[2] T. Ito, T. Iinuma, A. Murakoshi, H, Akutsu, K. Suguro, T. Arikado, K. Okumura, M. Yoshioka, T. Owada, Y. Imaoka, H. Murayama and T. Kusuda, Jpn. J. Appl. Phys., 41 (2002) 2394.

[3] W.S. Yoo and K. Kang, Electrochem. Soc. Proc., PV **2003-14** (2003) 111.

[4] W.S. Yoo and K. Kang, Electrochem. Soc. Proc., PV **2004-01** (2004) 3.

[5] J. Harnish, C. Carson, J. Foggiato, K. Kang and W.S. Yoo, Electrochem. Soc. Proc., **PV 2005-05** (2005) 25.

[6] W.S. Yoo and K. Kang, Ext. Abst. Int. Conf. on Solid State Device and Materials (SSDM) (2005) p. 524.

[7] W.S. Yoo, US Patents 6.376,806, 6,337,467, 6,809,035, 6,862,404, 6,916,376.

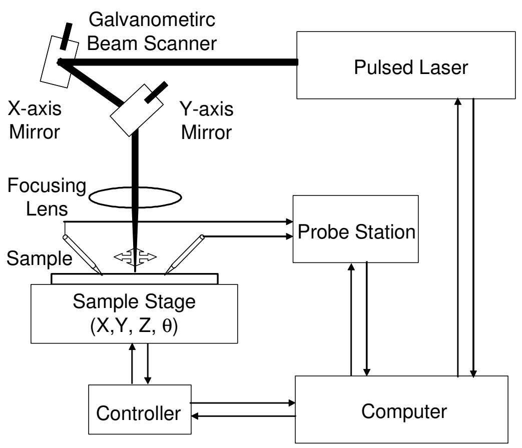

Fig. 1 Schematic diagram of pulsed focused-laser beam annealing system with probe station for *in situ* dopant activation monitoring.

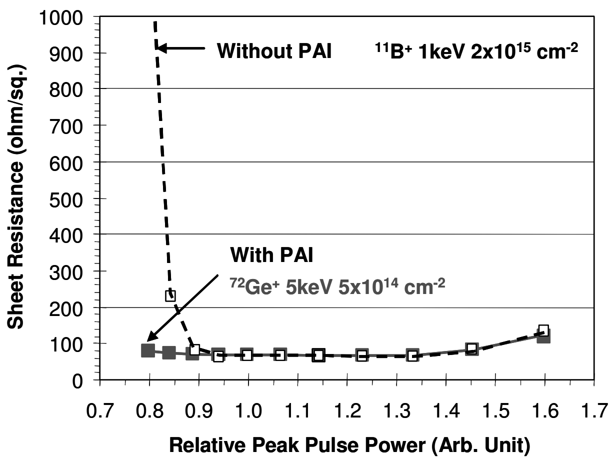

Fig. 2 Sheet resistance of B (1.0 keV, 2.0 x 10^{15} cm^{-2}) implanted Si with or without Ge (5.0 keV, 5.0 x 10^{14} cm^{-2}) PAI after annealing under various peak pulse power conditions.

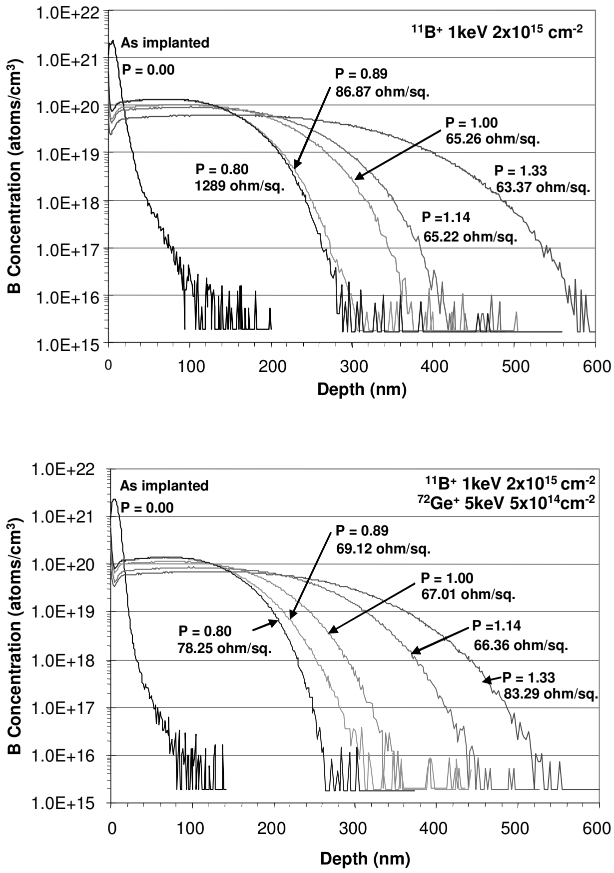

Fig. 3 Typical Rs values and SIMS B depth profiles of as-implanted and wafers annealed under various conditions. (Top: B implantation only, Bottom: B implantation with Ge PAI)

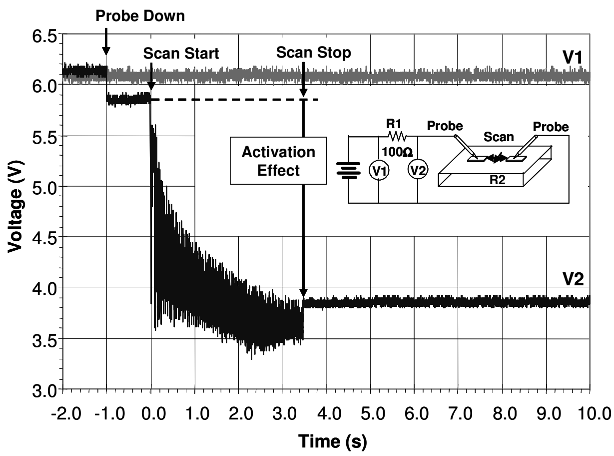

Fig. 4 Typical signature of *in situ* monitored dopant activation between probing pads during pulsed focused-laser beam annealing.