Improved Rs Monitoring for Robust Process Control of High Energy Well Implants

J. H. Kim *, S. Kim *, G.J. Ra* and R. N. Reece*, S. Y. Bae**

* Axcelis Technologies, Inc., 108 Cherry Hill Drive, Beverly, MA01915, USA

**Hynix - ST Semiconductor Limited., K7 Plot, Export Processing Zone, ZiangSu, Wuxi, China

Abstract

In this paper we describe a robust method of improving precision in monitoring high energy ion implantation processes. Ion implant energy accuracy was measured in the device manufacturing process using an unpatterned implanted layer on an intrinsic *p*-type silicon wafer. To increase Rs sensitivity to energy at the well implant process, a PN junction structure was formed by P-well and deep N-well implants into the *p*-type Si wafer. It was observed that the depletion layer formed by the PN junction was very sensitive to energy variation of the well implant. Conclusively, it can be recommended to monitor well implant processes using the Rs measurement method described herein, i.e., a PN junction diode structure since it shows excellent Rs sensitivity to variation caused by energy difference at the well implant step.

1. Introduction

As the devices are scaled down to sub-micron, strict control of implant process is needed to support yield improvement and to respond quickly to yield excursions. Process control and device matching as well as device yield depends on the accurate control of implant dose and energy at the retrograde well implant step. To meet this requirement, implant process monitoring is traditionally carried out by several methods including Therma Probe® (TW), a measure of silicon lattice damage, Sheet Resistance (Rs), a measure of the resistance of a doped and activated silicon layer, and Secondary Ion Mass Spectroscopy (SIMS), a profiling technique of dopant concentration vs. depth. Therma Probe measurement is non-destructive and needs no additional process steps after implantation. While TW is easier to perform than sheet resistance (Rs) techniques, Rs measurement is the dominant implant monitoring technique since Rs is directly related to matching electrical characteristics of devices by each implanter. All three techniques remain useful and popular, each with specific and different sensitivities and limitations.

Well implant processes in sub-micron generation devices can be particularly sensitive to energy variation, whether from voltage offsets in conventional DC high energy implanters, or energy variation resulting from limited resolution of final energy magnet (FEM) filtering on a system using AC acceleration of ions such as a linear accelerator (Axcelis LINAC)[1]. This kind of energy variation cannot be easily monitored by conventional measuring methods since energy sensitivity is quite a bit lower than dose sensitivity [2]. In this paper, we introduced a P-Well /Deep N-Well diode junction structure not only to detect such energy variations of implanters, but also to match N or P-well Rs values in production devices.

2. Experiments

Boron and Phosphorus species at each P-well and Deep N-Well energy were implanted into crystalline Cz, *p*-type bare Si (100) by using an implanter with a linear AC accelerator. The post implant anneal (PIA) was carried out at 1000℃ by using a rapid thermal anneal process, standard to conventional CMOS processing. All anneals were performed in an N_2 ambient. Sheet resistance values were measured using a four-point probe.

3. Rs comparison and monitoring with bare Si wafers

We compared the P-Well Rs trend in Deep N-Well of ~ 90nm DRAM device manufactured with three similar high energy implanters. The P-Well Rs of devices implanted on implanter A shows higher Rs than the other two systems, B and C. Comparative data is shown in Fig.1. Implanter A shows Rs approximately 5% higher even though the recipe had the same energy and dose, and had been matched using standard Rs techniques of just one implant step. This result reveals that conventional Rs matching by single implant dose split test on Si wafers is not always an accurate method for matching between implanter machines. The results indicated that these unmatched Rs characteristics appeared at only triple well structure, which coupled with P-Well and Deep N-Well.

Figure 2 shows the overlapped SIMS profiles of implant 400keV $11B^+$ ions, 1.0E13 atoms/cm^2 by implanters A, B, & C. The profiles do not reveal any significant differences in energy (depth or Rp) and dose among three systems by SIMS analysis.

Finally we designed a junction diode structure in the bare Si wafers which coupled with P-Well implants 400keV $11B^+$ ions to a dose of 1.0E13 atoms/cm^2 in Deep N-Well implant of a 1.2 MeV $31P^+$ ions to a dose of 1.0E13 atoms/cm^2. We compared Rs values of energy split test and RTA at 1000°C and 10s, as shown in Fig.3. We demonstrated that the Rs value increased with increasing the P-Well implant energy, and Rs decreased with decreasing P-Well energy. It indicated that Rs in P-Well region could be precisely controlled by P-type dopant concentration except that which was overlapped and compensated with N-type dopant in Deep N-Well region, by controlling the energy of P-Well implant.

In the LINAC based AC high energy system, final energy is determined by FEM calibration performed on each implanter. Calibration is carried out by using a DC ion beam of 80keV Ar^+, 10keV B^+, 270keV Xe^{+++}, and 210keV Xe^{+++} [1]. Figure 5 shows P-Well Rs matching after reduction of 10keV on system A by such a FEM calibration. The Rs trend of 90nm DRAM device after FEM calibration shows the energy is well matched between the three HE implanters as shown in Fig.6.

4. Conclusion

We can conclude that an Rs monitoring method by PN junction structure on bare Si wafer is a more sensitive tool to detect energy variation and to match multiple implanters in a device manufacturing fab.

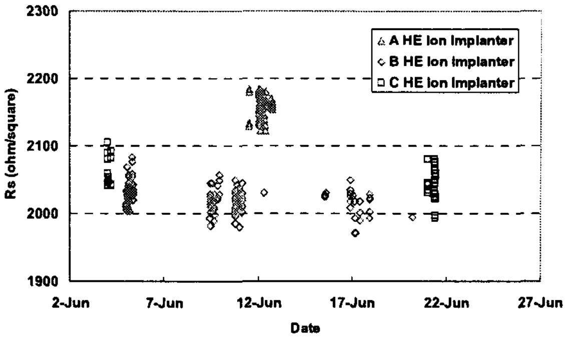

Fig. 1. P-well Rs trend of device lots from each high energy implanter.

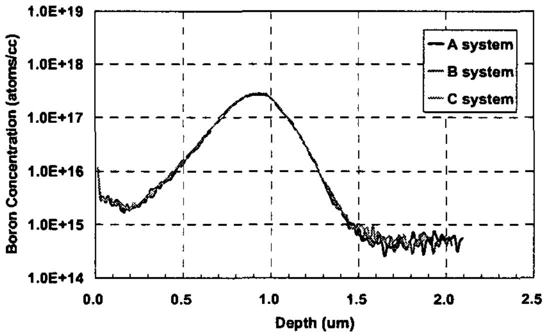

Fig. 2. SIMS comparison of P-Well implants of 400keV $11B^{+}$ ions to a dose of 1.0E13 atoms/cm^2 on the bare test wafers.

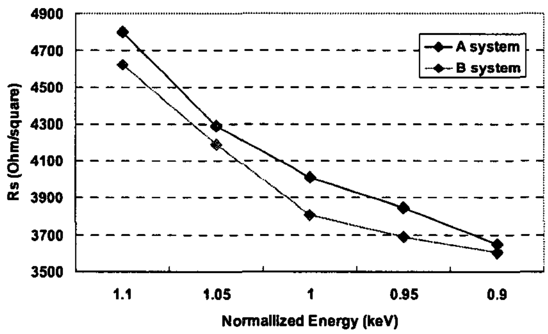

Fig. 3. Rs comparison by measuring PN junction structure (P-well/DN-well) with energy split tests between A and B implanters. Annealing perfomred at 1000℃ 10sec N_2 condition

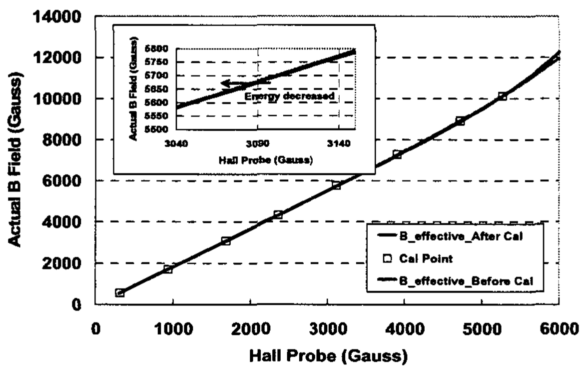

Fig. 4. P-well energy was decreased by FEM (final energy magnet) calibration as shown in above figure at the A implanter. The inset shows that hall probe gauss is decreased as much as 10keV of P-well energy.

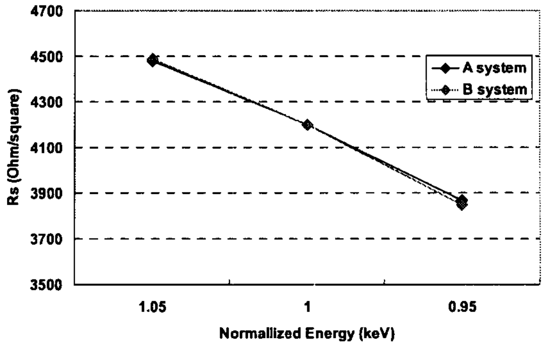

Fig. 5. Rs monitoring results after FEM calibration (energy reduced about 10keV at the A implanter). Annealing performedat 1000℃ 10sec N_2 condition after P-well/DN-well implant performed on the bare test wafers.

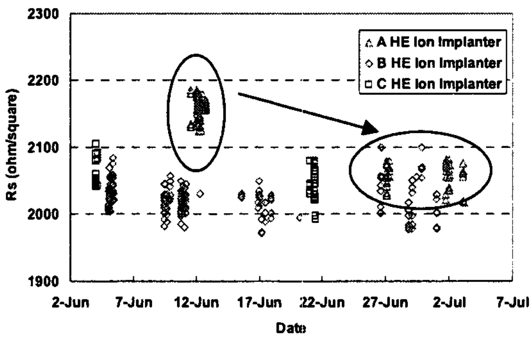

Fig. 6. Rs trend comparison of device lots at each high energy implanter. The arrow indicates Rs trend is successfully changed by the FEM calibration of A implanter.

References

[1] Noriyuki Suetsugu, Hiroyuki Kariya, Mitsuaki Kabasawa and Michiro Sugitani, IIT2000, pp. 448-451, Sep. 2000.

[2] Dennis Kamenitsa and Peter Lillian, IBID, pp. 674-677.