Ribbon and Spot Beam Process Performance of the Dual Mode iPulsar High Current Ion Implanter

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Abstract. Low energy implant process data are presented from a dual mode high current ion implanter. The iPulsar is a flexible single wafer implanter capable of running both ribbon beams with one-dimensional mechanical scan of the wafer and spot beams with two-dimensional wafer scan. The main components of the implanter are described and their operation explained. Boron concentration profiles in Ge pre-amorphized substrates, measured by secondary ion mass spectroscopy (SIMS) are presented before and after anneal with drift and decelerated beams. In addition, spot and ribbon beam as-implanted phosphorus and carbon profiles are presented and the characteristics of each mode of operation are discussed.

Keywords: Ion beam implantation, low energy, high current implanter
PACS: 41, 81, 82, 85.40.Ry

INTRODUCTION

The evolving demands for doping of semiconductors in latest CMOS technologies have driven significant changes in ion implantation equipment design and process capability. There is now an almost universal prevalence of single wafer implantation for high current, low energy processes and increased demand for accurate control of implant parameters such as substrate temperature, beam current density (dose rate) and angle of incidence. The importance of these parameters in junction formation and transistor operation has been recognized and particular effort placed in understanding the underlying mechanisms by which they affect dopant distribution and activation [1, 2]. Of particular concern is the ability to match process results whenever new implanters are introduced in a process line in order to avoid deviation and ensure consistent transistor performance [3]. Different beamline architectures, wafer scanning mechanisms and beam shapes can result in substantially variable process and device performance by influencing amorphous layer formation, defect generation and distribution and active dopant concentration. For that purpose, equipment capability and flexibility are particularly important in high volume manufacturing environments. The iPulsar high current ion implanter provides that capability through its flexible architecture that allows generation of both ribbon and spot beams for operation with one- and two-dimensional wafer scanning mechanisms respectively. The main components and process performance of the implanter are described next.

SYSTEM DESCRIPTION

The iPulsar is a second generation ribbon beam ion implanter with the added capability of running spot beams. It features a tall and open beamline architecture designed for efficient beam transport while minimizing beam strike on electrode surfaces. This helps keep particle generation to a minimum and reduces wear on beamline components, thus reducing maintenance costs. An overview schematic of the system is shown in Figure 1. Major components of the system are the ion source, analyzing magnet, uniformity and collimator multipoles, chicane deceleration electrodes, plasma electron shower, wafer scanning arm, faraday cup and wafer handling system.

FIGURE 1. Overview schematic of the iPulsar high current ion implanter.

An indirectly heated cathode (IHC) source is used capable of producing up to 90 mA of extracted ion current. The source is positioned vertically in the system and its geometry is optimized to produce uniform ribbon beams with height of up to 100 mm. The mass analyzing magnet has a 90^{o} bend and high acceptance designed for efficient transport of very tall beams. It can operate in two modes for two different beam paths, drift/straight deceleration and chicane deceleration. A series of electromagnetic multipoles are used to manipulate the beam shape, uniformity and angle distribution. A linear multipole helps expand the beam height to over 300 mm while a uniformity multipole adjusts the local beam density in order to produce a spatially uniform beam. A collimator multipole helps reduce the beam angle spread while a steering multipole adjusts the beam vertical position and angle.
The deceleration electrode assembly consists of two alternative beam paths, one for drift and straight deceleration and a second for chicane deceleration beams, as shown in Figure 2. The first is used primarily for high energy drift beams while the second gives production-worthy beam currents at very low energies are using high decel ratios (up to 45:1).

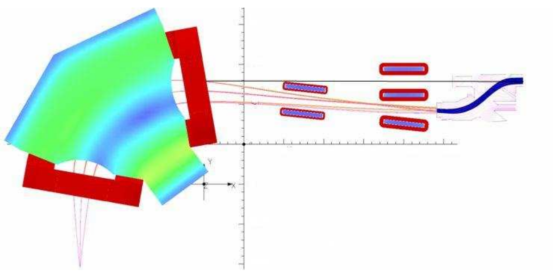

FIGURE 2. Straight and chicane deceleration beam paths in the iPulsar high current ion implanter.

The chicane deceleration path includes two bends of the beam that help reject any energetic neutrals, thus minimizing energy contamination. Additionally, the design of the chicane electrode limits the energy of any high energy contaminants to about 11% of the extraction energy, further ensuring very tight control of dopant profile and junction depth at very low implant energies [4]. The beam exits the chicane path on the original axis of a drift beam. Dual plasma electron showers using xenon supply sufficient numbers of low energy electrons for efficient beam neutralization and prevention of beam blow-up and charging damage [5].
The beam profile shape and angle distribution is measured with the use of a movable beam profiler, shown in Figure 3.

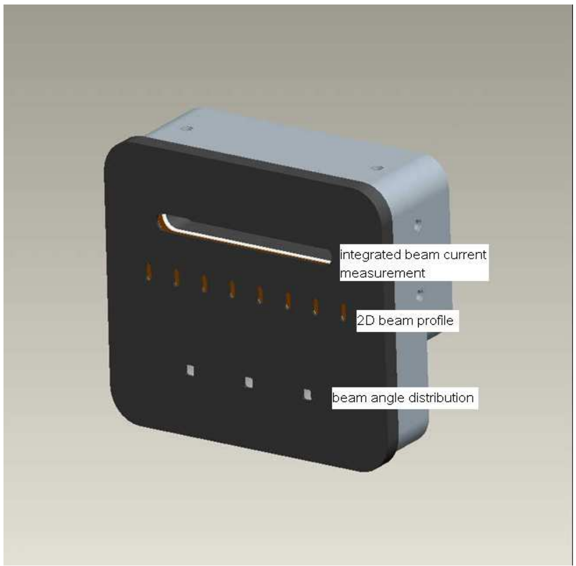

FIGURE 3. Beam profiler used for the measurement of the 2D beam profile and angle distribution.

The beam profiler is scanned vertically in front of the beam and it uses eleven magnetically suppressed faraday cups to obtain the two-dimensional beam current profile. Three separate angle profiling cups measure the beam angle distribution and a single slot is used for the measurement of the integrated beam current.
A scan arm equipped with an electrostatic chuck is used to scan the wafer in front of the beam during implant. Two distinct modes of operation are available, a 1D scanning mode using a tall ribbon beam and a 2D scanning mode using a spot beam, as shown in Figure

4. The tilt and twist angles of the wafer with respect to the beam can be set by independent movement of the scan head, including in-situ wafer rotation.

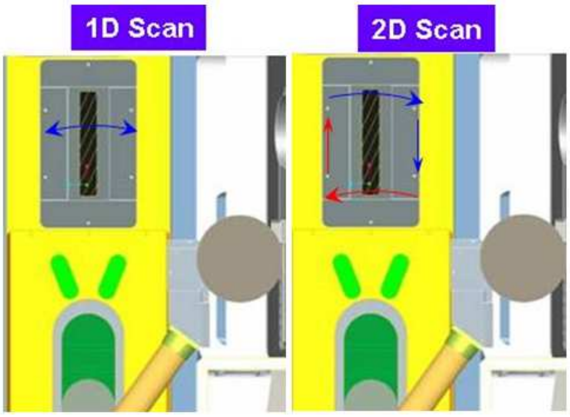

FIGURE 4. Wafer scan arm with 1D and 2D scanning capability.

The capability of the iPulsar to operate in either 1D or 2D mode provides great flexibility in implant process setup, as some important parameters depend strongly on the use of a ribbon beam in 1D or spot beam in 2D scanning mode. These include beam current density, dose rate and wafer temperature, which are known to influence amorphous layer formation and defect distribution after anneal.

PROCESS RESULTS

Boron, phosphorus and carbon implants were run on the iPulsar with different setup conditions and implanted species concentration profiles were generated using point by point corrected secondary ion mass spectroscopy (PCOR-SIMS) at Evans Analytical Group. N-type, single crystal silicon monitor wafers with <100> orientation were used for the boron and carbon implants and p-type wafers for the phosphorus implants. Boron implantation and anneal has been studied extensively for p-type doping [6] while phosphorus has found renewed interest recently for ultra-shallow junction formation in NMOS transistors due to its higher solid solubility compared to arsenic. This leads to better performance of NMOS transistors, necessary in order to match the enhanced PMOS performance afforded by the improved hole mobility in strained silicon substrates [7]. Carbon implantation is used for lattice strain introduction and for controlling the diffusion of boron during high temperature anneal [8, 9]. Table 1 shows the implant matrix and process conditions for the three species. The B and P substrates were pre-amorphized with a ^{72}Ge 30 keV, 5e14 cm^{-2} implant to create a 45 nm thick amorphous layer and prevent channeling. All decel beams used the chicane beam path of the implanter. For the C implants, CO_2 gas feed was used, exhibiting stable source operation with no adverse impact on source lifetime.

TABLE 1. Implant matrix run on the iPulsar.

#	species	beam/ mode	energy keV	dose cm^{-2}	drift/decel from keV
1	B	spot/2D	1	1E+15	drift
2	B	spot/2D	1	1E+15	decel from 8
3	B	ribbon/1D	1	1E+15	decel from 8
4	P	spot/2D	4	1E+15	decel from 12
5	P	ribbon/1D	4	1E+15	decel from 12
6	C	spot/2D	1.5	5E+15	decel from 10
7	C	ribbon/1D	1.5	5E+15	decel from 10

Two wafers were implanted with each of the B beams shown in Table 1 and one wafer from each was annealed at 1050°C, 30 sec in inert ambient. Boron concentration profiles for the as-implanted and annealed wafers were measured by PCOR-SIMS from Evans Analytical Group and the results are shown in Figure 5. The decel as-implanted profiles from the spot and ribbon beam implants are essentially identical in shape with the profile from the drift implant, indicating the absence of any measureable energy contamination. This is very important for shallow junction formation with ultra-fast annealing since the as-implanted profile is practically unchanged after anneal (diffusionless activation) and it determines the final junction depth [10]. The annealed profiles are also very similar in shape for all three conditions with small variations in total measured dose ranging between 2% and 11%. This could be due to the accuracy and repeatability of PCOR-SIMS stated at 10% and 5% respectively [11], variable dopant loss during anneal, generally ranging between 12% and 14% in these tests and small variations between the spot and ribbon beams dose control algorithms that can be easily corrected by proper dose matching procedures.

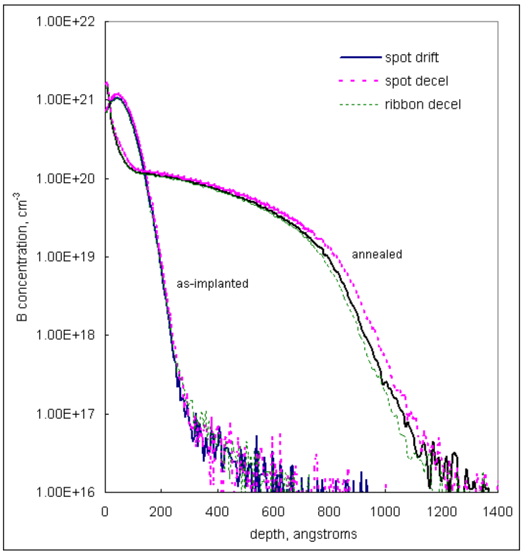

FIGURE 5. As-implanted and annealed SIMS profiles from Boron 1 keV, $1x10^{15}$ cm^{-2} implants.

Finally, the P and C as-implanted profiles are shown in Figure 6. As with the B profiles, no detectable tail due to energy contamination is observed. The C profile shows a concentration peak at the surface, most likely due to adsorbed contaminants at the wafer surface.

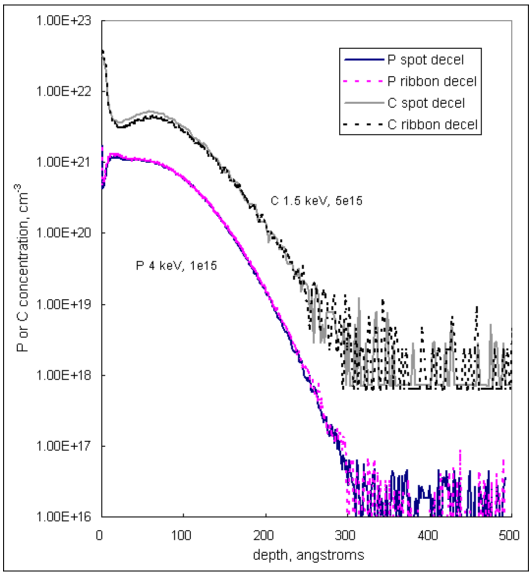

FIGURE 6. As-implanted P and C SIMS profiles.

CONCLUSIONS

The iPulsar high current ion implanter is a versatile system for low energy, high dose implants, allowing exceptional process setup flexibility with its dual mode ribbon and spot beam capability. Boron, phosphorus and carbon implants in various modes of operation show excellent species profile control with no detectable signs of energy contamination.

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