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ORIGINAL PAPER

Introducing the Purion H200™ single wafer high current implanter

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Abstract

The growing market demand for semiconductor chips designed to address new and emerging applications (especially in the power device market) are driving the need for single wafer high current implanters with a much broader energy range than traditional implant space, which is primarily designed around logic and memory high dose implant requirements. This paper describes the design and capabilities of the Purion H200™ single wafer high current implanter produced by Axcelis Technologies specifically designed to deliver high beam currents and productivity over a wide energy range from sub 10 keV to over 400 keV. We discuss the design, capabilities, and unique challenges with higher power implants and review the current applications needs being addressed by this implanter in high volume manufacturing of both silicon and silicon carbide devices.

Introduction

The strong global push to balance the ever-increasing need for higher-energy consumption in this new world driven by the Internet of Things (IOT) against the need to mitigate climate change is driving a strong demand for improving and adopting new energy efficient approaches. These include a shift toward integrating renewable energy sources, a strong pull for electrification of the automotive industry (shifting away from fossil fuels) as well as integrating new devices that enable higher-energy efficiencies. The result of this global megatrend is a strong demand for power devices that minimize the energy losses from various sectors ranging from Automobiles, Data Centers, Power converters, Chargers, and a Smartgrid, among other applications. In addition, there is also a strong demand for other devices including Analog, Bipolar/CMOS/DMOS (BCD), MEMS, and other technologies that enable the reduction of energy consumption through miniaturization of certain other functions. Such devices require highly productive implanters that can deliver high-current capability over a much wider energy and dose ranges on a single-wafer platform to deliver the highest yields and minimize the cost of chip production by increasing the output from fabs.

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Axcelis Technologies has launched the first single-wafer implanter called the Purion™ H200 that delivers the productivity of a high-current tool with the precision, accuracy, and energy range of a medium-current tool. This paper describes the capabilities of this implanter that has already been qualified in high-volume manufacturing fabs at leading power device companies for both Silicon and Silicon Carbide applications.

The Purion H200 architecture

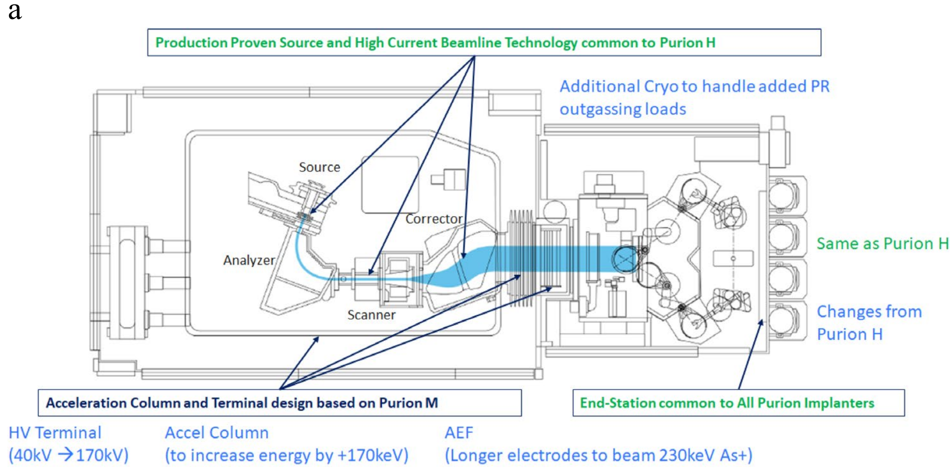
The Purion H200 is built by combining a mature high-current beamline from the Purion H series of single-wafer high-current implanters from Axcelis [1] that are capable of delivering > 20 mA of beam currents (As +, P +, 300-mm wafers) with a post-corrector-accel/decel and high-voltage topology of the Purion M series of medium-current implanter [2] that are capable of implanting single charge species at up to 335 keV) delivering the unique capability for implanting the commonly used dopants (B, P, As) with a maximum single charge energy range up to 230 keV (enabled through a maximum accel voltage of 170 kV) at high beam currents. The Purion H200 layout (top view) is shown in Fig. 1a to highlight the key architectural components for reference. The high-current beamline (leveraged from Purion H) uses an indirectly heated cathode source and is designed with all magnetic elements, 1. Analyzer magnet for mass selection, 2. Magnetic quadrupole lenses for beam focusing and shaping for efficient transport, 3. Magnetic scanner to enable independent control of beam uniformity without compromising the localized angular distributions across the wafer diameter, and 4. An S-bend corrector magnet that enables independent control of average beam direction and beam parallelism across the width of the scanned region. The beamline components described above along with the source and gas box are confined within a high-voltage terminal). Since the energy of the transported beam is referenced to terminal potential (that in turn, is referenced to ground), the final energy of the beam is the sum of the extraction and terminal potentials. It is important to note that this high-voltage topology enables efficient transport of the beam with optimal beam transport efficiency across a broad energy range since the terminal potential could be set to either accelerate or decelerate the extracted beam to its final energy. The accelerated (or decelerated) beam is then bent down through an Angular Energy Filter (AEF) with focus and suppression lenses and variable apertures exit slits to deliver a pure (energy contamination free) monoenergetic beam to the substrate which is processed within the high-throughput Purion™ platform wafer handling system. The Purion H200 also leverages the Vector™ control system that integrates both in situ beam angle metrology for horizontal and vertical beam directions as well as closed-loop dosimetry with constant focal length wafer scanning to deliver the most accurate angles and dose on the substrates.

Capabilities of Purion H200

High beam currents

Designed to deliver high beam currents with high doping precision (Dose, energy, and angles) over a wide energy range due to its unique post-correction accel/decel architecture, the Purion H200 addresses key bottleneck implants for the power, analog, and BCD device manufacturing flows at significantly higher productivity than previously available. The Purion H200 is also specified with maximum beam currents that enable customers to utilize the specified maximum beam currents in high-volume manufacturing giving additional flexibility in production. Representative spot beam currents in the > 40 keV energy range on the Purion H200 system for some commonly implanted species are shown in Fig. 1b. These beam currents are about 3 to 7 times higher than earlier medium-current systems operating over the same energy range. Below 40 keV, beam currents tend to

a



b

Species	Beam Current (emA)	Applications
As^+	≥ 35mA	Power, Analog, BCD, Mature Logic, Foundry
B^+	≥ 20mA	
BF_2^+	≥ 20mA	
P^+	≥ 35mA	
Sb^+	≥ 10mA	
Al^+	≥ 7mA	SiC Power Devices
N^+	≥ 20mA	
Ar^+	≥ 30mA	Material Modifications
H^+	≥ 25mA	Layer Transfer, Heterogeneous Integration
He^+	≥ 15mA	

Fig. 1 **a** Purion H200 beamline layout showing the various elements both common to the Purion H tools as well as the changes needed to support the extended energy range for this implanter. **b** Beam current capability and typical device applications for the Purion H200

get lower ~ 5–20% as the transport efficiency through the beamline becomes a limiting factor. Even though the maximum beam currents are available at > 100 keV, wafer cooling requirements typically limit the maximum usable beam currents.

High beam power handling capability

The use of ion implantation process with photolithography compatible (photoresist) materials is critical in semiconductor device manufacturing. It is important to keep the photoresist temperature below ~ 100 °C (well below the glass transition temperature of the materials used) during implant to avoid resist reflow (that impacts feature definition) and damage to the photoresist material that may result in blister defects (leading to particle generation). Such defects (blisters) may result from pressure buildup in gases (due to rapid heating if there is insufficient cooling) trapped below the damaged crust layer (that is formed due to implant damage of the photoresist) leading to rupture of the resist crust (blistering).

The Purion H200 offers different wafer cooling capabilities customized for different application needs. The extended cooling option allows customers to use up to 2 kW of scanned beam power for 300-mm wafers. This added cooling capability enables the use of higher beam currents in the beam power limited space. Since beam power is a product of beam energy (in keV) and scanned current (mA), a 2-kW cooling capability enables using 20 mA of beam current at 100 keV and 10 mA at 200 keV. Similarly, 2.3-kW cooling option recently released on the same tool enables the use of even higher beam currents for implants at energies exceeding 100 keV (e.g., 23 mA @100 keV, 11.5 mA@200 keV). These extended cooling capabilities are enabled via intelligent scanning algorithms available on the Purion Platform. It is important to note that different scanning rates do not change the total beam on wafer time which is calculated as Eq. (1), but only help with modulating instantaneous power rates on different parts of the wafer

$$Implant\ time = q.Target\_Dose.Scanned\_Area/Scanned\_Beam\_Current \tag{1}$$

Figure 2a shows the impact of 4 different scanning configurations on the maximum wafer temperature observed at different beam powers (achieved by tuning different scanned beam currents at same energy or increasing the energy at the same beam current) for 1e16 at/cm^2 dose implants with B + and As + species on 300-mm wafers confirming the ability to keep the temperature below 104°C in all 19 cases tested. Figure 2b summarizes the observations from photoresist integrity tests conducted on resist coated 300-mm silicon wafers under the same 19 conditions as the temperature dot tests (implants done back to back with the same beams). These were categorized as (a) no damage, (b) stress related stripes near wafer edge, and (c) blistering in Photoresist. As noted, we were able to demonstrate damage-free processing capability of the photoresist-covered wafers with no blisters or stripes at beam powers up to 2400 W through optimization of scan parameters (4) on the Purion H200 system.

Photoresist outgassing management

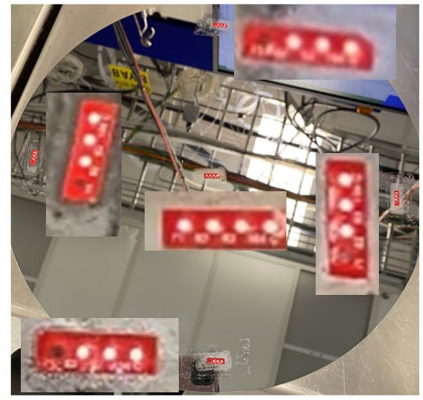
Outgassing from the photoresist during implant presents a unique dosimetry challenge as the beam current measurements done via Faraday cups do not detect neutralized atoms in the beam and thus may cause dose errors/uniformity issues on the wafers that are not acceptable in modern day implanters [3]. Since the outgassing flux (and thus beam neutralization) varies during the implant due to various factors including the changing wafer surface area being exposed to the beam during scan; type/wetness and surface coverage fraction of photoresist; accumulated dose; neutral gas density/pressure in the beam path; and neutralization capture cross-section coefficients, this issue needs to be handled carefully in the implanter design and factored into the dose control system. Purion H200 is designed with increased pumping in the process and AEF chambers. The tool is further equipped with variable slits that minimize the conductance for outgassed materials from traveling upstream. Lastly the dose cups used in closed-loop dose control during implant are located near the beamline exit and only measure the ions that are directed toward the substrate after making the bend through the AEF. The upstream location of the dose cups enables real-time monitoring of beam current changes (drop due to neutralization of the beam) during outgassing conditions (wafer scanning through the beam) which is then used to dynamically adjust the wafer scan velocity (slow down) during each pass with a specially developed dose control algorithm that compensates for delivers < 2% dose uniformity and < 2$ dose shift even under very challenging (heavily outgassing) high-power implant conditions. This is demonstrated in Fig. 3 where we compare the vertical profile uniformity (measured as 1 sigma of top to bottom line scan of target dose) measured of 2-pass implants with B^+ and As^+ at high beam currents at 3 different energy levels. As seen in the charts, with our compensation algorithm enabled (on), the dose shift (average of the blue profiles) and dose uniformity (1 sigma of the blue profiles) are significantly better than the same line scans with compensation turned off (standard dose correction was still on). The actual values for dose uniformity and dose shift are quantified in the right half of the figure. In all cases, both the dose shift and the dose uniformity were demonstrated to be better than 2% with the PR compensation algorithm enabled thus confirming a

Temperature Test Results

B+ 200keV 1e16		Scan1	Scan2	Scan3	Scan4
ROI Power (W)	2000	<82°C			
	2300	<82°C	<93°C	<82°C	<82°C
	2500		<93°C	<82°C	<82°C
	2800		<93°C	<82°C	<82°C

Temperature Test Results

As+ 120, 140keV, 1e16		Scan1	Scan2	Scan3	Scan4
ROI Power (W)	2040	<71°C			
	2400	<82°C	<82°C	<82°C	<82°C
	2800		<93°C	<82°C	<82°C



b

Photoresist Damage

B+ 200keV 1e16		Scan1	Scan2	Scan3	Scan4
ROI Power (W)	2000	No			
	2300	No	No	No	No
	2500		No	No	No
	2800		No	No	No

Photoresist Damage

As+ 120, 140keV, 1e16		Scan1	Scan2	Scan3	Scan4
ROI Power (W)	2040	No			
	2400	Yes	No	No	No
	2800		Yes	Yes	Yes

Fig. 2 **a** Results from temperature dot testing on wafers implanted with Boron or Arsenic beams with 1e16at/cm2 dose indicating the impact of various scan conditions on max temperature across the wafer (among all 5 temp dots). Photograph on the right shows the location of the temperature dot stickers on the wafer for As 2400-W implant as a sample (all tests were done similarly). Inserts are zoomed in images of the temp dot stickers that show that the 71-C dot was discolored, but 82-C dots were not confirming the temperature did not exceed 82 C on any of the locations tested on the wafer. Yellow highlighted cells in the summary table to the left indicate partial discoloration of the 93-C temp dot, while green highlight indicates no visible change. **b** Summary of Photoresist damage studies for under various beam power conditions for 1e16 B + and As + implants showing the value of optimizing the scan settings to prevent damage to the photoresist (observed near wafer edges). Important to note that the radial stress cracks may be an artifact of the blanket (unpatterned) photoresist layers

the excellent dose and uniformity control capability of the Purion H200.

Silicon carbide (SiC) option

The Purion H200 with SiC option offers the ability to process SiC wafers both at 150-mm and 200-mm wafer sizes. The SiC option integrates capabilities needed in doping SiC substrates including a source solution for Aluminum implantation, capability for heated implants for up to 650 °C wafer temperature, and reliable wafer handling for SiC wafers proven in several high-volume manufacturing fabs. The aluminum source utilizes a low temperature vaporizer with in situ CleanFlow technology that delivers high beam currents for typical dopants for SiC devices (7-mA Al^+, 20-mA N^+, 35-mA P^+, refer Fig. 1b). The Purion H200 tool with the SiC option also comes with an integrated preheat station and heated wafer clamp capabilities to deliver high productivity for bottleneck implants (especially high-dose Al, P, and N) in the SiC MOSFET manufacturing flows.

Available for 300-mm/200-mm/150-mm wafer sizes

The Purion H200 is offered in both 300-mm and 200-mm wafer sizes for Silicon substrates and in 150-mm and 200-mm wafer sizes for SiC substrates leveraging Axcelis' common wafer handling platform.

Applications space served by the Purion H200

The Purion H200 covers all medium (1e13 at/cm2) to high dose (typically up to 1e16 at/cm2 but extendable to 1e17 at/cm2 doses) implant applications from 10 keV up to 230 keV (and up to 460 keV with++) implant energies and thus valuable to power device (Si and SiC), analog chip, BCD, and mature device manufacturers as a versatile single-wafer high-current machine. The typical and expanded process space (dose/energy) for the Purion H200 are mapped for easy reference in Fig. 4. The dots represent various implants used in power, analog, BCD, and mature device manufacturing. It is notable that the scanned spot beam architecture (mimicking medium-current tools known for high dose and angle precision) enables lower-dose implants (1e12–1e13 at/cm2 dose) with excellent angle and dose uniformity as the small ion beam can be swept (scanned) across the wafer surface with tunable scan waveforms to deliver uniform dose across the sweep. This precision allows the Purion H200 to be used as a medium-current backup tool in a production fab. The tool is uniquely suited for ALL high dose (> 1e14at/cm2), higher-energy (≥ 60 keV) implants that are commonly used in power devices, including power MOSFETs, Insulated Gate Bipolar Transistors (IGBT), Bipolar transistors, and integrated analog and BCD devices. Furthermore, the Purion H200 with SiC option has opened the path for SiC device manufacturers to significantly improve the fab output by moving the bottleneck (high-dose p++ and n++ contact doping) implant chains onto the Purion H200 high-current tool while freeing up implant capacity on the medium-current tools, hence maximizing the overall bay productivity of their implant bays.

We should highlight that the unique architecture of the tool also enables new applications. These include high-dose higher-energy implants with heavy mass species (e.g., Ar, Xe, Sb, In) for material modification applications and high-dose proton and helium (H+, He+) implants up to 200 keV for layer transfer applications that may be useful in developing alternative substrates or used in heterogeneous integration schemes for advanced technology nodes.

Conclusion

The global movement away from fossil fuels as the primary energy source in favor of renewables coupled with a push for ever-more energy efficient solutions (including miniaturization of devices) is driving a demand for power and IOT devices. To support the production capacity expansions of such devices while driving the cost of manufacturing lower, new solutions are needed that address the unique production bottlenecks in the manufacturing flows and open new

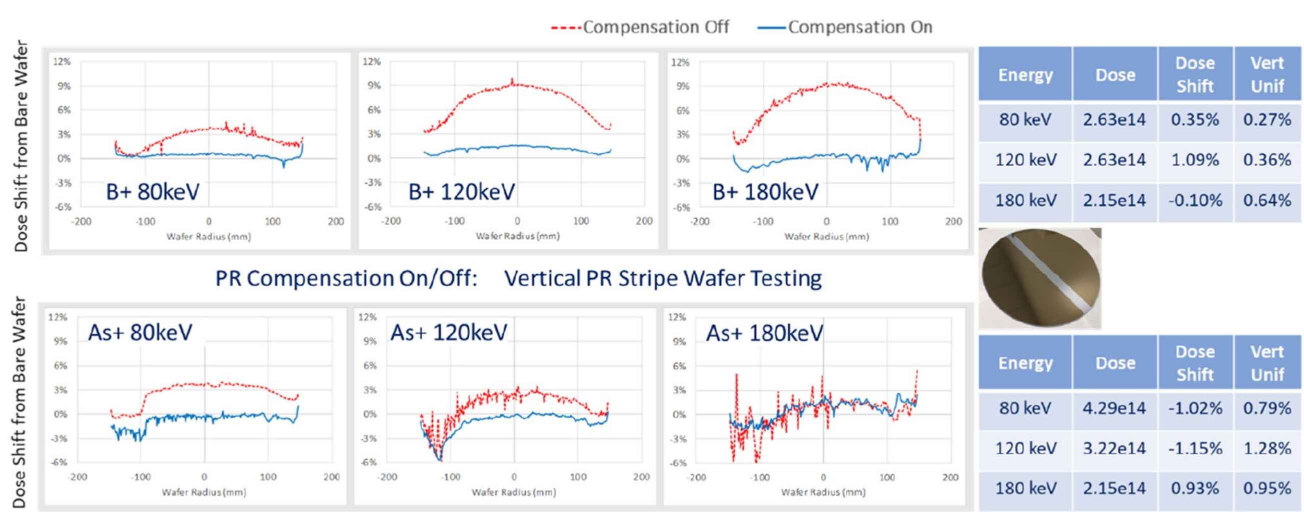


Fig. 3 Vertical dose uniformity profiles obtained at different beam energies (80, 120, 180 keV) for 2-pass implants with Boron (Top half) and Arsenic (bottom half) at highest beam currents showing the excellent dose uniformity and minimal dose shift with implants on wafers. The implants were done on PR-coated wafer with vertical striped region (shown in picture) at 20-cm/sec (nominal) scan speed to compare the uniformity with (blue line) and without (red-dashed line) PR compensation enabled

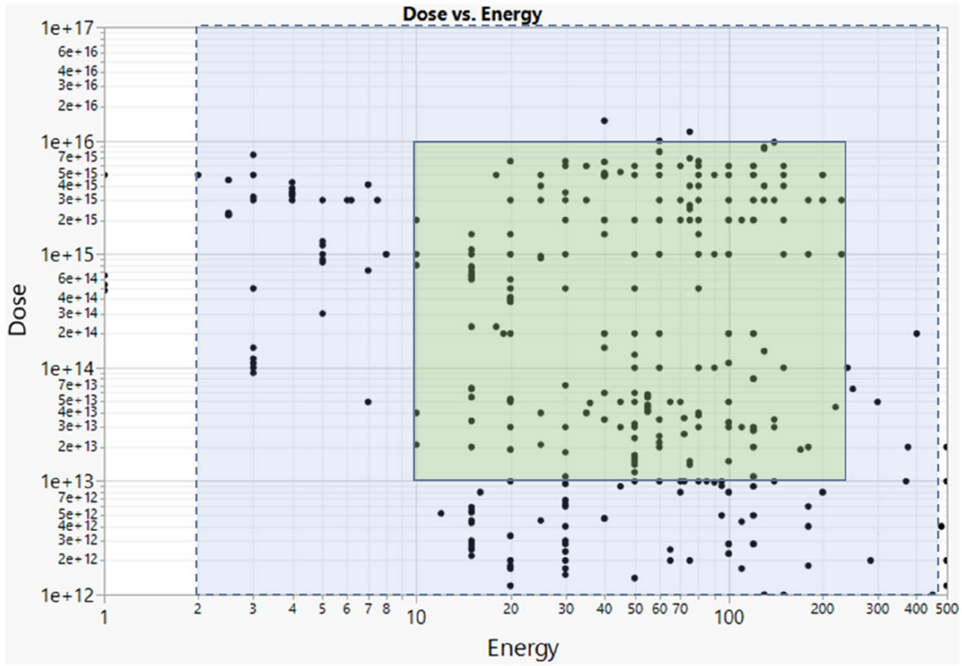


Fig. 4 Application space covered by the Purion H200 implanters. The green (inner) box represents typical operating space, while the blue (outer) box shows the extended capabilities of the tool. Dots represent various implant conditions used in power, analog, bipolar, mature, and BCD device manufacturing applications

application spaces to develop novel technology solutions for the future. To this goal, Axcelis Technologies has launched a new single-wafer high-current tool capable of covering the high- and medium-dose applications across a broad energy range from < 10 keV to > 200 keV (Single charge) for both Silicon and SiC device manufacturing. The Purion H200 tools are already integrated and qualified in leading power device manufacturing fabs for both device types and are opening up new implant applications with the wide process window that it covers.

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Data availability The datasets generated and mentioned in the paper are available from the corresponding author on reasonable request.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

1. B. Vanderberg, P. Heres, E. Eisner, B. Libby, J. Valinski and W. Huff, Introducing Purion H, a scanned spot beam high current ion implanter, in *2014 20th International Conference on Ion Implantation Technology (IIT)* (2014), pp. 1–4. https://doi.org/10.1109/IIT.2014.6940041
2. E. Eisner, J. David, P. Justesen, D. Kamenitsa, E. McIntyre, R. Rathmell, A. Ray, R. Rzeszut, Optima MDxt: A high throughput 335 keV mid-dose implanter. AIP Conf. Proc. **1496**, 340 (2012). https://doi.org/10.1063/1.4766558
3. L. Rubin, J. Poate, Ion implantation in silicon technology. Ind. Phys. **9**(3), 12–15 (2003)

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