

ClusterBoron™ Implants on a High Current Implanter

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Abstract. Advanced p-junction process tool throughput continues to be one of the principal drivers of the industry. First results from an octadecaborane ($B_{18}H_{22}$) ClusterIon® source integrated on an existing high current implant tool are presented. Beam current, throughput and process results are reported. The dose multiplication effect of the use of $B_{18}H_{22}$ means that an electrical current of 1mA produces a dopant flux equivalent to 18mA, while the energy equipartition means that a 20keV octadecaborane ion is process equivalent to a 1keV boron beam. Some modifications to a traditional high current beamline design were made in order to take advantage of the opportunities presented by this new ion source. A somewhat larger extraction slot was used and this, coupled with the fact that the ions have a large mass (210 amu) and therefore have high magnetic rigidity even at modest energies, drove the optics design toward a parallel-to-point configuration. Good mass resolution and control of beam size were demonstrated. Beam currents and throughput that are significantly higher than those available from traditional high current implanters were achieved, along with good process results.

Keywords: High current implantation; molecular implantation

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INTRODUCTION

A key figure of merit in high current, or high dose as it is increasingly described, ion implantation is beam current. As devices shrink and the energies get lower, the ability to generate and transport high ion beam currents becomes increasingly more difficult. Traditional high current tools have thus resorted to a number of techniques such as shortening the beamlines and using deceleration to access the lowest beam energies. Molecular implantation offers another alternative since the effective energy of the implanted atom is lower while the transport energy is higher. Therefore, both deceleration mode operation and energy contamination are avoided. Well known examples of molecular implantation include BF_2 and the dimers of arsenic and phosphorus (As_2 and P_2)^{1,2}. New source materials for molecular implantation include the boranes (B_xH_{x+4}) which have the additional feature that there are multiple B atoms per molecule, thus also multiplying the dose³.

Octadecaborane ($B_{18}H_{22}$) has both of these advantages. Since there are 18 B atoms per molecule, the dopant flux for a given electrical beam current is increased by that factor and thus also the effective beam current: 1 mA of delivered beam becomes 18 mA of dopant flux. In addition its high mass (210 AMU at the peak of the spectrum) leads to essentially a factor of 20 decrease in the effective energy: 60 keV extraction and transport yield 3 keV effective energy. Both of these effects mitigate space charge blowup of traditional high current tools since high extraction energy and relatively low current are transported to the wafer while yielding high throughput beams for enhanced productivity.

The 20:1 effective energy reduction allows some key high dose process applications to fall within the capabilities of mostly traditional high current tools. For example, the Dual Poly Gate (DPG) application space was chosen for this first implementation and thus the effective energy of 1.5 keV to 4 keV B is the target energy range. The rest of this paper will discuss

the equipment, show some resulting beam currents and throughput, typical mass spectra and resolution are discussed and beam size is shown, and finally include implant process results obtained to date.

EQUIPMENT

Ironically, the features previously mentioned, which allow for ease of transporting high beam currents at low effective energy, pose some new challenges for beamline design. The combination of high mass – up to 220 AMU and up to 80 keV extraction energy - implies very high magnetic rigidity in the analyzer magnet. Typical high current AMU magnets are designed for transporting 80 keV Arsenic and thus have a mass – energy product of about 6000 AMU – keV. Octadecaborane, on the other hand, requires roughly a factor of 3 higher rigidity of its analyzer magnet in the energy range of interest.

In addition, the ClusterIon[®] source allows for an increased length extraction slot to maximize extraction area and thus extraction current, further increasing the challenge of designing an analyzer magnet with sufficient capability. A novel approach of using a smaller pole-gap magnet in a horizontal configuration was used to take advantage of an existing magnet design as a drop-in replacement to a standard high current beamline. The existing magnet is essentially the same as is used in the Axcelis Paradigm high energy tools as the final energy magnet. Since the magnet’s pole gap was not wide enough to allow full acceptance of the slot when mounted vertically, for this teststand the source was mounted horizontally, which changed the beamline optics from point-to-point to parallel-to-point. In addition a downstream electrostatic quadrupole was installed to control beam spot size. Shown in Fig. 1 are the elements of the beamline in this first teststand.

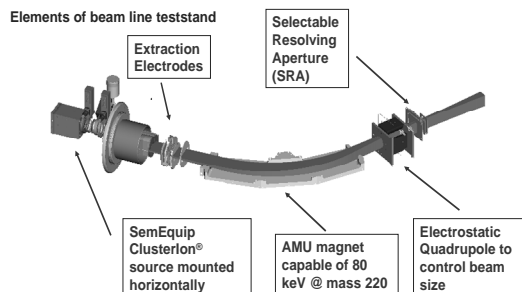


FIGURE 1. The beamline elements of the teststand.

However, for less than the highest DPG energies, a standard high current beamline can be used for integration of the ClusterIon[®] source and a second teststand was, therefore, outfitted in this way. For that second teststand the maximum extraction energy was limited by the analyzer magnet to less than 30 keV (max effective B energy of less than 1.5 keV) but it served to also demonstrate beam current and throughput but in a more traditional optics setting.

In moving forward with productization of this technology a dedicated analyzer magnet was designed that is capable of handling the high magnetic rigidity demands of the DPG application, while allowing for preservation of the traditional optics and a vertical source orientation.

BEAM CURRENTS AND THROUGHPUT

Octadecaborane is transported with reasonable efficiency in a high current beamline. Shown in Table 1 are the parameters for 18 mA of effective beam current at 2 keV effective energy, which current is significantly higher than available from a traditional high current implanter. Yet, this first source had not been fully optimized for extraction area. A second iteration with a larger extraction slot yielded nearly 28 mA of effective beam current and this is shown in Fig. 2, where the beam current and transmission (electrical mass-resolved beam current to extraction current ratio) are shown plotted versus the source’s emission current for 20 keV extraction energy. Future improvements are expected to yield 40 mA effective beam currents by the end of the year, driven largely by optics improvements to both the source and beamline. For a 1.0E16 dose at a beam current of 40 mA, more than 50 wafers per hour is expected to be the typical DPG throughput for 300 mm process.

	Currents	Electrical	B Effective
Beam current		1.0 mA	18 mA
Extraction current		4.7 mA	
Suppression current		0.1 mA	

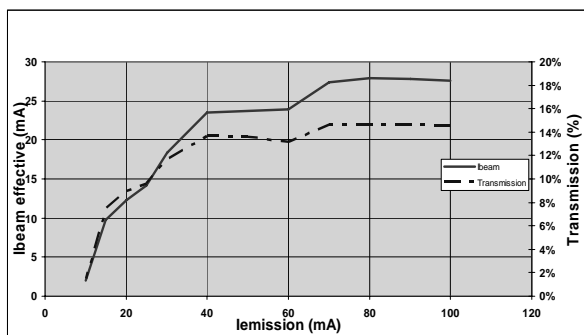


FIGURE 2. Beam current and transmission versus source emission current.

MASS SPECTRA, MASS RESOLUTION AND BEAM SIZE

The dominant feature of the mass spectrum of octadecaborane consists of a large, broad peak centered just beyond mass 200. While $B_{18}H_{22}$ is formally mass 220, the width of the spectrum peak (fine structure) can be understood to be made up of different numbers of hydrogen atoms in the molecule and the binomial distribution of the isotopes present in natural boron material³. Similarly, the next lowest mass borane, $B_{17}H_{21}$, has its endpoint mass at 208 but is peaked at approximately mass 196. Shown in Fig. 3a is a high resolution spectrum and in Fig. 3b is a comparison of two spectra obtained with different widths of the resolving aperture. With a narrow, 8 mm aperture, the feature of the $B_{17}H_x$ is visible while it is contained in the wider, 33 mm aperture. In order to maximize beam current a wider slit is desirable while the minimization of energy and dose contamination calls for a narrower slit. While these requirements go in opposite directions, it has been seen that accepting 15 AMU at the peak of the $B_{18}H_{22}$ spectrum (mass resolution of 14) is sufficient to include less than 1% of B_{17} in the accepted beam current which guarantees less than 1/18% dose error⁴. The next most prominent feature of the mass spectrum is the doubly charged octadecaborane peak located at approximately mass 100.

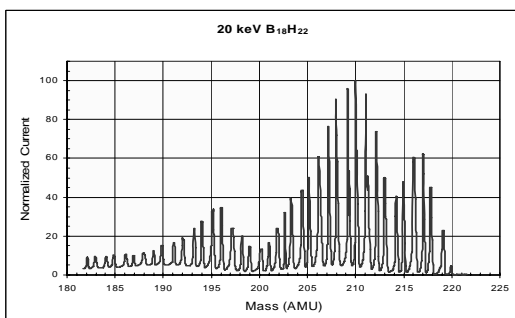


FIGURE 3a) Ultra high resolution spectrum showing individual hydrogen atom components

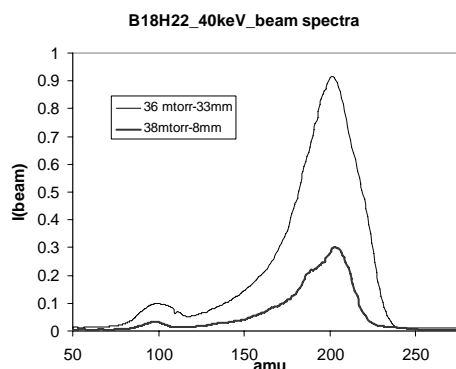


FIGURE 3b) Comparison of mass spectra obtained with two resolving slits.

The beam size as obtained in the high current implanter was found to be quite reasonable, even without utilization of the quadrupole lens downstream of the AMU magnet. Shown in Fig. 4 is a typical profile of the beam at the disk for a 40 keV extraction energy (2 keV equivalent) and an effective beam current of 12 mA .

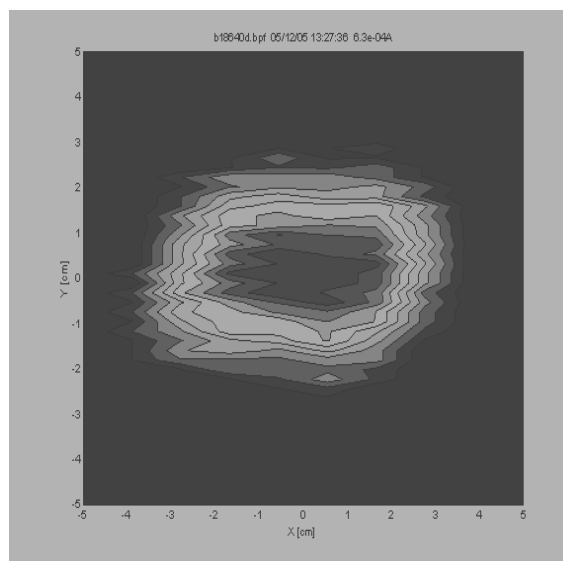


FIGURE 4. Typical beam size measured at disk.

PROCESS RESULTS

Above and beyond beam current, the next characterization challenge for octadecaborane occurs in the assessment of process results. Uniformity and Rs have both been found to be within specification for the equivalent B recipe and are indicated in Table 2.

The difference in R_s can be compensated with a dose trim factor. Particles have been seen to be within spec on the test stand and are shown in Fig. 5 indicating no fundamental difference for molecular implant. Metals contamination also is within spec and is shown in Table 3. One additional process note is that the profiles from B18 are always shallower than those of B when implanted into crystalline silicon as a result of suppression of channeling which results in a self-amorphization with B18 implants. This is shown in Fig. 6.

Condition	R_s (mean)	%SD (mean)
B18	136	0.43
B	126	0.65

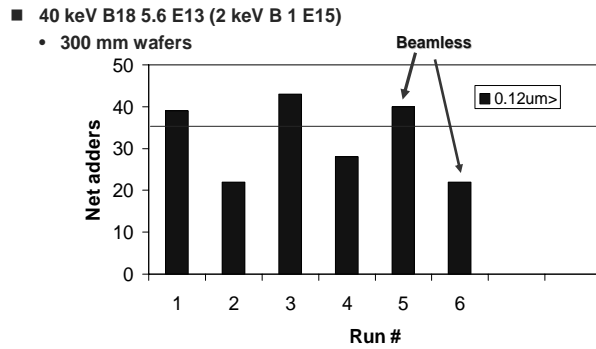
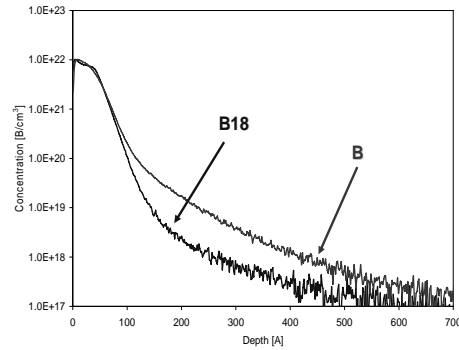


FIGURE 5. Sample particle data.

Metal	Results ($10^{10}/\text{cm}^2$)	Spec ($10^{10}/\text{cm}^2$)
Al	64	100
Cr	0.095	5
Cu	0.015	5
Fe	1.1	5
Ni	0.13	5
Ti	0.44	5



Channeling is suppressed in B18 implants – self amorphizing when implanted in crystalline silicon

Figure 6. Profiles of B18 and B.

SUMMARY

First results from the integration of a ClusterIon[®] source on a high current ion implanter have been shown. Beam currents that are significantly higher than available from traditional high current tools have been demonstrated with good process results.

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