A HIGH-CURRENT OXYGEN ION SOURCE

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Summary

Production of buried oxide layers in silicon by ion implantation requires very high currents of atomic oxygen ions for an acceptable production rate of implanted wafers. A high-current dc ion source developed at Chalk River has been adapted for this application. Total beam current from the source was 230 mA at 52 keV with a 9.5 A arc. Based on the 60% O^+ fraction, measured on a source with only three of a possible seven apertures open, up to 138 mA of O^+ are available for implantation. Oxygen consumption ranges from 2-3 scc/min (3.4-5.1 Pa·L/s) at typical operating conditions, and filament lifetime from 10 to 15 hours. This paper describes the source and its performance. The source is presently in use on a commercial prototype high current oxygen implanter.

Introduction

One of the most promising new techniques[1] for the fabrication of integrated circuits is Silicon on Insulator (SOI), where the active part of the circuit is fabricated in a very thin layer of silicon on an insulating substrate. Presently, the best method for forming SOI is ion-implantation[2]. Oxygen ions, with an energy of from 200 keV to 400 keV penetrate a short distance into the wafer and, combining with the silicon where they stop, form an insulation layer of SiO_2. The wafers are held at ≈ 600°C while being implanted to permit continuous annealing of any damage to the surface layer of silicon. Further high temperature annealing after implantation aids in the formation of a thin, defect-free silicon layer on an oxide layer with a sharp boundary between the two. The reduced circuit-to-circuit interference, possible because of the shielding insulating layer, permits closer spacing of devices giving increased speed and reduced power consumption. Other advantages are reduced tendency to latch-up and improved radiation resistance (since free charges formed in the bulk substrate cannot migrate through the oxide layer).

Since macroscopic quantities of SiO_2 are formed, high doses (10^{18} ions/cm^2) are required. The ion sources presently used provide less than 10 mA of O^+ so production rates are low and costs are high. Also, because of the long implantation times required, contamination is a problem. For economic production of SOI wafers, an ion source providing at least 100 mA of O^+ is necessary and 200 or 300 mA desirable. The source also needs to operate stably and provide good beam quality because a 2-stage acceleration scheme, where the source voltage is adjusted to match the current and a second accelerating tube provides most of the energy gain, is preferred to permit independent control of beam energy and current and to reduce difficulties in disposing of the molecular ions formed in the ion source. Good beam uniformity aids in achieving the ± 5% implantation uniformity required. To reduce downtime in a production environment, the source components must have a long lifetime and, especially in the case of the filament, must also be easily maintained. This paper describes an ion source that meets these requirements.

Description of the Ion Source

This source is a variant of one developed for use on high-current cw proton accelerators[3]. Figure 1 is a photograph of the ion source and Fig. 2 shows the major source components and the electrical connections. Plasma is generated in a magnetically confined hot-cathode reflex-arc or duoPIGatron. The filament used for operation with oxygen is made from 1.3 mm diameter rhenium wire, 60 mm long, formed into a non-inductive flat spiral. The intermediate electrode uses a mild steel core to shape the magnetic field provided by the coil. Argon is injected through the intermediate electrode to reduce oxygen damage to the filament. The upper part of the plasma generator acts as an electron feed for the reflex arc chamber, where most of the ionization takes place. Electrons coming through the canal in the intermediate electrode are trapped on the magnetic field lines, and so cannot

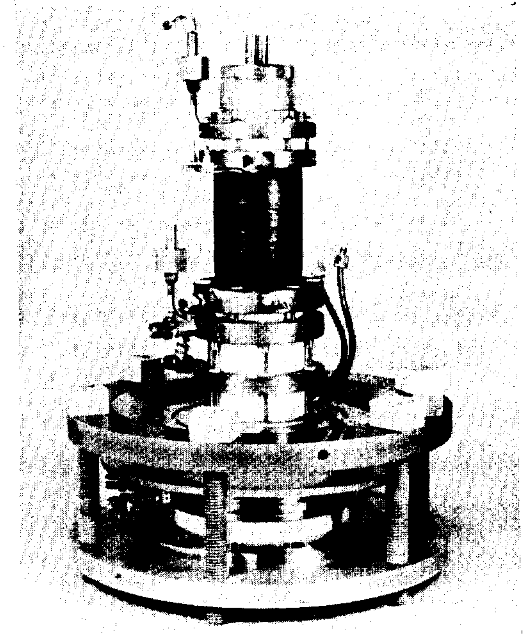

Fig. 1 Photograph of ion source.

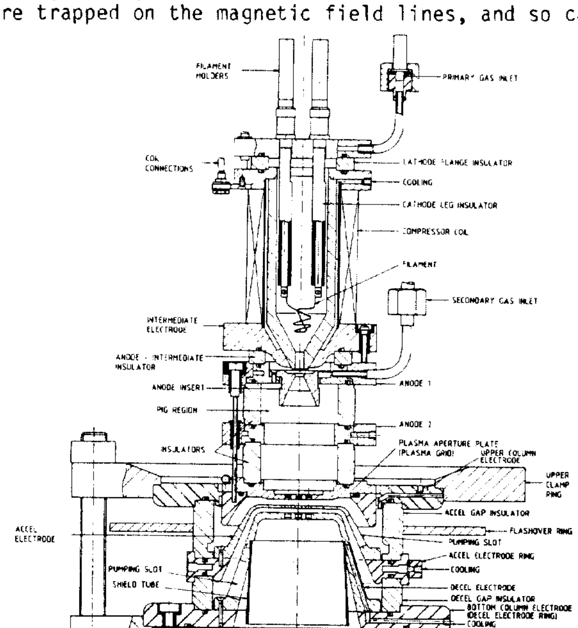

Fig. 2 Drawing of ion source.

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go directly to the anodes. Both the plasma aperture plate and the intermediate electrode operate at about 50 volts negative with respect to the anode. (The cathode is about 100 volts negative.) Thus, the electrons are electrostatically trapped axially and magnetically trapped radially - providing an efficient plasma generator. Since the density of the electron beam controls the plasma density, shaping of the magnetic field distribution provides a large area of uniform plasma at the exit apertures.

The ion beam is extracted through seven 5 mm diameter apertures in a hexagonal array (with one aperture at the centre). The apertures are shaped on the downstream side to control divergence and reduce aberrations. This shaping removes the need for a separate focus electrode and its associated power supply. The good beam quality available with this system provides low spill on column electrodes (reducing sparking and damage) and low halo on the beam. Water cooling of the plasma generator and column electrodes permit stable operation at full output with little electrode erosion.

This source, although more complex and difficult to design than others[4], provides very good gas and arc efficiency. The double chamber design allows use of an inert cover gas fed into the cathode chamber to protect the cathode from attack by the oxygen. The low plasma potential reduces sputtering so that beam impurities and erosion of the plasma generator electrodes are minimal. The high current density provided by this source permits a compact design and the small electrode area at high gradient in the extraction column reduces sparking. The multiple apertures provide high current at low energy and permit tailoring of the beam intensity distribution. The simple, self-aligning mechanical design provides easy assembly and excellent source-to-source reproducibility.

Table 1

Operating Parameters

Filament	89 to 90 A	8.5 to 9.5 V
Coil	0.9 to 1.3 A	45 to 70 V
Arc	<3 to >10 A	60 to 125 V
Argon Flow	0.7 to 0.9 scc/min	(1.2 to 1.5 Pa·L/s)
Oxygen Flow	2.6 to 3 scc/min	(4.4 to 5.1 Pa·L/s)

Performance

Table 1 gives typical values for ranges of the operating parameters of the ion source. Most of the optimization of the ion source was carried out with only three of the seven apertures open to limit damage to the measuring equipment on the test stand. Figure 3 shows beam current as a function of arc current at three different coil currents. The beam current increases with arc current and with coil current. However, the coil current is not a completely free parameter. For best source stability, the coil current must be increased from 0.9 to 1.1 A as the arc current increases from 4 to 10 A. Too high a coil current can reduce beam quality. Figure 4 shows matched beam current as a function of extraction voltage, where the matched condition is found by adjusting the voltage until the beam, as viewed at a point 40 cm downstream from the extraction apertures, is sharply defined. The matched current with a coil current of 1.3 A is significantly lower than with 0.9 or 1.1 A on the coil. This is not caused by changes in the effective mass of the beam which varies only slowly with arc and coil currents. The cause is most likely perturbation of the plasma meniscus by the magnetic field.

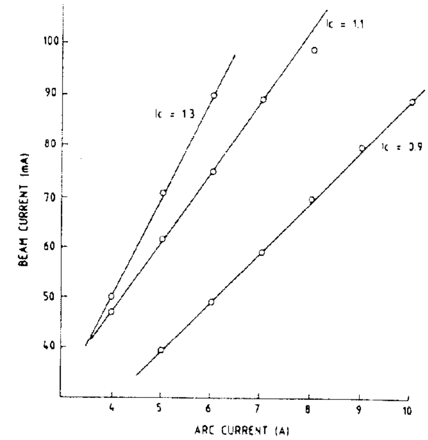

Fig. 3 Beam current from three apertures vs arc current, for three values of coil current I_c(A).

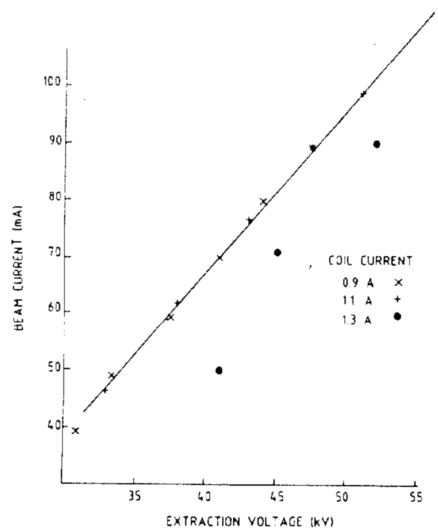

Fig. 4 Matched beam current from three apertures vs extraction voltage.

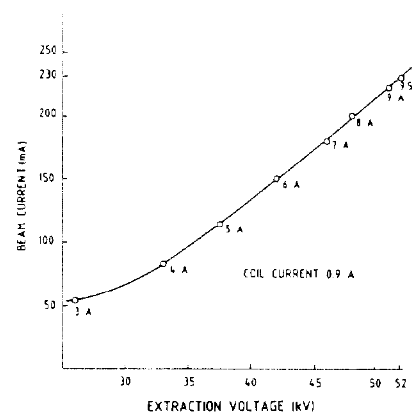

Fig. 5 Matched beam current from seven apertures vs extraction voltage.

Figure 5 shows the matched beam current as a function of extraction voltage with seven apertures open. The coil current was maintained at 0.9 A and the gas flow was slightly lower than in the previous set of measurements. The maximum current was 230 mA at 52 keV with a 9.5 A arc. Ion species ratio measurements carried out with three apertures open (Table 2) show a fairly consistent 60% of O^+, thus the maximum O^+ current from the source was 138 mA.

Table 2

Ion Species Ratios

Arc Current	% Ar^+	% O_2^+	% O^+
7 A	12	28	60
8 A	13	30	57
9 A	17	22	61
10 A	17	23	60

$Ar^{++} \leq 1\%$

Coil Current	0.9 A
Argon Flow	0.7 scc/min (1.2 Pa·L/s)
Oxygen Flow	2.6 scc/min (4.4 Pa·L/s)

To the eye, the individual beamlets are well defined and well separated 40 cm downstream from the extraction grids. To achieve this small degree of spreading, the beamlets must be more than 95% space charge neutralized. Figure 6 shows a phase space plot for a beam from 3 apertures in a line, measured 56 cm downstream from the extraction column. The solid contours shown are at two percent of the peak intensity and enclose 95% of the beam. The parallelogram enclosing all the beamlets has an area of 173 cm-mrad for a normalized emittance ε_r of 0.121 π cm-mrad. The dotted contours show where the beams from the other apertures would be.

After a few hundred hours of operation at several currents, only the filament showed any obvious damage. No long runs to test filament lifetime were carried out. However, filament lifetime during the test program varied from 10 to 15 hours. The source operated stably over a wide range of conditions and the reproducibility of beam current was limited by the reproducibility of power supply and gas flow settings (a few percent). Performance of a second source assembled from completely different parts showed the same consistency.

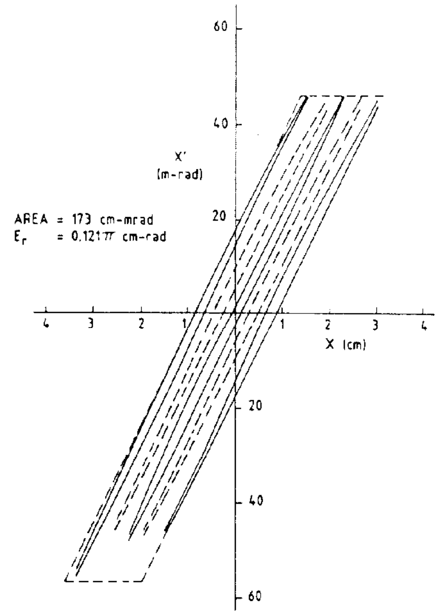

Fig. 6 Phase space plot of beam.

Conclusions

This paper has outlined the design and performance of a high-current cw oxygen ion source that, in its present form, can provide 138 mA of O^+ at 52 keV with about 1 kW of arc power and 3.3 scc/min total gas flow. Higher current is possible by increasing the size of the apertures, or by increasing their number. The current density at the outer apertures is ≈ 5% higher than at the centre, indicating that a larger extraction area is usable.

Two ion sources have been installed at Eaton/Nova in Danvers, Massachusetts, one on a test stand and the other on the prototype oxygen implanter. Performance on these facilities is as good as on the test stand at Chalk River.

Acknowledgments

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