Production-worthy Al beams for SiC applications

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This paper describes a new ion source optimized for Al beam production. Source lifetimes of over 250 hours of dedicated Al use have been demonstrated, with stable operation throughout life. Beams are tuned automatically with success rates exceeding 95%. Flowing hydrogen into the injector extraction region as well as through the plasma chamber is important for stable operation; a system to supply hydrogen via the electrolytic decomposition of water has been developed and is described.

Keywords—Ion source, aluminum, silicon carbide, hydrogen

I. Introduction

The market for silicon carbide (SiC) power devices is a rapidly growing segment of the overall power devices market, predicted to reach $1B by 2022. Using ion implant to fabricate devices poses different challenges than those encountered in implanting silicon (Si). The lower crystal quality of SiC wafers and the fact that damage cannot be fully repaired, even by a high temperature anneal once a critical damage threshold has been exceeded [1], require that many implants be done at temperatures >500°C. Aluminum (Al) is often preferred over boron as a p-type dopant due to its higher degree of ionization at a given concentration [2]. The low diffusivity of Al in SiC, (4.64×10^{-16} cm^2/s at 1350°C c.f. 2×10^{-10} cm^2/s in Si at the same temperature) requires multiple implants to produce extended profiles [3].

II. Aluminum Feeds For Ion Sources

Unfortunately, in contrast to boron, there are few gaseous sources of Al, and none convenient for use in the conventional Indirectly-Heated Cathode (IHC) ion source. Practical choices are limited to solid targets placed in the ion source, which liberate Al via sputtering and/or chemical action, or materials placed in a heated vaporizer close to the ion source and raised to a temperature sufficient to generate the 10 mtorr or so of vapor pressure required by the source. Materials been used for as sputter targets include Al_2O_3 and AlN, while vaporizer options included $AlCl_3$ and AlI_3. In the case of materials placed in the ion source it is inevitable that some of the Al-containing material will be present in the plasma at all times..

Unfortunately, these feeds suffer from the common deficiency that, while Al^+ beam currents of several mA can typically be obtained, source lifetimes are very limited, typically to a few tens of hours. The usual failure mode is high voltage instabilities ("glitches") caused by the deposition of insulating material in the ion source and the electrodes defining the extraction optics. The usual mode of failure is glitching between source and suppression electrode.

One response is to intersperse Al operation with other species, designed to clean the source and extraction electrodes, but this puts undesirable constraints on job scheduling or tool availability. A preferred alternative is to flow a co-gas into the ion source simultaneously with the dopant gas, with a chemistry chosen to mitigate the deleterious effects of the dopant feed.

III. Preventing Deposition With Aluminum Tri-Iodide

After tests of potential feeds, AlI_3 was selected as the vaporizer material to be used in the version of the Purion M, a modern medium current implanter [4], tailored for SiC applications and featuring high temperature wafer handling.

Without the use of a co-gas AlI_3 exhibits the same characteristics as other Al alternatives – it produces adequate beams currents of Al^+ and Al^{++} but after a period of only up to tens of hours source-suppression glitching becomes so frequent that cleaning is required.

The cause of the glitching appears to be the formation of insulating compounds in the extraction region. In addition, iodine is condensed on cooler surfaces in the source. When the source is exposed to atmosphere, this iodine reacts with water vapor to produce HI and HIO. To avoid exposure it is necessary to vent and pump the source chamber several times before removing the source. Sources typically show heavy brown deposits, as shown in Fig. 1.

Fig. 1. Ion source following AlI_3 operation

Initial attempts were made to control glitching and deposition by introducing ~0.5 sccm of H_2 as a co-gas. The expectation was that the hydrogen would lead to the formation of gaseous products that would be pumped away, according to the reactions of the type:

$$2AlI_3 + 3H_2 \rightarrow 2Al + 6HI \quad (1)$$

While glitching and deposition was somewhat improved it was still not production-worthy; although the arc chamber itself was cleaner, deposition on the extraction electrodes led to instabilities and the source body showed deposition also.

In response, a gas distribution system external to the arc chamber was added to the ion source in the form of a 1/8" diameter stainless steel tube positioned around the source body just below the height of the arc chamber. This tube has a series of holes along its length, half of them pointing towards the extraction region, and the other half aiming backwards towards the bushing isolating the energized source. A gas line and flow control system separate from the arc chamber gas supply system supplies H_2 to this bleed system.

Tests showed that flowing ~3 sccm of H_2 through this bleed system was sufficient to maintain source, electrode, and bushing cleanliness with minimal loss of beam current from the higher pressure in the extraction region. Fig. 2 shows the condition of the source body, arc slot, and suppression electrodes following 192 hours of dedicated AlI_3 operation. No deposition is evident and no reaction by-products were observed when the source was vented. The gas bleed ring is visible in the left hand image.

IV. Source Stability and Performance

Preventing deposition results in stable source operation. Fig. 3 shows a trend plot of a ~1.5mA Al^+ beam for 16 hours from about hour 25 of source life. The beam current (brown trace) varies by less than 10% over this period and only 23 glitches in the suppression current (red trace) were observed.

A stable beam having been established it was possible to optimize the AutoTune performance of the system. Table 1 summarizes the results of a five-day test running implants designed to mimic typical production Al^+ and Al^{++} recipes. Standard 150mm diameter SiC wafers were used.

Fig. 2. Ion source following 192 hours of AlI_3 operation with the new bleed system

AutoTune success rates exceeded 95% and the average AutoTune time was less than three minutes.

AutoTune can also successfully transition to and from the other common SiC dopants of P, B, and N.

In marathon tests using dual vaporizers filled with AlI_3 source lifetimes >250 hours for dedicated Al operation and >350 hours for mixed species operation have been observed. These lifetimes are limited by the capacity of the vaporizer reservoirs.

V. In-Situ Hydrogen Generation

Although the gas box of the Purion implanter systems is certified for use with high-pressure hydrogen cylinders, some users prefer not to use such cylinders. Sub-atmospheric source of H_2 are available from major implant gas suppliers but are significantly more costly than pressurized gas.

In response, a system based on a commercially available hydrogen generator was developed for use in the implanter gas box. This system utilizes the electrolytic decomposition of distilled water to produce hydrogen at better than 99.9995% purity. No differences are observed in the mass spectra of beams using bottled and generated hydrogen and metals testing shows no elevated levels of any contaminates when using the generator.

The entire system of hydrogen generator, water reservoir, and gas flow controls fits into a single gas card space in the Purion gas box, as shown in Fig. 4.

The generator incorporates a desiccant cartridge to remove water vapor from the hydrogen feed. This cartridge, which can be replaced from the front panel of the generator, is sized to last 1000 hours of operation. The water reservoir, sized at ~250 ml, similarly supports 1000 hours of use. Software controls alert users to the need to replace the desiccant cartridge and hardware interlocks prevent operation of the generator without sufficient water in the reservoir.

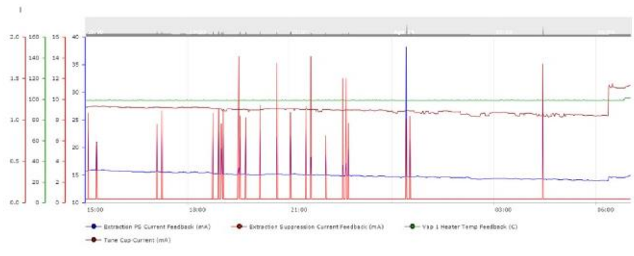

Fig. 3. Stability plot of source running AlI_3 with H_2 feeds into arc chamber and extraction region

TABLE I. Summary of Al Implant Marathon

Beam	I_B puA	Wafers	Glitches/ wafer	Glitches/ h	Mean Tune Time (m:ss)
Al^+	1800	1400	0.03	1	2:43
Al^+	1500	230	0.04	2	3:29
Al^{++}	100	175	0.31	9	2:30
Al^{++}	100	300	0.04	1	3:41

Fig. 4. Hydrogen generator installed in implanter gas box

The generator system contains a small, pressurized ballast tank to smooth gas delivery. The volume and pressure of the gas contained in the ballast (<0.5 liter, <100 psig) are low enough that even in the event of an instantaneous release of the entire contents, the exhaust air flow through the gas box will prevent the concentration of hydrogen reaching the 4% Lower Explosive Limit (LEL) [5].

VI. Conclusions

A new source design, featuring injection of a deposition-inhibiting gas into the extraction region as well as into the ion source, results in a dramatic improvement in source life when running depositing gas chemistries. Achieving stable beams enables improvements in AutoTune beam tuning performance for such beams run from a vaporizer.

A new hydrogen generation system provides cost-effective, safe, generation of the necessary flows of hydrogen from water, while occupying only the space of a single gas cylinder in the implanter gas box.

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