Design of a Critical Application Air Ionizer for Semiconductor Manufacturing

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Abstract - A new alpha/pulsed/air-assisted bar ionizer is described. It utilizes a unique asymmetrical sinusoidal voltage waveform with air flow to deliver ions up to 1 m. It produces discharge times [1] <10 seconds with maximum offset voltage of <±5 V, typical. The bar uses <0.9 lpm of air /cm. of bar. Since it has no chemical interactions, it is suitable for certification up to Class 1.

I. Introduction

As feature sizes on semiconductor devices shrink, the CDM damage threshold drops. For feature sizes below 10 nm, the CDM damage threshold becomes as low as disc drive magnetic recording damage threshold. The goal of this development is to achieve fast decay times at distances <1 meter with greatly reduced swing voltage using α particles instead of corona as an ion source. Also, new cleanliness requirements are more stringent for both front-end and back-end manufacturing. Unlike α, corona ionizers chemically interact with the air and with their own emitters. Alpha ionizers operate at ISO Class 1.

Pulsed DC ionization technology reduces recombination and thus allows the ions to travel much further than steady state ionization before recombining, thus neutralizing a larger area. In most instances, long distance results in pulsed ionization with a maximum voltage of such ionizers (typically <150 V) beyond emerging semiconductor industry demands. One of the goals of this study was to find a way to reduce this swing voltage.

This paper presents an advance over the hybrid pulsed alpha design [3] to serve intermediate ionizer to target distances (30-90 cm) with fast discharge (<10 s [2]) and low swings (max offset <±10 V).

II. Sensitivity of Next Generation Semiconductors

Semiconductors are sensitive to electrostatic discharge, particularly in the manufacturing process and thus air ionization is employed to neutralize static charge on insulators and isolated conductors. Corona ionization was used in the past to deliver ions up to ~4 meters but produces now unacceptable voltage swings on the target. At shorter distances, the challenge is greater to minimize voltage swing.

A. Properties of particles of ionizing radiation

Naturally occurring alpha particles are well suited to this application due to their atomic weight and high kinetic energy which enables them to ionize air molecules and not the walls of the tool being ionized. α Particles deposit their energy (ionization) along their path, peaking just before the particles come to rest. See Figure 1.

^{210}Polonium produces a 5.39 α MeV. Its energy deposit vs path length, called the Bragg Curve was first measured in 1903[4] and is shown in Figure 1. Note that the majority of the air ions are created near the end of the path of the α particle. This is called the Bragg peak.

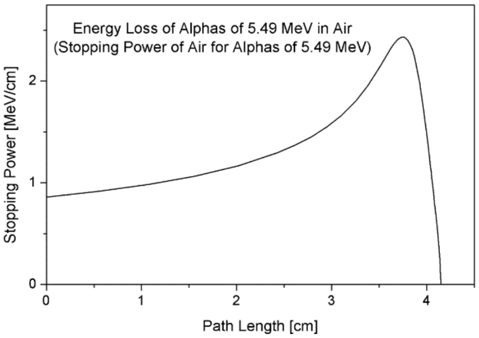


Figure 1: The Bragg curve for Polonium

The short range of the α particles of just a few centimeters in air makes them excellent ion sources close to the target (<10 cm) but ion recombination makes alpha sources alone poor ion sources for greater ion travel distances.

B. Pulsed Ion Technology

Corona ionization has been used for decades with pulsed technology, alternately creating + and - ion clouds at cleanroom ceilings. This is done by alternately employing a positive voltage level and a negative voltage level. Airflow moves the ions long distances to neutralize large areas. The ions travel with low recombination since + and - ions are separated in space and time. See Figure 2. The + and - ions are repelled successively by the electric field from the ionizer, and as they move away, are borne on the air flow. In the case of corona ionization, these voltages also serve to ionize the air and must be very high, 10-20 kV. For hybrid alpha ionization, <2 kV is used.

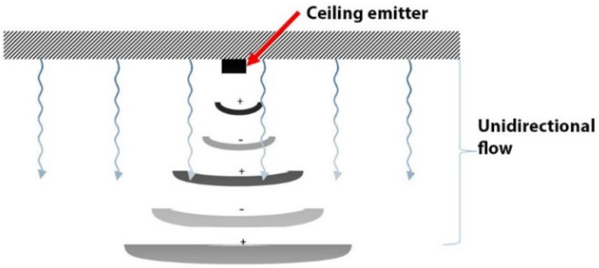


Figure 2. Pulsed ionization in cleanroom airflow.

C. Hybrid Ionization Technology

Present generation [6] hybrid ionization technology employs an accelerating voltage which switches polarities slowly (~ 1 Hz). This voltage (~2000 V), is also used by corona technology and separates the ion polarities by repelling one polarity at a time [6]. The smaller accelerating voltage most certainly will result in a lower swing voltage measured at the CPM.

D. Pulsed Ionizer Signals

A typical Charge Plate Monitor (CPM) signal for a pulsed DC corona ionizer is shown in Figure 3. The square wave is the ionizer voltage and the lower waveform is the CPM signal (plate voltage). Note that the plate voltage shows a short fast edge as the ionizer polarity switches. This signal for current ionizer configurations has always been present but has been ignorable due to its small size. For close proximity ionization this is a major contributor to swing voltage and will be discussed below. See Figure 4.

Commonly, the maximum CPM swing voltage created by the ionizer was set to <±150 V by the install technician. This provided static elimination without creating electrostatic discharge.

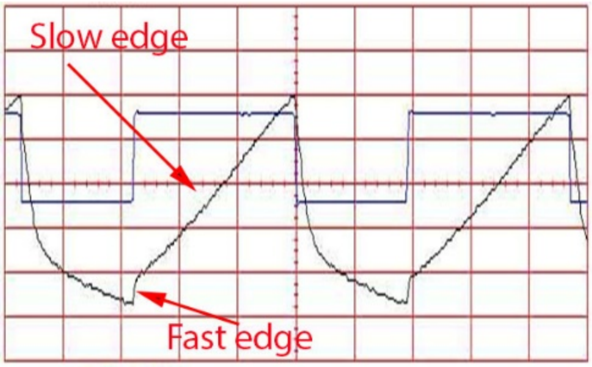


Figure 3. Typical CPM trace for a corona ionizer.

Figure 4. Hybrid alpha ionizer with square wave. Note the taller fast edge compared to Figure 3.

The schematic for a SPICE simulation of a ceiling emitter over a Charge Plate Monitor is shown in Figure 5 and the results of the simulation is shown in Figure 6. The component values used are typical of an ionizer 2 meters above the CPM. Figure 3 and Figure 6 are in agreement.

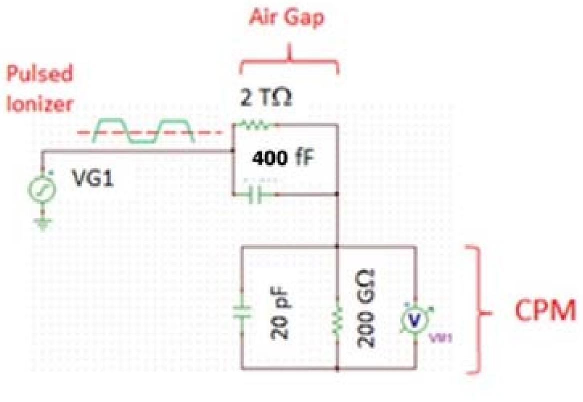


Figure 5. Ionizer and CPM equivalent circuit.

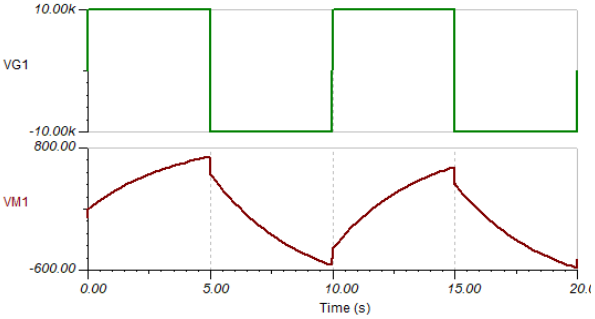


Figure 6. Results of SPICE simulation.

In Figure 4 the fast part of the edge is the majority of the swing. In order to minimize the swing voltage caused by the ionizer, it is therefore important to understand the fast component of the CPM waveform.

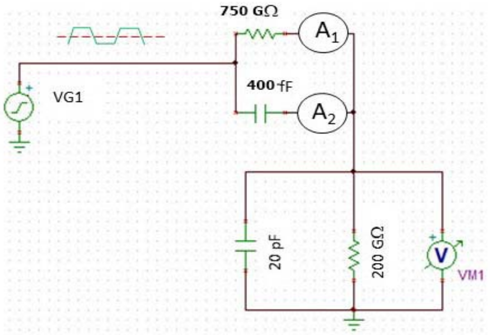


Figure 7. Simulation with displacement current and conduction current artificially separated.

Through the process of selecting different component values, it became clear that the fast part of the signal is the result of displacement current. This is caused by the capacitance between the ionizer and the charge plate. The displacement current from the ionizer-CPM capacitance creates the fast edges (field induction). The equation for displacement current I is:

$$i_{displ} = C\frac{dV}{dt}$$

Here V is the voltage on the capacitor, C. The difference between displacement current (field induction) and conduction current (ion movement) is addressed in Figures 7 and 8.

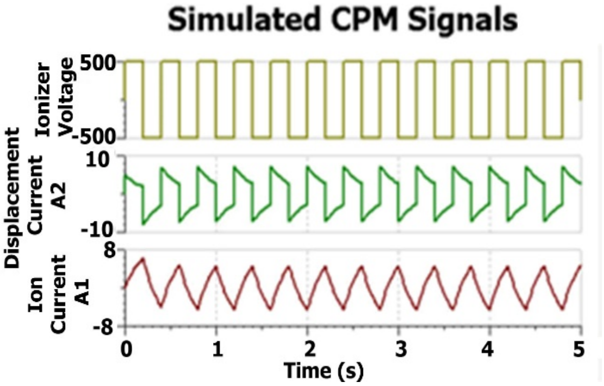


Figure 8. SPICE waveforms of displacement current and ion current.

The displacement current, A_2, and the ion current, A_1, waveforms were created in SPICE. The parasitic capacitance CPM plate is larger than for a ceiling emitter (400 fF vs 50 fF) and the ionized air resistance is lower 750 GΩ vs 2 TΩ. The result is increased contribution from the displacement current.

III. Design Considerations

The displacement current from the edges cause most of the swing but do not discharge the target. Because the conventional square wave used for ionizers has strong harmonics, a sine wave will produce less displacement current.

The use of a sine wave instead of a square wave was simulated and the results are shown in Figure 9. The displacement current is out of phase with the ion current so that superposition is less than the sum of the voltage swings. Also, without harmonics a sinewave produces a smaller displacement current. Figure 9 and Figure 7.

For this reason, the new ionizer design employs a sine wave to separate + from - ions instead of a square wave. It also employs a modest airflow to transport ions to the target device. The sinusoid with no harmonics produces similar discharge performance to a square wave but with less swing through suppression of the displacement current. See Figure 9.

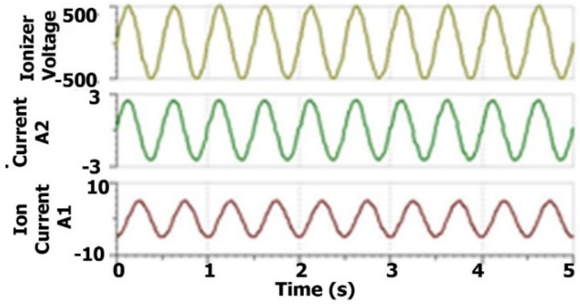


Fig 9. SPICE simulation of sine wave ionizer signals.

The design utilizes multiple small (500 µCi) alpha sources. This size of each is < the limit for NRC licensing so no state or federal paperwork is required. Conservation of charge guarantees inherently balanced ionization. The overall ionizer DC stability is set by only the HV supply and the air flow. This is in contrast to a corona ionizer for which balance depends upon the sharpness of the emitter points, the cleanliness of the points, the barometric pressure and ambient temperature. Use of alphas as an ion generator results in an ionizer which is set at installation and never adjusted or cleaned throughout its life.

The sources are fully encapsulated so are safe for handling by people. Studies have been done on a silicon wafer in direct contact with the source. The most sensitive analytical tests detected no foreign material on the wafer contained in the source.

The sources decay over time but recombination also drops so the ionization is ~constant for a year after which the alpha sources must be replaced. A mechanical design was selected to make source change simple.

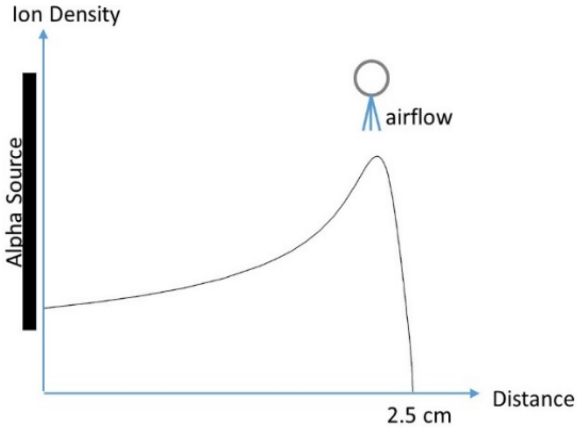


Figure 10. Source position to optimize ion harvest.

The design applies the airflow to the ion cloud from the source at the Bragg Peak in (Figure 2). See Figure 10. Placing the air tube adjacent to the Bragg peak results in the best ion harvest and the lowest air flow requirement.

The cost of CDA can be a large expense so low gas flow cost is significant (typical industry cost is in the order of is $0.001 per cubic meter). Cost is estimated at $7/year [8] (24/7/365) compared with other ionizers which use 10-100x as much CDA.

The product is mounted in a plastic housing but the case was removed to show the ionizer engine in Figures 11a-11d.

Figure 11a. The circuit board is clean owing to the use of the microprocessor.

Figure 11b. The complete assembled bar.

Figure 11c. The bar with cover removed to show how the sources are loaded

When a unit was evaluated, the correspondence to the simulation was excellent, but, the baseline of the measurements was not zero.

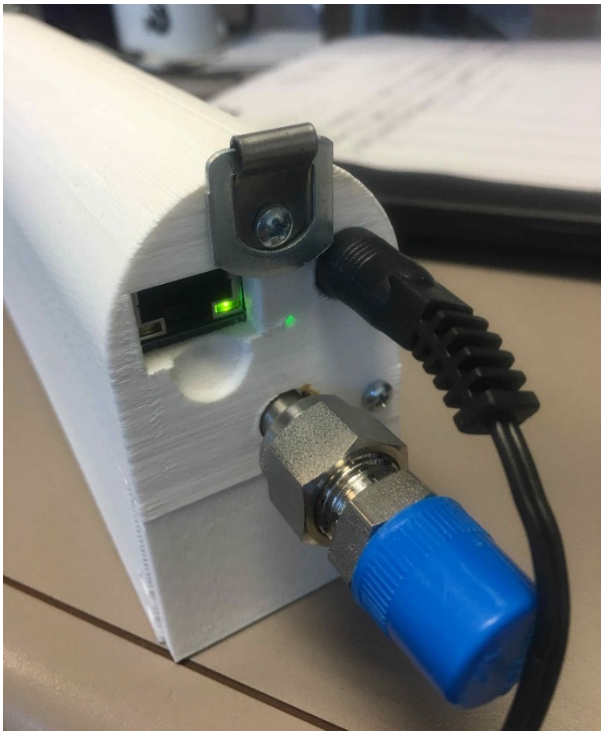


Figure 11d. Power, air and control inputs.

Additional investigation showed that the offset is ~~real~~ and related to the air flow. The atomic weight difference between oxygen (16) vs nitrogen (14) caused the offset. Lighter molecules have higher drift velocity. See Figure 12.

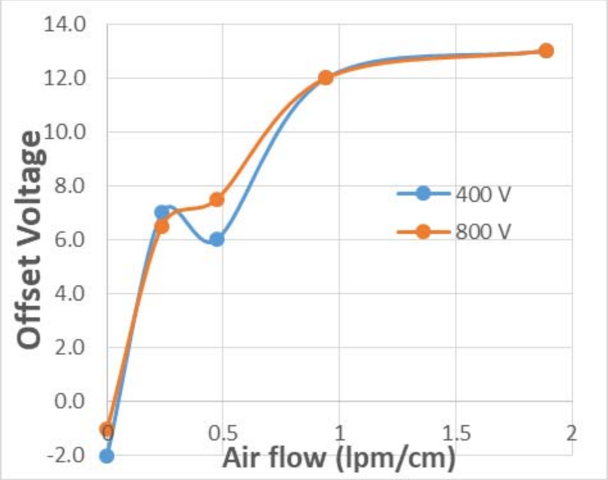


Figure 12. Response of DC offset to airflow at 18".

Analog oscillators, digital synthesis, and digital playback can create sine waves. At low frequency, inductor and capacitor sizes are prohibitive. Thus, the memory plus Digital-to-Analog Converter design was chosen. See Figure 13.

To correct for imbalance due to airflow, the ionizer waveform is an asymmetric sine wave (patent pending). The positive and negative lobes of the sine wave are allowed to have a programmable difference in duration. This difference cancels the offset from the atomic weight differences of O_2 and N_2. See Figure 14. (Patent pending)

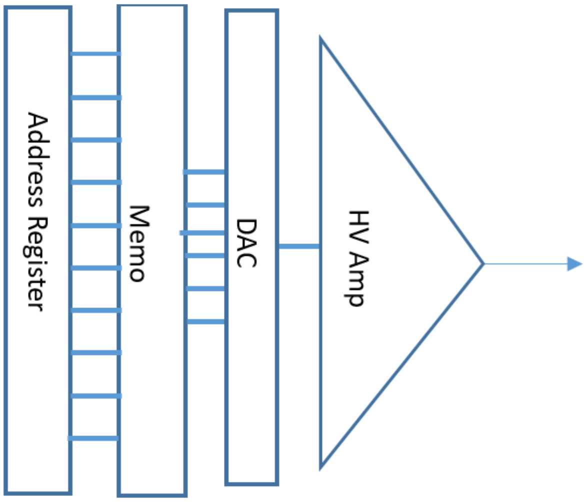


Figure 13. Creating custom waveforms

This programmable asymmetry allows the offset to be created without using the range of the output amplifier as would a DC shift.

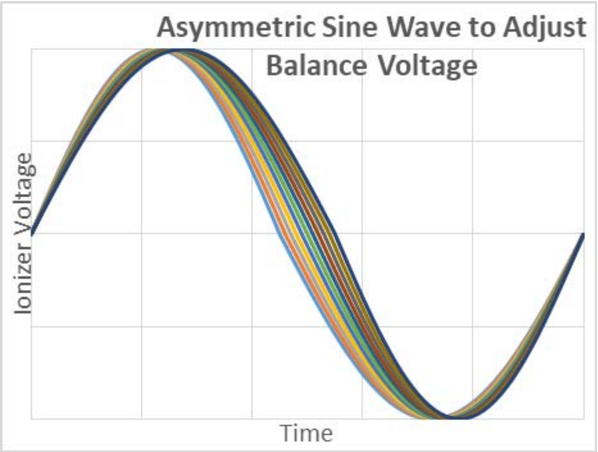
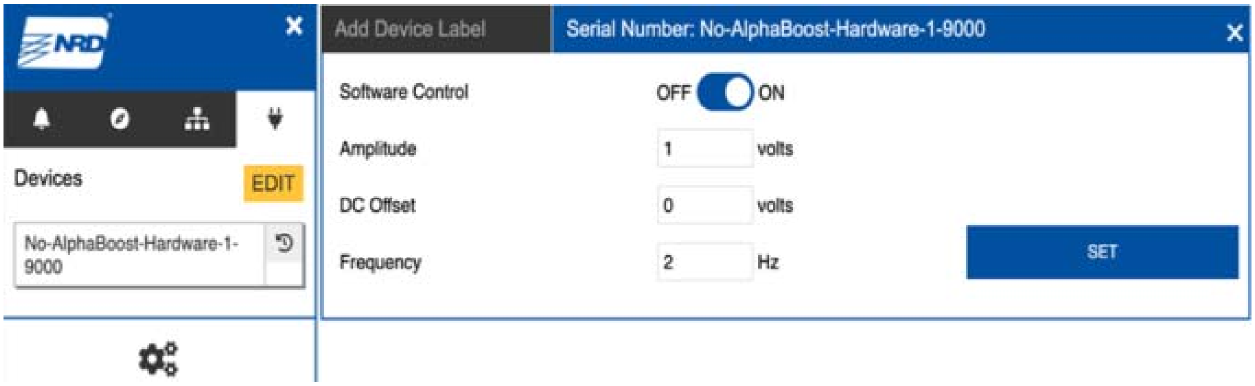


Figure 14. Asymmetric sine wave used to balance the ionizing.

The interface is very simple since it only involves adjustment of three parameters, swing, offset and frequency. See Figure 15.



Devices

No-AlphaBoost-Hardware-1-9000

Add Device Label

Serial Number: No-AlphaBoost-Hardware-1-9000

Software Control OFF ● ON

Amplitude 1 volts

DC Offset 0 volts

Frequency 2 Hz

Figure 15. Simple user interface

A. Performance Measurement

The bar was measured in still air with a Monroe 288B CPM. Care was taken to eliminate the CPM transient response by using a digital oscilloscope to record the CPM's analog output [7].

Alpha ion creation relates only to the alpha source activity unlike the two complex processes required for corona ion creation. Therefore, this ionizer is much less sensitive to changes in the environment than corona.

Table 1. Results of bar measurements at 12"

Freq (Hz)	DC Offset (V)	Air Flow (lpm/cm)	DT+ (s)	DT- (s)	Max offset (V)
Boost Amplitude=800 V					
1	-30	1.6	8.1	8.6	6.3
2	-30	1.6	7.4	8.7	2.6
4	-30	1.6	6.7	8.1	2.4
10	-30	1.6	6.4	8	3.2
1	-58	1.6	2.9	2.9	6
1	-58	0.7	7.9	8.2	15.1
10	-58	0.7	10.3	10	10.9
Boost Amplitude=400 V					
1	-30	1.6	7.9	8.3	4.8
2	-30	1.6	8.1	8.2	3.72
4	-30	1.6	6.5	7.8	3.72
10	-58	1.6	8	7.6	1.1

It is clear that higher air flow and larger boost amplitude results in faster discharge. Maximum offset was nicely controlled by adjusting the DC offset. See Table 1.

B. Total Cost of Ownership (TCO)

This bar has a much-improved cost of ownership compared to corona bars. The mechanism for creating air ions is related only to the activity of the sources. In contrast, Corona ion creation depends upon the cleanliness of the needle points, their sharpness and the presence of other objects nearby. For example, moving a new tool into the fab adjacent to a corona ionized tool will shift the Voltage balance of the ionizer. All of these dependencies result in the need for re balancing corona ionizers.

The cost of CDA can be a large expense so low gas flow cost is significant (typical industry cost is in the order of is $0.001 per cubic meter). Cost is estimated at $7/year [8] (24/7/365) compared with other ionizers which use 10-100x as much CDA.

IV. Conclusions

Displacement current and airflow generated offset were unimportant for older ionizers with ±150 V swings but our goal was offset of <±10 V. Thus both of these effects had to be designed out. Sinusoidal accelerator voltage and asymmetric sine wave signals were successful in dealing with these issues.

The goal of this design was to achieve very fast discharge time (<10 s) with very low maximum offset (±10 V). This design study achieved these goals and resulted in an ionizing bar which used alpha particles to generate fast discharge with little swing, thus meeting the design goals.

V. References

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