

Generating Air Ionization With No Contaminating Particles

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Abstract—Modern semiconductor manufacturing employs air ionizers to reduce the effects of static charge. These effects are contamination control from electrostatic attraction and on physical damage from discharges. Conventionally, air ionization is generated by corona from needle electrodes, but there are particles generated by this process. In the past, these particles have been too small to affect the manufacturing process, but this is no longer true. The latest small structures on the wafer have reached the limit where these particles will harm the product. This paper discusses the mechanism for particle creation and presents a design which creates no particles.

I. INTRODUCTION

Semiconductor, flat panel and disk drive manufacture all suffer from yield loss from physical damage to the product caused by discharge. Such discharges sometimes create sufficiently high electromagnetic impulses to confuse the microprocessor in automated equipment¹. In addition, contamination is an issue in part of each of these processes. Electrostatic attraction arising from static charge greatly increases the amount of contamination landing on the product during manufacture^{2,3}. Each of these effects is reduced through the use of air ionization. Ions add conductivity to the air and provide a path to ground for surface charge on insulators and floating conductors.

Typically, air ionizers employ high voltage on sharp needle electrodes. There are several mechanisms (discussed below) by which this ionization process generates unwanted particles. There has been quite a bit of work done on selecting the needle electrode material, sharpness voltages levels employed, and the waveforms of the high voltage signals. All of these design improvements have served to reduce but not eliminate the particle generation effect⁴. Particle generation results in both contamination and white fuzz balls on the needle electrodes which, inter^{??}, reduce the generation of air ions and eventually defeat the action of the ionizer. The development of so-called clean ionizers have limited

particle generation to nano-particles which could be ignored until recently, when semiconductor manufacturing started to produce devices with nano-scale features. See Figure 1. The mechanisms by which corona ionizers generate gas-to-particle conversion are well understood and will be discussed below. The effect is inherent to the process and improved designs can only serve to minimize such particle generation and not eliminate it.

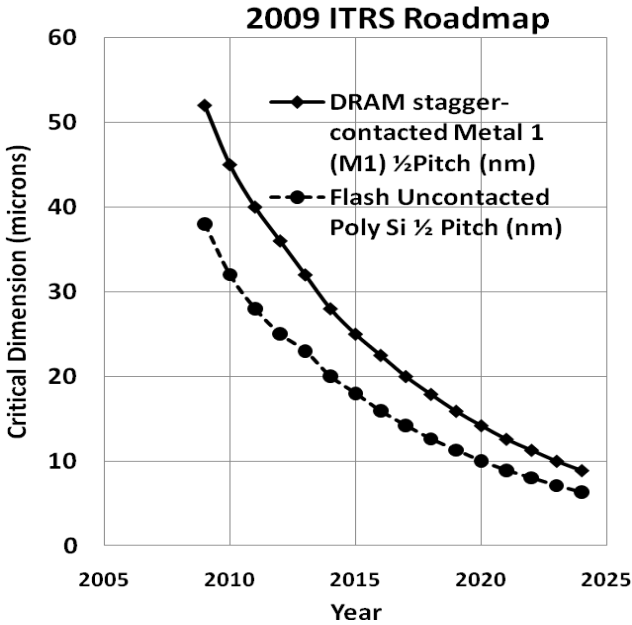


Figure 1. International Technology Roadmap for Semiconductors shows the evolution of smaller and smaller feature sizes on microchips.

Air ionization can be generated by the use of radioactive isotopes which dissipate the kinetic energy of particles from radioactive decay through ionization of the medium through which they pass. The process is self sustaining and has no chemical/particle creation—consequences because it does not involve high temperature plasma as does the corona ionizer. The hybrid process was first proposed by Wilson⁵ who did some initial testing but never produced a product. We report construction and testing of such a product with the addition of compressed gas delivery.

II. THE CORONA IONIZER

The corona ionizer employs needle electrodes which are biased to a high voltage (10-20 kV) to create air ions. Both DC and AC ionizers are available. Corona ionizers create particles both by erosion of the emitter tips, and by their plasma at the needle tips acting as a chemical reactor and converting airborne molecular contaminants (AMCs) to small particles which, in turn, agglomerate into larger ones.

Generally, the cleanest ionizers (most erosion free) are the ones that run at the lowest power output. The electron current from a needle electrode can cause pitting of adjacent material or of the emitter electrodes themselves. See Figure 2. This result in large (~0.1-5 μm) particles of emitter material being liberated from the needle electrode into the environment of the cleanroom. This is minimized by using a configuration that avoids recombination of positive and negative ions so that the ions received at the charged object will be adequate in numbers, while the power dissipated at the emitter tip is minimized.

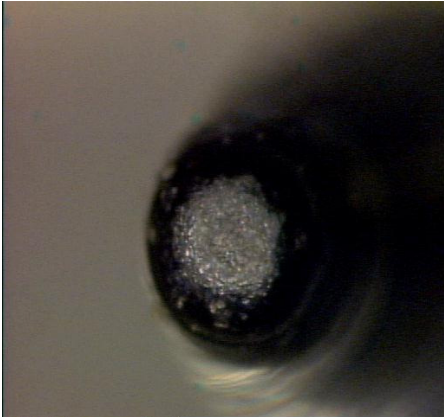


Figure 2. Pitting of a corona ionizer's needle electrode.

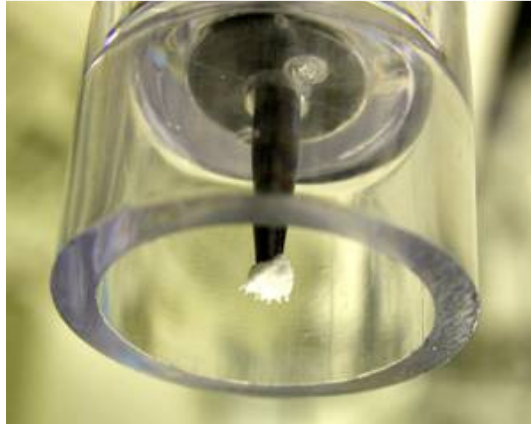


Figure 3. Corona needle electrode with fuzzball6 .

The second effect, gas to particle generation, involves effectively cooking AMCs at the emitter tips. Some of the particles are collected on the needle electrodes (See Figure 3) The ionizer creates a low energy plasma at the emitter tip which achieves a rather high temperature due to Joule heating. This temperature has been calculated by the authors. The power dissipated into the plasma is given by

$$W=iV \quad (1)$$

Here i is the corona current drawn by the needle tip and V is the potential to which the needle electrode is biased. The model used for this calculation is shown in Figure 4. Taking the power to be dissipated by conduction up the needle electrode (black body radiation was ignored) with

$$2 < i < 10 \mu\text{A} \text{ and} \quad (2)$$

$$10 \text{ kV} < V < 20 \text{ kV} \quad (3)$$

The temperature elevation above ambient for Silicon or Silicon Carbide emitter electrodes is in the range 200-1000°C over a volume of 0.7 mm³. This will disassemble complex organic solvents which are dissolved in the air as they pass through the emitter tip. These AMC's form a "soup" of free radicals which recombine into various permutations of the original atomic constituents of the AMC's that traveled past the emitter tip. These small particles are attracted to the needle electrode by the dielectrophoretic force which is attractive no matter what the polarity of the electrode⁷.

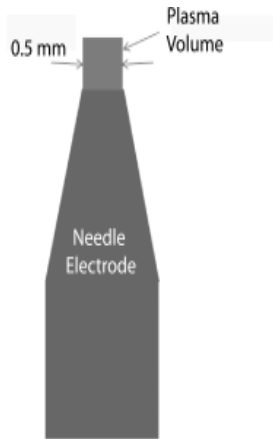


Figure 4. The model used for calculating the temperature of the plasma at the needle electrode tip.

As the small nano-particle is drawn into the electrode, it agglomerates additional material and grows. Typically the particles achieve a size of 5 to 50 nm which will certainly interfere with fabrication of modern 25 nm structures if they land on the wafer.

The first step in reducing this effect is to use an electrode material which has good mechanical and thermal conductivity properties. Both Silicon and Silicon Carbide stand out for this application. While there are some waveforms⁷ which reduce the magnitude of the effect and the size of the particles, such techniques do not eliminate the particles.

III. THE ALPHA PARTICLE-BASED IONIZER

Alpha particles, being Helium nuclei, are substantially heavier than other radioactive decay particles. For example, an α particle is ~8000 times more massive than a β particle. For that reason, it travels much more slowly than a β of the same energy. At the lower speed, its electric field has more time to deliver energy to molecules it passes close to and; thus, it causes much greater deposition per unit path length than the comparable β . See Figures 5 and 6. Alpha particles from Po²¹⁰ have an-energy of 5.4 MeV and travel only ~4 cm in air. Each Alpha creates approximately 250,000 ion pairs along its path length. In contrast, the ion density from Beta radioactivity is much less concentrated and; hence, less effective at controlling static charge.

Conservation of charge dictates that Alpha particle-based ionizers create a perfectly balanced population of positive and negative ions with no need for adjustment. Also, because they do not have a high density, high temperature plasma, they do not create a high concentration of free radicals or agglomerate them into nano-particles.

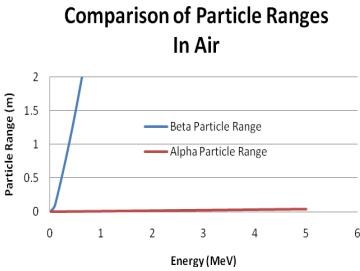


Figure 5. Range of Alpha and Beta particles in air.

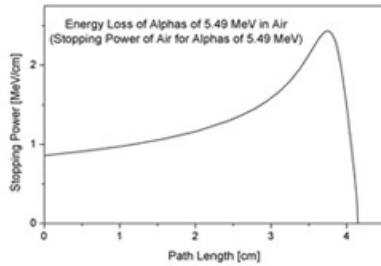


Figure 6. Energy deposition rate for Po^{210} Alpha particles in air.

As can be seen from Figure 6, the air ionization created by an alpha particle-based ionizer is located within 4 cm of the source. Charge on adjacent objects (within ~10 cm) will be dissipated because the fields from the charged object will draw the ions to it. Beyond that distance, other means are required to cause the ions to travel to the target charged object. For example, the disk drive industry employs Alpha-based ionizers along with a blower (fan) to deliver ions over a distance of 30-60 cm. The choice of Alpha technology is based upon the sensitivity of the delicate magneto-resistive heads to discharge, and the fact that the perfectly balanced Alpha ionizer cannot create an offset voltage on the product or anything in the environment. A small Alpha ionizer (~2.5 cm across) is shown in Figure 7 and the AlphaBoost product is shown in Figure 8.



Figure 7. A NRD Nucleospot 5 mCi Alpha Ionizer

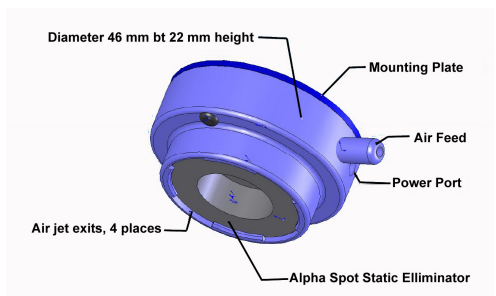


Figure 8. The AlphaBoost Ionizer Structure [Figure 7?](#)

Unfortunately, blowers or compressed gas cannot be used to move the ions to the target in clean rooms which employ unidirectional flow (laminar flow) to achieve extreme contamination control (Federal Standard 209E class 10 = ISO 14644 - 1 ISO Class 4). For this reason, Wilson⁵ stole a trick from the corona ionizer design. Corona ionizers are sometimes mounted on the ceiling of a cleanroom and the air flow from the HEPA filters is used to move the ions down to the target charged objects. Often the ceiling can be as much as 4 meters high and without special precautions, virtually all of the ions entrained in the unidirectional flow find ions of the opposite polarity and recombine.

Corona ionizers mounted on the ceiling often use a technique called pulsed DC. This involves applying a high potential to one needle electrode and then to the other. By pulsing the system very slowly, the positive and negative ions are separated from each other so that recombination is dramatically limited. At the limit, only one polarity of ions exists in the air column between the ionizer and the target. The very high voltages applied to the needle points drive the target voltage positive and negative by roughly 100 V in succession, and ultimately the system finds an equilibrium voltage about which the target object swings. When this voltage exceeds some threshold, commonly around 100 V, the possibility of damaging discharges from the product becomes real. Because the driving voltages often are as much as ± 20 kV, the two HV supplies must be accurately balanced. As the ionizer collects fuzz (Figure 3), balance suffers; thus maintenance of the ionizer through cleaning and balancing is very important for corona technology.

IV. THE HYBRID ALPHA IONIZER

. It is the technique of pulsed DC that is at the center of this hybrid ionizer. The Alpha-based ionizer makes air ions continuously. By biasing a "pusher" electrode behind the source to successive positive and negative voltages, ions are extracted from the ion "cloud" in proximity to the alpha source through electrostatic repulsion. The goal is to move them on the air flow in the cleanroom and to avoid recombination.

Ions drift in an electric field. That is to say that they experience many collisions, but if the electric field is constant, the ions achieve a terminal velocity called the drift velocity. The drift velocity of air ions in an electric field is given by⁸

$$V_d = E / 0.45 \text{ V/cm-m}^2 \quad (4)$$

Here V_d is the drift velocity in cm/sec and E is the electric field in V/cm. Roughly, the electric field extends a distance away from the ionizing electrode equal to the "diameter" of the electrode, d . Thus, for an applied voltage, V , the electric field near the ionizer is given by

$$E = V / d. \quad (5)$$

For a value of V of 350 V and an electrode of diameter 2.5 cm,

$$E=14,000 \text{ V/m or } 140 \text{ V/cm} \tag{6}$$

and

$$V_d= 300 \text{ cm/sec}=3 \text{ m/sec}=600 \text{ fpm} \tag{7}$$

This is roughly ten times faster than the laminar flow rate of the cleanroom air speed so it is clear that the electric field from such a modest voltage will move the ions 2.5 -3 cm away from the source much faster than the air flow would carry them.

As the transverse dimension of the pusher electrode is increased, according to Equation 5, the larger the electrode, the lower the field but the longer it extends toward the target charged object. We have found that the optimum size of the pusher is equal to the size of the source.

An extra benefit to the hybrid configuration, trade named AlphaBoost®, is that the ionizer has dramatically lower swing than does a comparable corona ionizer. See figure 9. These data were recorded using an AlphaBoost ionizer swinging at ±500 V. This is dramatically less than the voltage on the needle electrodes of a corona ionizer (often ±20 kV). Thus, the swing voltage is much lower than that of a corona ionizer.

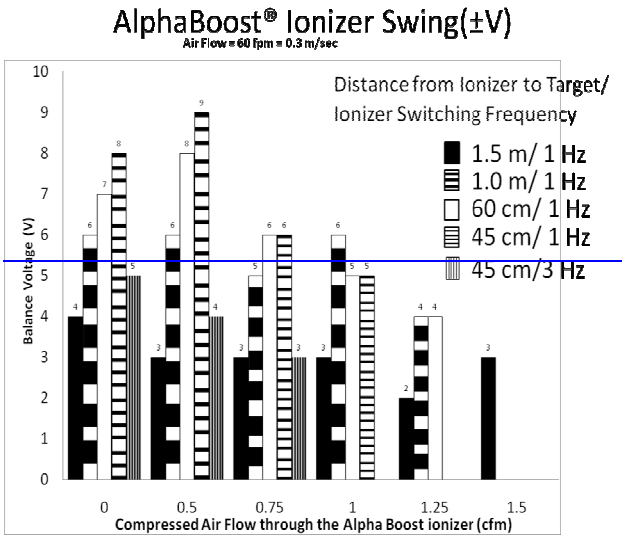


Figure 9. Voltage swing of the ionizer at various distances and various compressed air flow rates.

Such a low swing voltage opens the door to several options. Several applications involve use of a blower at a work station. With the use of pulsed DC and very moderate compressed gas flow, the blower could be replaced and the unit operated with swings limited to ≤±5V. This would be a benefit because the present use of ionizers with fans is objectionable to operators who complain of being cold and of dry eyes. (They frequently react by turning off the blower when no one is looking.) This has a

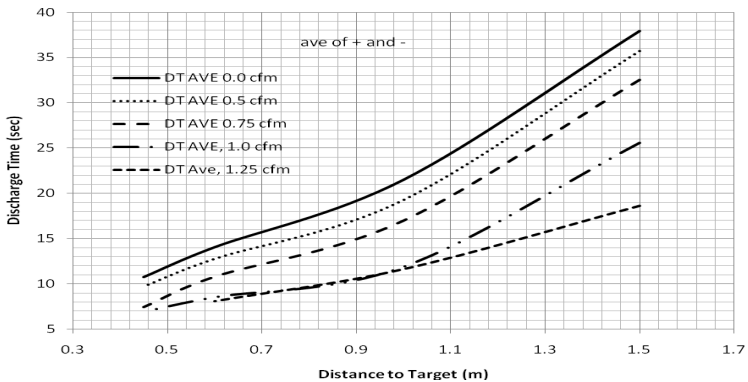
serious yield implication. See Figure 10. Note that the swing is low enough that for many applications, and to achieve even faster discharge times, it could be increased by raising the HV waveform above its present limit of ± 500 V.

In addition to the swing Voltage, the ionizer is characterized by its discharge times. These are the times required for the ionizer to discharge a 20 pF 15 cm x 15 cm metal plate from 1000 V to 100 V.



Figure 10. Power plug was pulled by operator and kept so that it was difficult to detect that the fan was off.

The discharge time that can be achieved is related to the distance from the ionizer to the target, but it can be optimized by selecting the pulse frequency. For the sake of simplicity, data were recorded for a frequency of 1 Hertz but there is an indication that higher frequencies should be used for very short distances and lower frequencies for longer dis-



tances.

Figure 11. Discharge performance of AlphaBoost Ionizer at various distances to the target for a range of compressed gas drive. Pusher Voltage= ± 500 V.

The data for Discharge Time vs Distance to the target over the range 45 cm to 1.5 meters is shown in Figure 9. To simplify the presentation without losing any relevant information, the average of positive and negative discharge times is presented. The data were recorded in a flow field of 60 fpm and compressed air assist was also used. Air flow rates of 0 to 1.25 cfm were used.

The effects of the compressed air assist can be seen from the data. It is clear that air assist offers and improvement of a factor of two. For many applications, for example, use inside of semiconductor process tools, typically the ionizer is mounted 1 meter above the target and the data show that the ~20 second performance with no air assist is better than typical corona ionizers in the same application. The typical performance of a corona ionizer in this application is 30-45 seconds. Note that with 1.25 cfm of air assist, the discharge times drop to 12 seconds. This is extremely good performance and will be helpful in high charging applications such as wet processing and both wet and cryogenic cleaning.

The ionizer was tested for particle creation using a condensation nucleus counter which is capable of counting 5 nm particles. The result was that no particles in excess of background were detected.

V. CONCLUSION

More work is required to fully characterize the technology but initial studies have shown that AlphaBoost is a viable technology and can offer performance gains which are needed in a variety of applications. This product is likely an enabling technology for the newly announced 22 nm production because it offers fast discharge times with zero particles added.

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