

Clean Corona Ionization Technology

Peter Gefter
Simco-Ion
phone: (1) 510-217-0614
email: pgefter@simco-ion.com

Jack Menear
Jack Menear Associates
phone: (1) 831-462-9338
email: jack.menear@gmail.com

Abstract - A need for clean corona ionizers has been long recognized (but unrealized) within the semiconductor, disk drive, and photonics industries. Particle-ion mobility separation provides the solution. Lower-weight ions reach the target; higher-weight particles are trapped. Cleanliness matches X-ray and nuclear ionizers with lower cost, less maintenance, and fewer installation/safety barriers.

I. SUMMARY

Clean (particle free) corona ionizers for static charge neutralization are an understood need, particularly for semiconductor processing, disk drive, photonics and other critical technologies . The semiconductor industry is expanding operation in noble and electropositive gases like argon and nitrogen to avoid oxidation of sensitive objects (products).

Super clean conductive gas streams are ideal solutions for many static related problems [1, 2]. Protection of an ion emitter from ambient air with a dry air or nitrogen sheath is an effective method to decrease debris buildup. However, that method cannot protect ion emitter from corona/plasma related erosion or sputtering [3]. That means corona generated particle will move to the product by the same protective CDA/ nitrogen gas streams.

The technique to achieve corona ionizer cleanliness in the nanoparticle range, especially for electro-positive gases, has been elusive for two reasons.

First, ion balance control of bipolar corona discharge in electro-positive gases is forced to operate within an extremely tight range to prevent negative (electrons) current avalanches [3,4]. Corona feedback is optimized to maintain that tight ion current range.

Second, corona ionization is highly energetic, and the ion emitter surface is under continuous electron/ ion bombardment [1, 2]. Ion emitter reactions eventually generate particles in the 10-100 nm range. Some particle generation within a corona discharge is currently considered unavoidable.

Clean corona ionizers are designed for operation in facilities, mini-environments and equipment, where compliance with ISO 14644 Class 1 (at 0.1 micron) and extended ISO Class 1 (at 10 nm) is specified.

II. SEPARATING PARTICLES FROM IONS VIA ELECTRICAL MOBILITY

Corona generated particles can be separated from charge carriers, like ions and electrons, using electrical mobility differences and vacuum. This separation occurs within the ion/electron generation plasma zone, which is close to the corona emitter tip. For example, diatomic nitrogen ions weigh 28 amu, and move quickly from the ion generation zone toward a reference (non-ionizing electrode). Then the ions continue moving toward a charged target via electrostatic repulsion.

Particles are much heavier than nitrogen ions, move slower in an electric field, and are removed from the ionization zone with an internal vacuum strategy. In short, ions move toward the target of charge neutralization. In contrast, particles move away from the target (and toward the vacuum port), where they are captured with an internal filter.

Ionization frequency, service gas flow rate, ionization zone dimensions, and vacuum flow rate are balanced to optimize performance. It should be noted that neither an external vacuum source nor an external filter is needed.

The following diagram figure 1 visualizes concept the ion/particle separation.

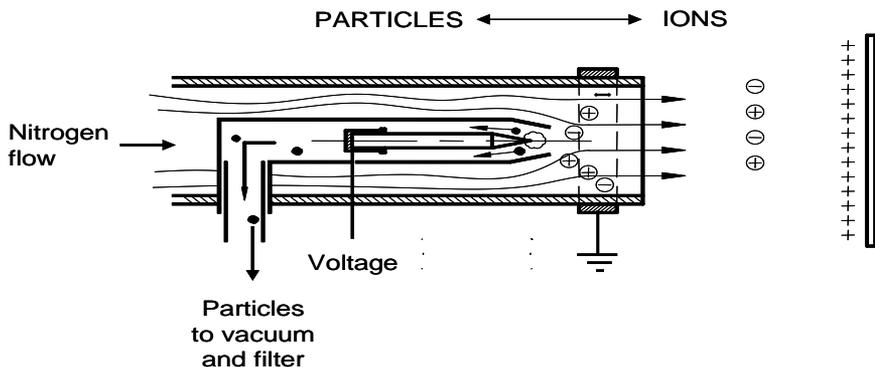


Fig. 1. In- line ionizer structure visualizing concept of the ion/particle separation

A high pressure source of gas (nitrogen or CDA) is connected to a channel inside the ionizer. A high velocity stream of clean gas flows through the channel at 30 - 100 liters/minute. An ion emitter is configured as a sharp point and positioned inside a protective nonconductive shell. The emitter tip is recessed relative to output orifice of the shell. High voltage power is connected to the blunt end of emitter. The back of the shell is connected to vacuum port and filter. A reference electrode is positioned outside the channel, and is connected to the same ground as the high voltage power supply.

Gas ionization occurs when the high voltage exceeds corona threshold for the emitter/gas combination. Positive and negative charge carriers are produced by an AC corona discharge near the emitter tip. Electrical and diffusion forces move charge carriers from plasma region toward the reference electrode. In corona drift region (close to reference electrode), the intensity of the electric field is low, and the gas stream moves positive and negative ions through the channel outlet to target of charge neutralization.

Ion emitters are usually made from corrosion-resistant metals, such as stainless steel, tungsten or titanium. According to Roger [1] stainless steel has the highest erosion rate, followed by thoriated tungsten emitters. Single-crystal silicon emitters have the lowest erosion rate. Moreover, semiconductor applications prefer non single-crystal silicon emitters to avoid contamination by metallic particles [1].

Corona discharge produces ions, electrons and byproduct particles in the plasma region [3]. Without a protective shell (see Figure 2) these particles would eventually be delivered to the charge neutralization target. With a protective shell, the gas flow pattern differs. The shell produces a pressure difference between the outlet and the vacuum port. Vacuum flow creates a drag force that moves particles from plasma region to vacuum port.

Charge carrying ions move via the high intensity electrical field into the main gas stream, past the reference electrode, and to the target. Corona generated particles move by vacuum flow in the opposite direction to the filter, where they are trapped. Vacuum flow can be applied closer to the emitter tip through a side vacuum port as shown below.

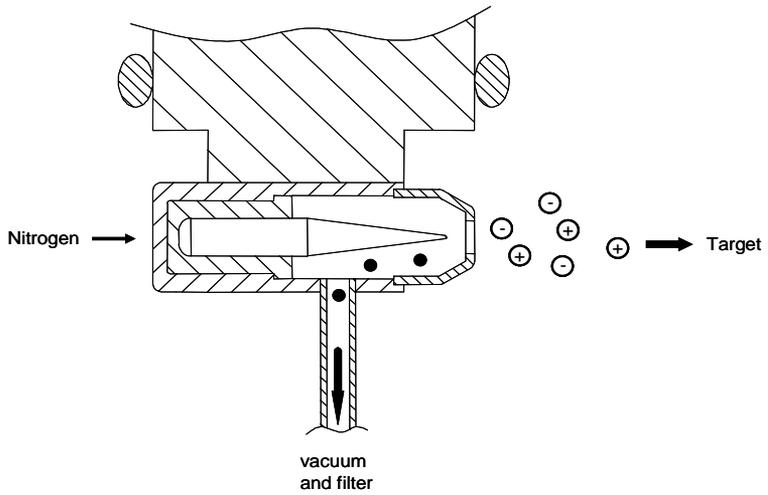


Fig. 2. Ion emitter protective shell with vacuum port.

III. Testing Clean Corona Ionizers

A. Simultaneous Measurements of Particles, Discharge Time and Ion Balance

The test apparatus employed for simultaneous measurements is shown in Figure 3.

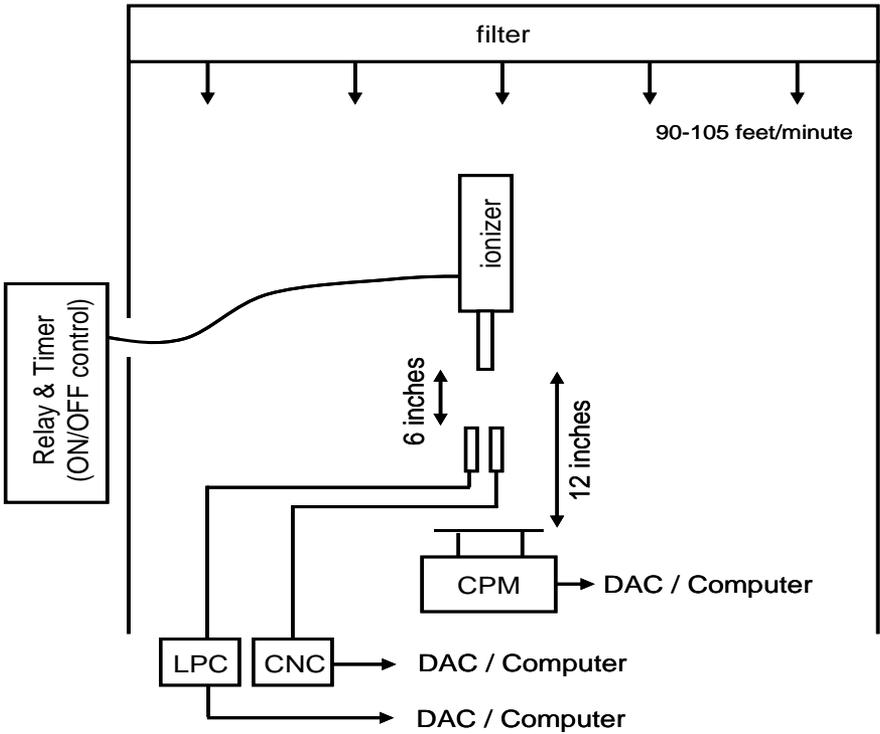


Fig. 3. Test setup for simultaneous monitoring ionizer performance and particle emission.

In this test setup, the Monroe Model 280 CPM was 12 inches below the ionizer. Two particle counter probes were 6 inches below outlet of the ionizer - between the ionizer and the CPM. One laser particle counter had measuring sensitivity ≥ 100 nm. One Hach Model 1104 CNC particle counter had measuring sensitivity ≥ 10 nm.

The main reason for this experimental setup is to collect data on particles and performance stability simultaneously. There is an option to turn on and of ionizer and monitor particles and performance during start up periods. This setup is efficient and allows a valid long term test. But naturally, discharge times are longer because particle probes are positioned between the CPM plate and the ionizer outlet.

B. Long Term Discharge Times and Balance

An example graph of discharge time (upper section of the graph) and ion balance (lower section of the graph) stability shown in Figure 4. Data was collected using the test setup in Figure 3. Ionizer was connected to Dewar with liquid nitrogen at 99.999 % purity.

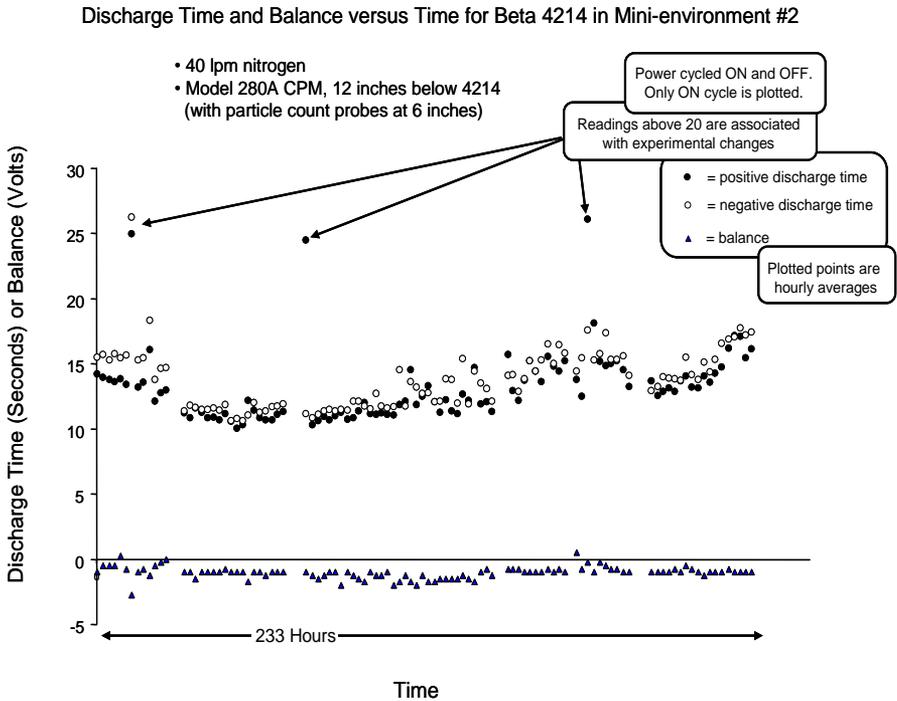


Fig. 4. Discharge time and ion balance long term test results in nitrogen for clean corona ionizer.

C. Shorter Performance Term Tests (without Particle Counts)

To measure discharge times without interference from particle probes, Figure 3 was modified. The particle probes were removed, and the CPM was centered directly below the ionizer. The distance between ionizer and CPM was changed from 12 inches to 6 inches.

As expected, much shorter discharge times are recorded. See Table 1 as an example.

Table 1: In-line ionizer performance in super clean nitrogen

Discharge Time (Seconds) and Balance (Volts) at 6 Inches / No Manifold			
Test Number	Positive Discharge	Negative Discharge	Balance
1	2.4	2.7	-4
2	2.4	2.7	-5
3	2.5	2.7	-5
4	2.4	2.8	-4
5	2.4	2.5	-6

Discharge times are defined as the time needed for the ionizer to reduce 1000 volts (either polarity) on a 20 Pico Farad CPM plate to 100 volts.

D. Cleanliness Based on Particles ≥ 10 Nanometers

Figures 5 and 6 show cleanliness achieved with the differential ion- particle mobility technology. In both cases, particle levels were below the “extended ISO Class 1 (at 10 nm) limit”. The limit of 34 per cubic foot is calculated by using the formula in ISO 14644, Section 3.2, entitled “Classification Number”*.

* Note that “extended ISO Class 1 (at 10 nm)” is an in-house standard based on ISO Standard 14644. However, ISO Standard 14644 does not formally support extrapolation to 10 nm.

10 nm Particle Counts versus Time for Beta 4214 in Mini-environment #2

- 40 lpm nitrogen
- CNC probe was 6 inches below 4214.

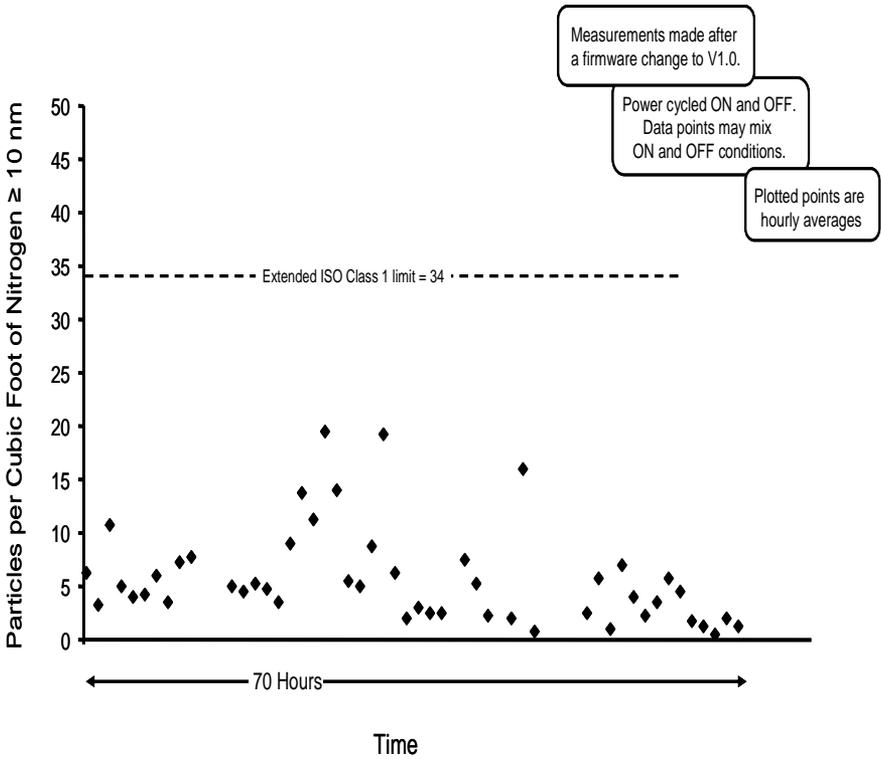


Fig. 5. In-line ionizer cleanliness test results in nitrogen with cycled power on and off.

- 100 nm particles/ft³ averaged 0.011. The ISO Class 1 limit is 0.283.
- 10 nm particles/ft³ averaged 4.7. The extended ISO Class 1 limit is 34.
- Balance (not plotted) ranged from 0 to -3 volts.

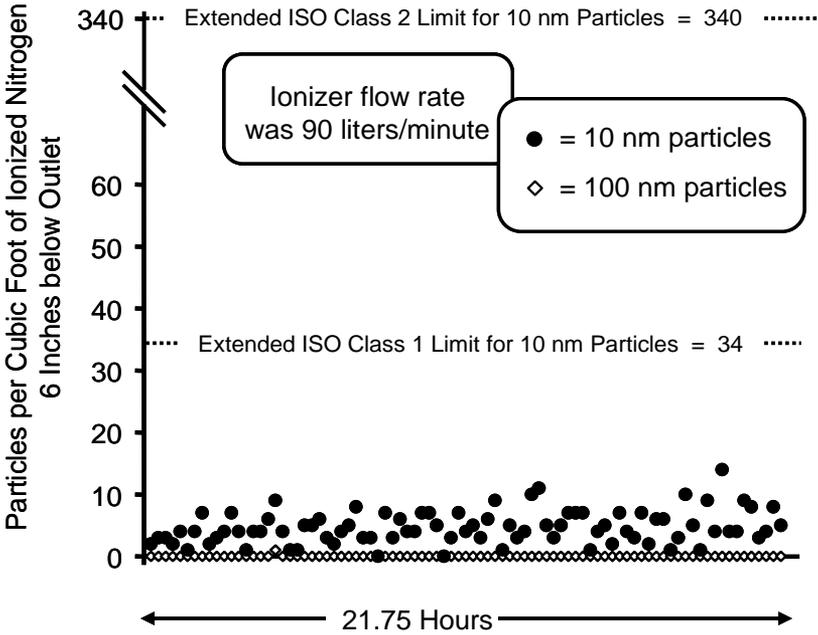


Fig. 6. In-line ionizer cleanliness test results with high flow rate of super clean nitrogen gas.

Ionizers in Figures 5 and 6 used single crystal silicon emitters. Ionization voltage at nominally 40 kHz was applied to the emitter. Voltage amplitude was optimized to minimize emitter erosion, to minimize particle generation, and to deliver robust ion output. Tests were performed in ISO 14644 Class 1 (at 0.1 micron) clean rooms. Temperature and humidity were monitored, but not controlled.

The differential mobility cleanliness strategy reduced 10 nm particles by a factor of 261 when vacuum flow was between 3 and 10 liters/minute. In one example without vacuum applied, 10 nm particles averaged 1226 per cubic foot. With vacuum applied, 10 nm particles averaged dropped to 4.7 per cubic foot (refer to Figure 6).

E. Particles \geq 100 Nanometers

Particles \geq 100 nm averaged 0.011 per cubic foot of air. This is well below the ISO Class 1 (at 0.1 micron) of 0.283 per cubic foot.

IV. PARTICLE MEASUREMENT EQUIPMENT AND PARAMETERS

A. Particles \geq 100 nm were measured with a Hach [Met One] Model 2100C laser particle counter. The Model 2100C samples air or nitrogen at a rate of 1 cubic foot per minute.

Each sample period was 10 minutes with a 5 minute hold period between samples. For data reduction, particle counts in each 10-minute sample period were divided by 10 to get average particles per cubic foot.

B. Particles \geq 10 nm were measured with a Hach [Met One] Model 1104 CNC particle counter. The Model 1104 samples air or nitrogen at a rate of 0.1 cubic foot per minute.

Each sample period was 10 minutes with a 5 minute hold period between samples. Particle counts in each 10-minute sample period represent the particles per cubic foot. No division is needed.

V. DISPERSION NOZZLE FOR LARGE AREA DISCHARGE

Because the ions are created close to the ionizer's delivery tube, addition of a fast-through dispersion nozzle or manifold allows to cover wide area static charges neutralization [8]. With an ionizer 500 mm from a target plane, a 1000 mm by 400 mm rectangle area can be discharged within useful time periods.

VI. EDUCTOR FOR INTERNAL VACUUM / CONSERVATION OF NITROGEN

An on-board eductor captures some of the energy of incoming pressurized nitrogen/ CDA to generate the particle removal vacuum. External vacuum is not needed. Nitrogen (or other gas) is not lost in the filtration process. After particles are removed by filtration, evacuated nitrogen is returned to the main nitrogen flow.

VII. OPERATION WITH CDA OR HIGH PURITY NITROGEN / CLEANLINESS TARGETS

The above information focuses on application to a nitrogen/argon environment. However, the technology is adaptable to CDA (clean dry air). Corona discharge in CDA further generates byproducts like ozone and nitrogen oxides. Vacuum flow in plasma zone significantly reduces all corona byproducts. In both electropositive and negative gases, particle concentrations in the ionized gas are below the quality control specification of 34 particles per cubic foot of gas ≥ 10 nm.

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