SECURING THE AI ERA

Why Advanced Semiconductor Nodes Require Zero-Particle Photon Ionization

PREPARED FOR SIMCO-ION, TECHNOLOGY GROUP | SUBMITTED BY VERITY CONTENT PARTNERS
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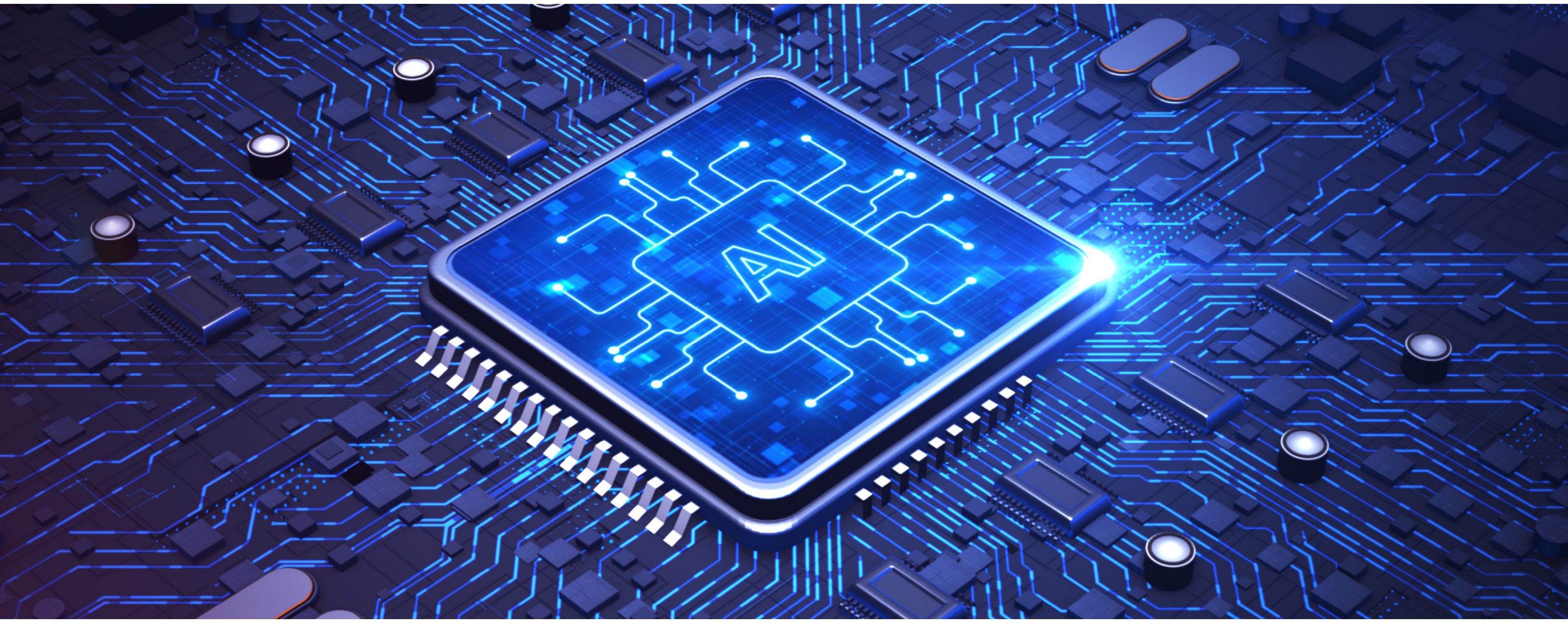

The semiconductor industry is undergoing a paradigm shift driven by artificial intelligence (AI), high-performance computing (HPC), and heterogeneous integration. As devices scale down to sub-5 nm logic nodes and transition to advanced architectures like Chiplets and High Bandwidth Memory (HBM), traditional manufacturing tolerances have evaporated. Critical backend processes, specifically Hybrid Bonding (HB) and Panel-Level Packaging (PLP), now require frontend levels of cleanliness, demanding atomic-level flatness on copper interconnects.

In these environments, electrostatic charge and particle contamination are the leading causes of fatal yield loss. However, legacy static control technologies, specifically corona ionizers, can introduce risks with these advanced nodes due to their propensity for tip degradation over time and the potential to disrupt critical airflow patterns.

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This paper examines the contamination challenges inherent in next-generation semiconductor manufacturing and introduces Soft X-ray Photon Ionization as an innovative and vital solution for achieving the “absolute zero” particle cleanliness required to secure future semiconductor yields.

THE AI/HPC MARKET DRIVERS: A CRISIS OF TOLERANCE

The global semiconductor market is on a trajectory to exceed $1 trillion by 2030, driven by the massive demand from AI data centers and HPC applications [1,2]. This growth is facilitated not just by transistor scaling (Moore’s Law), but increasingly through “More than Moore” heterogeneous integration, utilizing Chiplet architectures and HBM stacks [3].

These new architectures rely heavily on advanced packaging techniques to interconnect the functionality of separate dies into a single system. The industry is rapidly moving from traditional solder bumps (at ~100 µm pitch) to microbumps (at ~20 µm pitch) and is now decisively moving toward direct copper-to-copper Hybrid Bonding (HB) for high-density interconnects. [4]

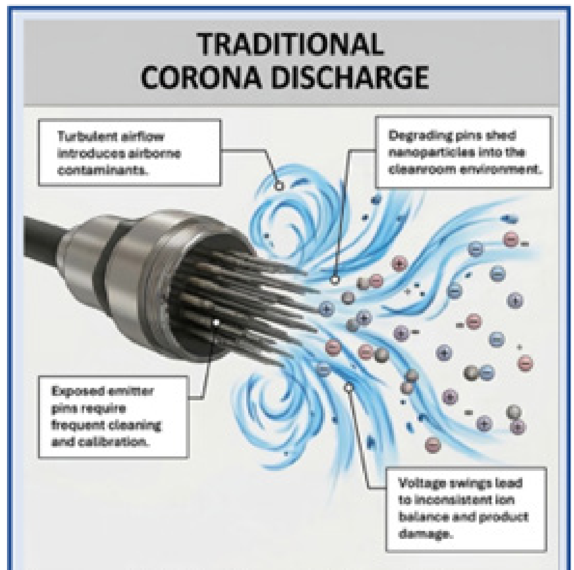
Hybrid bonding enables direct connection of copper pads between die-to-wafer or wafer-to-wafer stacks, supporting true 3D integration with interconnect pitches below 10 microns. This technology is critical for 16-high and future 24-high HBM stacks.

The Tolerance Contraction: While microbumps could accommodate minor height variations or contaminants by “reflowing” during assembly, Hybrid Bonding requires the bonding surfaces to be atomically flat (surface roughness <0.5 nm. At these scales, the definition of a “killer particle” has contracted significantly. Because copper pads must match perfectly, even a single 1 µm particle trapped between surfaces can create a 10 mm diameter bond void, effectively scraping the entire die stack [5].

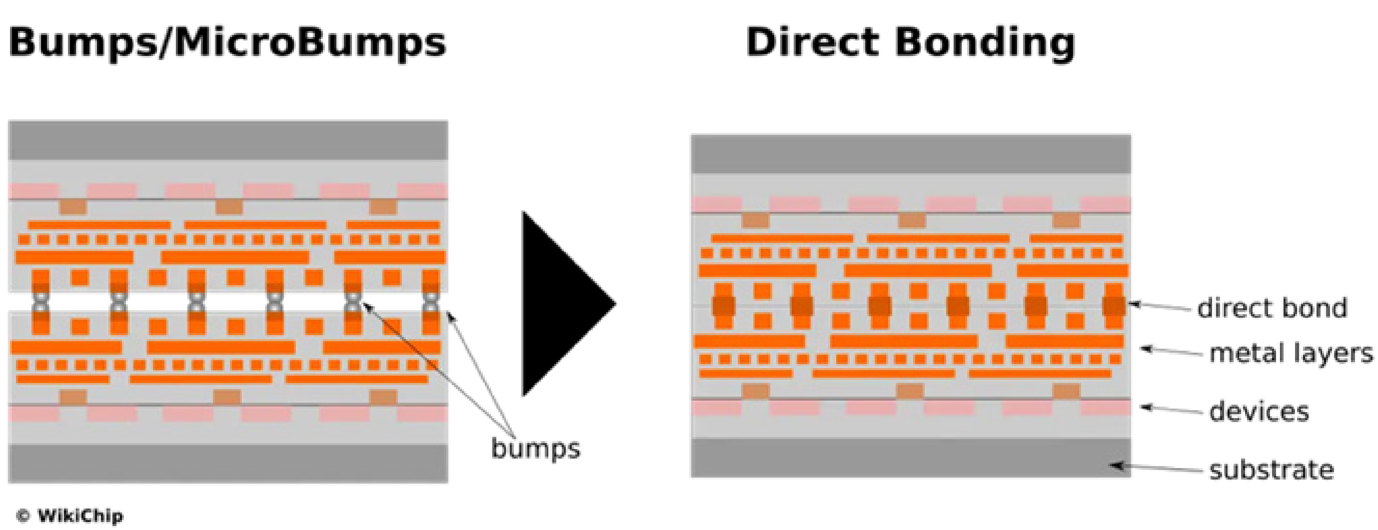
LEGACY STATIC CONTROL: THE CONTAMINATION DILEMMA

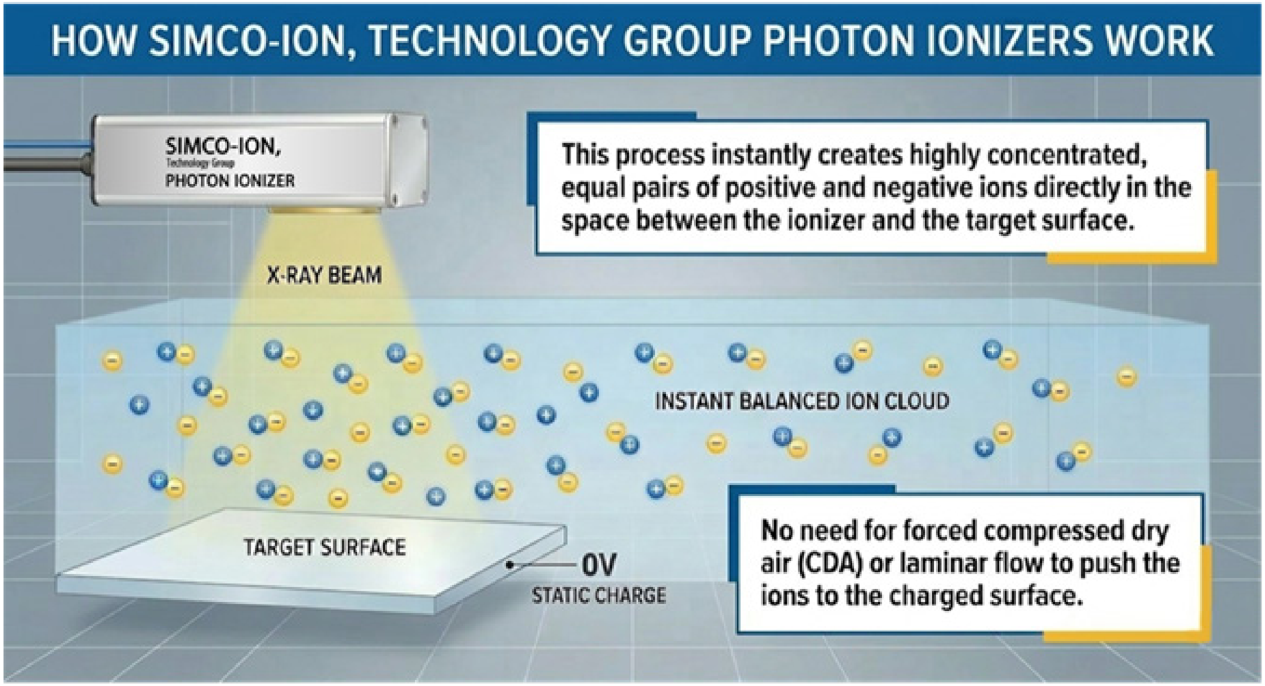
Controlling static charge is critical in semiconductor manufacturing to prevent Electrostatic Discharge (ESD) damage to sensitive circuitry and, more commonly in backend processes, to eliminate Electrostatic Attraction (ESA) that pulls airborne contaminants onto pristine substrates [6,7,8].

For decades, the standard technology for static control has been corona discharge ionization. This process uses high high-voltage (AC or DC) applied to sharp metal emitter pins to tear electrons from air molecules, creating positive and negative ion pairs. Forced air, either from the room’s laminar flow or compressed dry air (CDA), then transports these ions to the target surface. [9]



Traditional Corona Discharge (cd)





[12]

However, corona technology possesses intrinsic challenges for applications in sub-micron manufacturing environments:

1. **Emitter Pin Erosion and Particle Shedding**

The high-voltage corona discharge generates massive, localized heat and electrical stress on the emitter pins. Over time, this causes the pins to erode, sputtering nanoparticles directly into the mini-environment. As the industry moves from ISO Class 5 cleanrooms toward ISO Class 2 and Class 1 mini-environments required for Hybrid Bonding, these self-generated nanoparticles become a critical source of killer defects.

2. **Airflow Disruption**

Because ions generated by corona discharge recombine rapidly, they must be "pushed" to the target surface. This often requires complex piping of CDA or the use of internal fans. Introducing turbulent or high-velocity air in confined tool spaces disrupts laminar airflow. In many micro-environments, laminar flow is crucial to sweep particles away from the wafer. Interrupting this flow allows contaminants to swirl within the tool, increasing the likelihood of ESA depositing them on sensitive substrates.

3. **Ozone Generation and AMC**

The corona discharge process inherently creates ozone (O_3), which can contribute to Airborne Molecular Contamination (AMC) and oxidative damage on sensitive metallic surfaces, specifically copper pads in HB applications.

PHOTON IONIZATION: A NEW STANDARD OF PURITY

To meet the sub-micron tolerances driven by HB, PLP, and EUV (Extreme Ultraviolet) lithography, the industry requires static control that guarantees absolute zero particle generation and operates seamlessly within highly engineered airflow environments. Soft X-ray Photon Ionization represents this necessary technological shift. [10,11]

The Process

Unlike corona technology, which uses high voltage on exposed metal points, photon ionization utilizes a fully sealed, ruggedized vacuum tube to generate low-energy (soft) X-rays. These photons are directed at the air volume within a critical mini-environment. When a photon collides with an air molecule (nitrogen or oxygen), it displaces an inner-shell electron via the photoelectric effect, creating a positive ion. The displaced electron is rapidly captured by

The Paradigm Shift – From Airflow to Light: Traditional ionization relies on forced air and degrading metal pins, introducing turbulence and contamination risks. Photon technology neutralizes static via soft X-ray light—instantly, cleanly, and without disrupting your process aerodynamics a neutral molecule, forming a negative ion. This method creates ion pairs simultaneously in massive quantities, independent of metal pins or high voltage grids, resulting in intrinsically balanced ion output (0V balance) without complex tuning.

The Photon Advantage for Advanced Nodes

Photon technology provides three critical advantages that directly address the failings of corona technology in advanced semiconductor applications: [9]

1. Guaranteed Zero-Particle Purity

Because the Soft X-ray generation process occurs within a hermetically sealed vacuum tube, there are no exposed emitter pins to erode, pit, or sputter particles. Photon ionizers generate zero particles, making them the only technology suitable for safeguarding ISO Class 1 and ISO Class 2 environments required for sub-micron hybrid bonding or EUV reticle handling.

2. Airflow Independence

Photon ionizers generate ions directly within the air volume where the soft X-rays travel. Ions do not need to be transported or “blown” from an emitter tip to the wafer. This “airflow-independent” operation allows for effective neutralization in stagnant air volumes or within critical mini-environments without introducing air turbulence that could stir up contaminants. Photon units can be mounted easily within confined process tools where forced air is impractical.

3. Maintenance-Free Operations

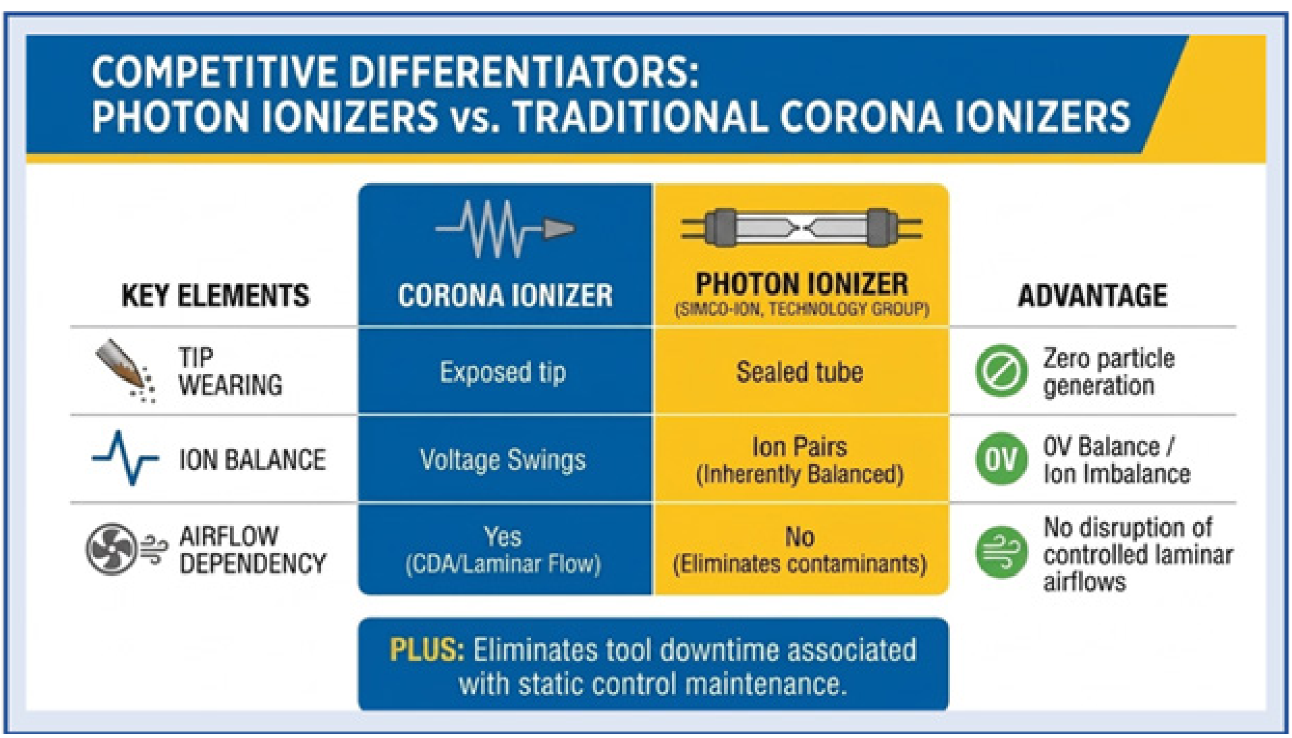
Traditional corona ionizers require frequent cleaning and tip replacement to manage particle emission and maintain ion balance. This creates expensive tool downtime and requires human intervention in critical clean spaces. Photon ionizers have no consumable parts and require no cleaning or calibration, ensuring continuous “State of Control” and significantly reducing total cost of ownership.

> *Misson Critical Yield Insurance: Zero particle shedding. Zero airflow dependencies. Inherent, maintenance-free 0V balance. Soft X-ray technology eliminates the tool downtime and calibration routines associated with traditional static control.*

Critical Application Nodes for Photon Technology

By integrating photon technology during the OEM phase, manufacturers can completely eliminate static charge barriers during the most sensitive manufacturing steps. [9]

- **Hybrid Bonding Modules**: Protecting atomically flat copper surfaces from ESA-driven particle attraction during alignment and bonding, utilizing zero-particle, zero-airflow ionization.
- **EUV Lithography Tools:** Safeguarding hyper-sensitive EUV mask reticles, where a single 50 nm particle can cause repeating defects across every die on a wafer.



COMPETITIVE DIFFERENTIATORS:
PHOTON IONIZERS vs. TRADITIONAL CORONA IONIZERS

KEY ELEMENTS	CORONA IONIZER	PHOTON IONIZER (SIMCO-ION, TECHNOLOGY GROUP)	ADVANTAGE
TIP WEARING	Exposed tip	Sealed tube	Zero particle generation
ION BALANCE	Voltage Swings	Ion Pairs (Inherently Balanced)	0V Balance / Ion Imbalance
AIRFLOW DEPENDENCY	Yes (CDA/Laminar Flow)	No (Eliminates contaminants)	No disruption of controlled laminar airflows

PLUS: Eliminates tool downtime associated with static control maintenance.

Photon ionization eliminates particle shedding and provides fast neutralization in vacuum-adjacent mini-environments.

- **High-Speed Advanced Packaging Robotics**: Integrating compact Photon Pin ionizers into pick-and-place tools to neutralize die-level static charge rapidly (<1 sec at 6 inches) without adding weight or disrupting aerodynamics.
- **PLP and Metrology**: Using Photon Bars to provide inherently balanced 0V output over large panel surfaces in automated metrology or roll-to-roll tooling without disturbing internal tool laminar flow.

CONCLUSION

The migration toward AI-driven architectures is not merely a scaling challenge; it is a contamination control imperative. The contracted tolerances of Hybrid Bonding, EUV, and HBM have rendered traditional corona ionization obsolete for critical process nodes. The nanoparticle emissions and airflow disruptions caused by corona discharge are fundamentally incompatible with the requirement for atomic-level surface purity.

Soft X-ray Photon Ionization is the only technology capable of delivering the mandated zero-particle cleanliness and airflow independence required to secure next-generation semiconductor yields. As architectures become more complex and integration densities increase, embedding Simco-Ion, Technology Group's Photon technology will become a baseline requirement for securing the yield insurance necessary for the AI era. [12]

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Desmond Lee is the Product Marketing Manager at Simco-Ion, Technology Group. He began his career with the company in 1996 as the Regional Sales Manager for the Asia markets. A dedicated professional, Desmond is a member of the ESD Association and has held the iNarte ESD Engineer certification since 2004.

ABOUT SIMCO-ION, TECHNOLOGY GROUP

Simco-Ion, Technology Group is a global leader in advanced static control and contamination management for high-precision manufacturing. For more than 36 years, it has helped leading manufacturers boost yield, product safety, and process stability across industries, including electronics, batteries, and clean energy.

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