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Basics of Contamination by Electrostatic Attraction

Now You'll Know Your ESDs

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Excess electrical charge plays a significant role in contamination. It can cause an energetic discharge ("electrostatic discharge" or "ESD") that causes damage, and it can attract particles, by means of "electrostatic attraction" or "ESA," that can lead to damage.

The presence of excess charge on a surface can create an electrostatic field that causes the formation of a spark (ESD), which can damage microelectronic components and give rise to electromagnetic signals that disrupt, for example, robotic equipment. The presence of excess charge on a surface also creates an electrostatic field that will accelerate deposition of oppositely charged particles and thus accelerate contamination.

The dominant type of ESA is almost always the "Coulombic" interaction: the attraction or repulsion of a charged particle by a charged surface. The number of particles deposited on a surface is proportional to:

- particle charge and concentration,
- the electrostatic charge per area on the surface, and
- the duration of exposure.

This article reviews just the basics, using semiconductor manufacturing as the example application. More information on electrostatic attraction of particles in cleanroom conditions is available in the articles and book listed in the bibliography.

Deposition

Figure 1 shows the situation schematically, where a particle of charge $-q$ is attracted to a surface having a charge $+Q$ (polarity opposite of that of the particle) per area A. The particle reaches a terminal velocity v in a uniform field rapidly, as illustrated in *Figure 2*; the time scale for micrometer-size particles to reach terminal velocity is microseconds, µ*s*, being roughly proportional to the square of the particle size.

Very close to the surface, the electrostatic field due to the net charge Q will be similar to that from a uniform sheet of charge of density Q/A:

$$E = k\, Q/A$$

The electrostatic deposition is expected to be proportional to Q/A, the charge density. The factor k will depend on the system of units used.

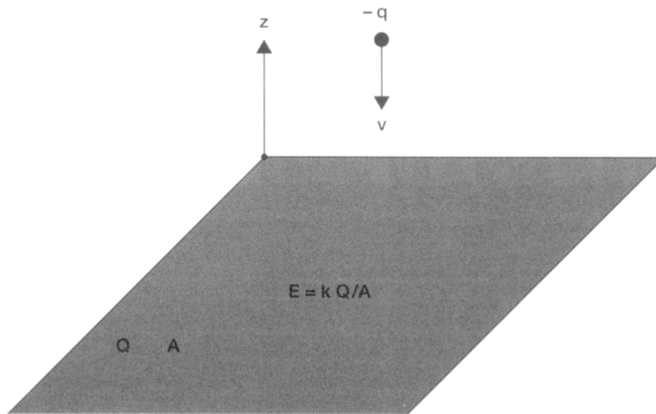

Figure 1. *A particle of charge -q is attracted to a surface having a charge Q (of opposite polarity) per area. The particle reaches a terminal velocity v*.

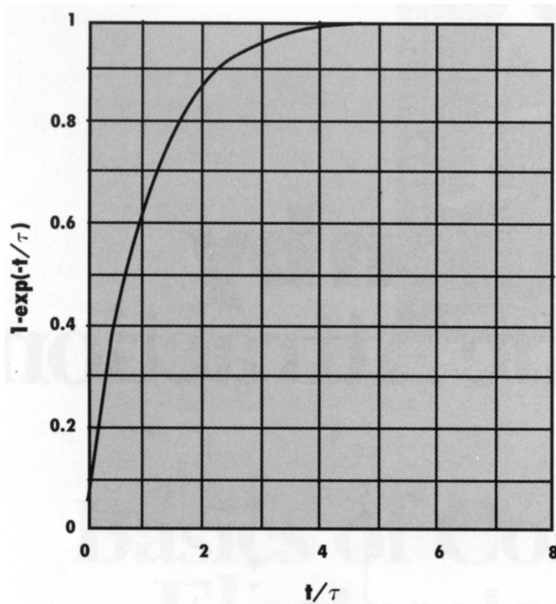

Figure 2. *Schematic of 1-exp(-t/) approach by a particle to terminal velocity. The characteristic time scale, , for micrometer-size particles to reach terminal velocity is microseconds, µs.*

For particles of diameter *d* and charge *q*, the deposition flux *j* (number per area per second) is the product of their number concentration *c*, their charge; the electric field *E*; and their mechanical mobility, *B*, the terminal velocity they achieve per unit of applied force:

$$j = c\, q\, E\, B$$

and the total number would be the integral of the flux over the area over the time of exposure, and would be given by:

$$N = c\, q\, E\, B\, A\, t$$

if these factors were constant and uniform.

The group *q E B* is also known as the "electrostatic deposition velocity." These factors are discussed briefly next. Diffusion and inertia are usually negligible and will be ignored, so the particle concentration can be considered uniform for prediction of deposition flux.

For a spherical particle, the particle mechanical mobility, the terminal velocity per unit external force is:

$$B = C(d) / 3 \quad \mu d$$

where *C(d)* is the Cunningham slip correction (roughly *C(d) = 1 + 0.16 μm /d at NTP*),   is 3.1416, μ is the gas viscosity, and *d* is the particle diameter. As the particle size decreases below a micron, *B* goes from being proportional to $1/d$ to $1/d^2$.

In a normal atmosphere, the positive and negative ions tend to have roughly equal effectiveness in charging particles, so that the particles are roughly equally positive and negative, with some tendency for negative charge to predominate. Roughly half the particles will be attracted and half repelled by a net charge on the wafer. Special circumstances, such as corona discharge deionizers that are not balanced, could change this. Without ionizers, cleanrooms tend to have relatively low levels of ions compared to the outdoor or other indoor atmospheres, because the filters readily remove ions from the recirculating air. There are many charging and discharging mechanisms for particles, so q is hard to predict.

It is generally true that the larger the particle, the larger the charge, with q dependent on roughly the size to a power between the square root of size to the square of size. Deposition velocity is defined as   *= j/c = qEB = flux/concentration*. It has been found that there sometimes exists a minimum of deposition velocity, *q E B*, in the particle size range of 0.1 to 1 μm.

It may seem that the increase in particle deposition of particles of one polarity (e.g., positive) would be offset by the decrease in particle deposition of particles of the opposite polarity. This is roughly true, until the deposition of particles of one polarity is stopped completely; still higher fields will continue to accelerate deposition of particles of the other polarity further, with no increased offsetting reduction.

Much work has been done concerning the deposition of particles on charged silicon wafers in a cleanroom. The predictions of Liu and Ahn[1] and of Cooper et al.[2] were that deposition velocities (without electrostatic effects) would be near 0.001-0.01 cm/s. Pui et al.[3] confirmed this in the laboratory using monodisperse fluorescent particles having minimal charge (thus minimal electrostatic effects). Wu et al.[4] found deposition velocities were about an order of magnitude higher for ungrounded wafers in a cleanroom than for grounded wafers. Cooper et al.[2] used a minimal charge distribution (Boltzmann) and a Federal Standard 209 Class 100 cleanroom particle size distribution and predicted that an electric field as low as *E= 100 V/cm* would produce an order of magnitude greater deposition with gravity plus diffusion than these two mechanisms combined produced without the electrostatic field. Further details are available in the book edited by Donovan.[5]

Control

The basic formula for the number of particles (of size d) attracted to the surface:

$$N = c\, q\, E\, B\, A\, t$$

suggests various alternatives for control:

1. The concentration of airborne particles, *c*, should be kept to a minimum, using standard contamination control approaches.

2. The particle charge *q* should be made minimal by using air ionizers.

3. The electrostatic field $E = k\ Q/A$ should be minimized by preventing charging of the surface and by draining charge from the surface by grounding or using a bipolar (positive and negative) air ionizer or by wet wiping or by wiping with a static dissipative cloth (grounded).

4. The mobility, *B*, of the particles is determined primarily by their size and is fixed.

5. The area of interest, *A*, is likely to be fixed.

6. The duration of exposure, *t*, should be minimized by reducing high values of *c, q*, and *E*, as rapidly as feasible.

Summary

Charged surfaces accelerate the deposition of particles of opposite polarity, accelerating contamination.[6] Deposition rates per surface area are proportional to the electric field (surface charge density) and to the particle charge, concentration, and electrical mobility. Current standard contamination control procedures can minimize concentration. Air ionization and other static control techniques are able to reduce particle charge and surface charge, reducing this source of particulate contamination.

Bibliography

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