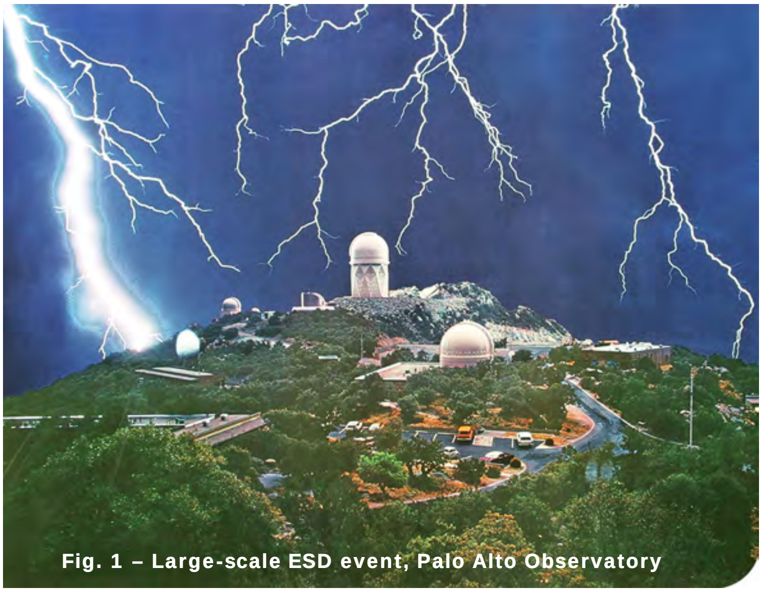


Fig. 1 – Large-scale ESD event, Palo Alto Observatory

Low humidity and high surface resistance are the main causes for undesirable surface electric charges in semiconductor production.
The first part of this essay describes the negative effects of such charges on the required purity of silicon chips (wafers) during the production process and shows which points in the production flow are exposed to electrostatic discharge (ESD), which can damage the semiconductor products.

Triboelectric Charges

in the Semiconductor Production Environment

Lodevicus Hermans,
Win Labuda

Content

In particular,serious production problems occur when due to ESD events the electronic control units of the production facilities fail – or even worse, when changes in the programmed process steps occur. Furthermore, the effects of corrective measures, such as the use of air ionisers in the immediate vicinity of the facility are explained.
The second part of the essay deals with such electric charge and discharge phenomena which occur in connection with the use of cleanroom consumables, with a special focus on cleanroom wipers and cleanroom papers.
The third part of the essay describes the physical principles underlying surface electric charges and discharges.

Part I:

Visible examples of ESD events are lightning discharges during thunderstorms. In such macro-discharge processes, voltages of several thousand kilowatts occur. The disaster of the German airship “Hindenburg” is due to such an ESD event.

Main causes of electrostatic charging:

→ Charging by friction (triboelectric charging)

Typical electrostatic charge (Volt)	Relative humidity		
Event / activity	10%	40%	80%
Walking on carpet	35.000	15.000	1.500
Removing teflon carrier from ultrapure water (Image A)		20.000	
Covering support frame with foil (Image B)		40.000	

→ Charging by induction (contactless charge separation)
Examples: “hair-raising effect” near the TV screen,
attraction of particles by charged objects

Fig. 2

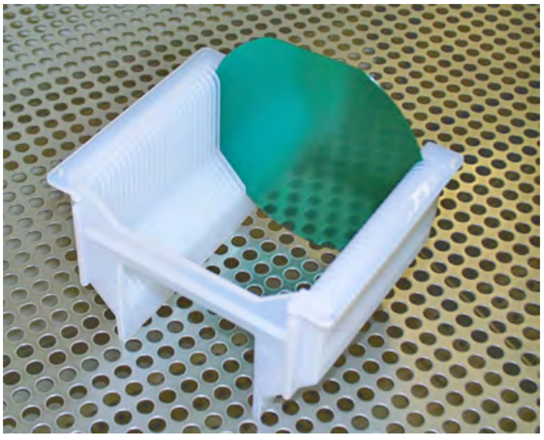


Fig. 2 A

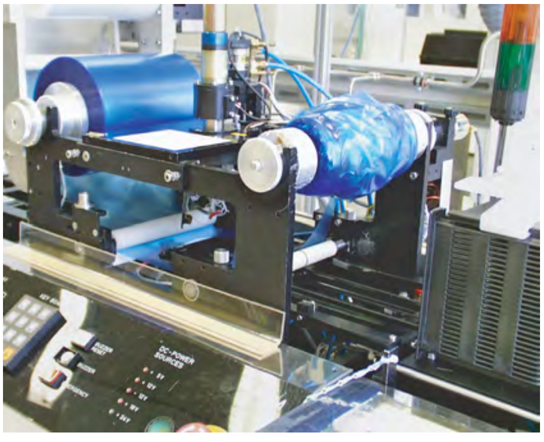


Fig. 2 B

In 1937 this zeppelin was on a voyage from Europe to the U.S.

Due to weather conditions, the flying object had become highly charged, although the outer skin was designed to be electrically conductive. However, a tear had occurred in the outer skin and when the zeppelin approached the landing mast in Lakehurst,there was a spark discharge. The hydrogen content of the airship exploded, leading to the infamous disaster. The main cause of electric charges is friction (triboelectric charge). Some examples from daily life:

- Walking across a carpet can cause electric charge to a person who then „suddenly“ discharges when touching metal parts (door handle).
- Getting out of a car can also cause such charge/discharge processes.

People can feel electrostatic discharges from about 3000 volts. However, the level of a surface electric charge correlates significantly with the ambient humidity. In a dry environment, electrostatic fields of high potential can develop. The semiconductor production environment is particularly at risk, because the humidity there is usually below 50%. Another cause for surface electric charges is electrostatic induction. In contrast to triboelectric

Particle contamination of Si wafers by electrostatic charge

Exposure time: 2.5 hours in the wafer test, cleanroom class 1000

Significantly increased particle contamination of the Si wafers with existing surface potential

Induction effect of wafer 2 on wafer 1 causes an inhomogeneous particle distribution on wafer 1

Increased particle deposition on surfaces in the vicinity of charged objects

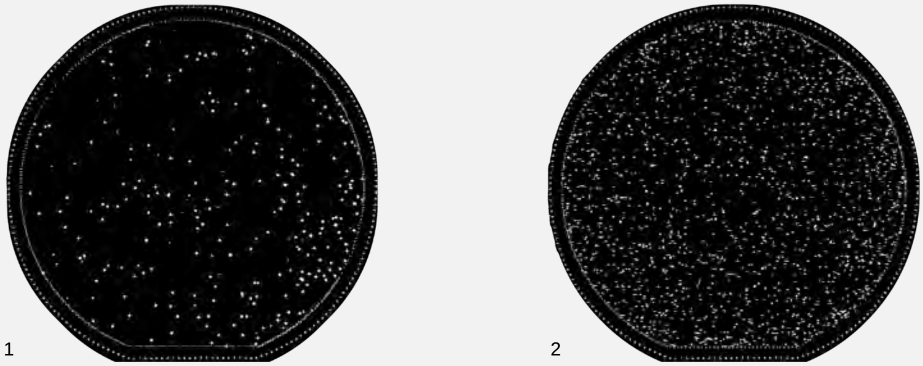


Fig. 3

Fig. 3 A < 0.1 kV charging 1.5 kV

charges due to friction, induction is a contactless charge transfer.

Most of us have experienced this “hair-raising” phenomenon when nearing a TV screen with bare arms. (cf. also Von der Waals generator).

Charged objects often have undesirable effects in semiconductor production:

1. They attract particles that impair the required surface cleanliness.

2. They are the cause of spark discharges which damage the finished products.

Physical Principles

Experiments

In Fig. 2 the charge phenomena are summarised once again.
The particle contamination of the silicon wafers results in the failure of the finished wafer, especially when they are contaminated with large particles, so-called killer particles.
Through the experiment described below, the influence of charges on particle contamination is made clear.
Under ambient conditions corresponding to cleanroom class 1000, two silicon test wafers are positioned on different wafer cassettes.

Particle contamination of Si wafers by electrostatic charge

Typical hand movement during semiconductor production (200 x)

Potential < 0.1 kV

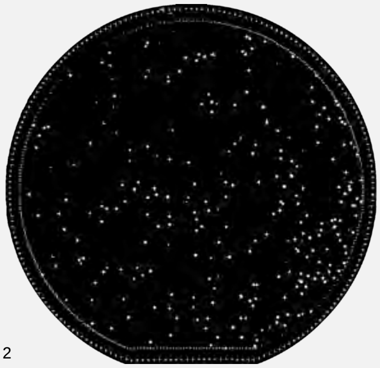
Potential 1.5 kV

Cleanroom class 10, Lam. Flow 0.35 m/s

Normally, protective gloves are worn in the cleanroom. In In this experiment were not worn in order to generate particles.

Significantly increased particulate contamination of the silicon wafers with existing surface potential.

1



2

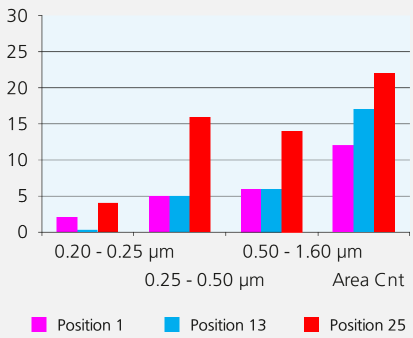
→ Ionisation systems are required in charged areas where wafers are handled.

Fig. 4

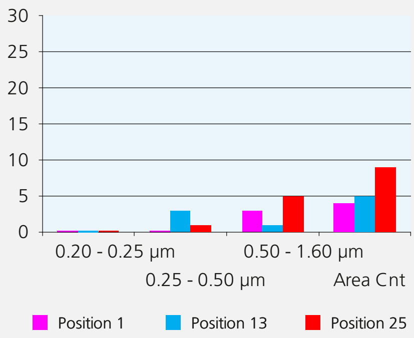
Particle contamination of Si wafers by electrostatic charge

Particle contamination of Si wafers by electrostatic charge. Exposure time in RRK 10:24 hours

Ioniser switched off. 3.5 kV



Ioniser switched on. 0.1 kV



→ Ionisation systems are essential over carrier storage places in wet chemistry.

Fig. 5

Installation of an ioniser leads to particle reduction in the furnace area

Charging of the wafer handler leads to defect density problems in the furnace technology.

The wafer handler is non-conductive: Friction handler / wafer charging

Fig. 6

Fig. 6 A Vertical diffusion furnace

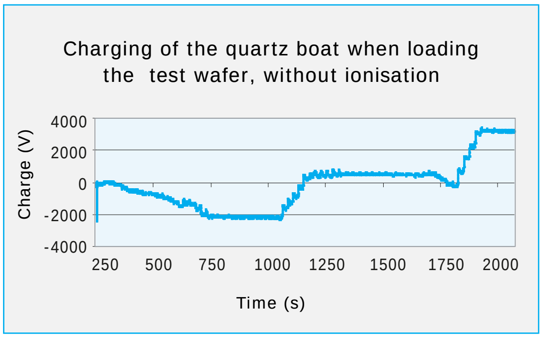


Fig. 6 B

One wafer cassette consists of a conductive polycarbonate; the other of non-conductive teflon (PTFE), and is electrically charged. A portion of the electric charge of the cassette has been automatically transferred to the disk (induction). Both cassettes are next to each other on an electrically conductive table. The result of the particle count after 2.5 hours exposure time showed that the particle contamination was ten times higher on the charged wafer.

PTFE cassettes are indispensable for semiconductor production, especially in the wet etching and subsequent cleaning processes due to their material characteristics. If possible, however, conductive cassettes should be used or suitable ionisation systems should be installed.

In Fig. 4 a second experiment is illustrated. This time, two wafers are positioned under cleanroom class 10 conditions on the two wafer cassettes. Here, however, the particle source is the typical hand movement of a person in the cleanroom. Through the hand movement, a certain amount of skin abrasion occurs between the cuff of the cleanroom overall and the forearm of the person. In the non-charged wafer, the skin abrasion particles flow down past the wafer due to the laminar air flow (distance between wafer and hand about 10cm). The charged wafer on the PTFE cassette, however, attracts the particles, and therefore there is significantly higher particle contamination on the wafer.

Electric Charges in the Production Process

Example 1: As already mentioned, Teflon cassettes are often used in wet-chemical cleaning processes. These cassettes are stored in special carrier storage places in the immediate vicinity of the cleaning facilities. Due to the low humidity and the laminar air flow, the cassettes charge up to a potential of 20,000 volts and thus attract particles. In this case, the person working with these cassettes is the greatest source of particles.

From the cassette surface, the particles are then released during the subsequent purification process into the liquid, resulting in the contamination of the wafers.
To prevent such charges, air ionisers are offered by several manufacturers. Fig. 5 shows how such systems work. The particle contamination of the cassettes is measured indirectly by means of three silicon wafers, which are stored in these cassettes for 24 hours. In this arrangement the influence of air ionisers on the particle contamination is clearly measurable. In particular, the number of particles > 2 µm, thus real killer particles, are significantly reduced when the ioniser is turned on.
The result can be determined: Ionisation systems that are mounted over the cassette storage places of the cleaning processes reduce particulate contamination.

Example 2: Another particle source, which can be eliminated by integrating an ioniser, is shown in Fig. 6.

In a vertical diffusion furnace, domains with higher particle concentrations occur frequently on the wafer surface. The reason for this was discovered during a defect analysis: electrostatic charging of the wafers. The person handling the wafers, who took them out of the cassettes and put them in the quartz boat, was in this case non-conductive.

The friction between the person and the back side of the wafer causes a charge which is passed on to the quartz boat when the wafer is put in it.

In a test sequence with 100 wafers, depending on the material of the wafer back side (poly – silicon, nitride …) both positive and negative charges of this boat were determined. After installing an ioniser over the I/O station of the diffusion furnace, the charge of the person handling the wafer and thus also of the quartz boat were eliminated. This is clear from the defect density data after installation of the ioniser (see Fig. 7).

Example 3: The effects of a defective ioniser are shown in Fig. 8. The defect density trend of the silicon wafers is visible within a specified time period in a wet etching module. Due to the high particle contamination, this module had to be removed from the manufacturing process. By testing the individual etching and/or cleaning modules, the dryer in it was localized as the source of the particles. The identification of this ioniser as particle source was achieved by measuring

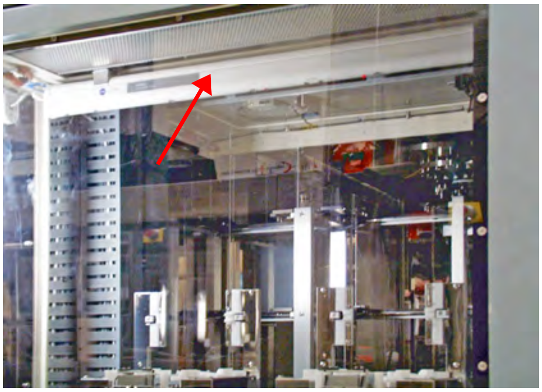


Fig. 7 Integrated ioniser over the I/O station eliminates the charging of the person handling the wafers.

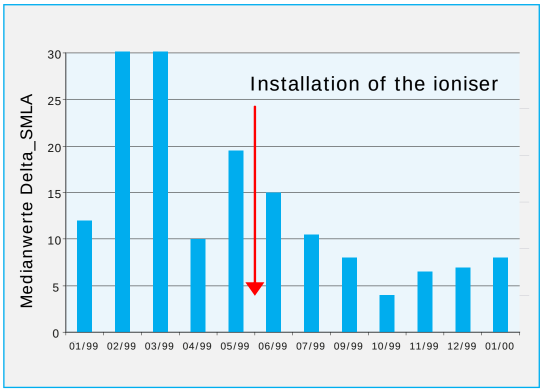
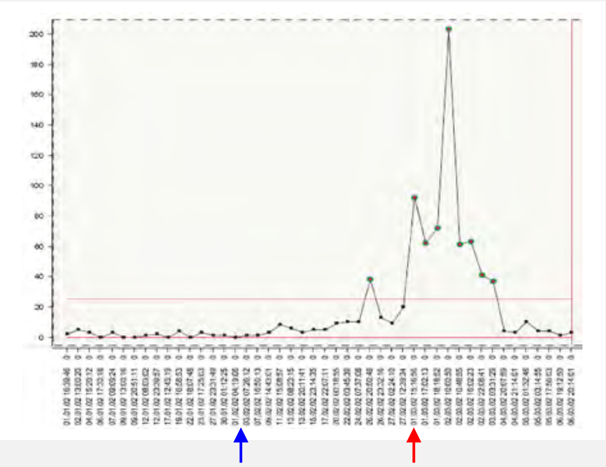


Fig. 7 A After installing the ioniser, the defect density trend does not show any more particle bursts.

Particle contamination due to a defective ioniser during wet etching



Defect density trend January - March 02

From Feb. 02 Increasing defect density trend within the specification

From 1 March: Stoppage of the HMR wet etching unit due to massive particle increase

Fig. 8

Fig. 8 A HMR wet etching unit

the particles upstream and downstream from the ioniser. Moreover, the EDX analyses of the particles pointed clearly in the direction of the ioniser. Upon closer examination, barely visible spark arcs between the ioniser needles were observed. After the defective ioniser was replaced, the defect density once again reached the prescribed value.

There are different types of ionisers available. In a semiconductor factory such ionisers must not be installed everywhere, but locally where unwanted charges are determined. These systems can be installed both under the filter cover, within the mini-environment or directly in the semiconductor equipment (see Fig. 10). Special cases exist in nitrogen lines, in drying units or in fans, where no air flow for ion transport is available.

Example 4: A further effect of the electrostatic charges on the semiconductor production is the direct damage to the microstructures by discharge phenomena (ESD events), (see Fig. 11). In certain technologies with a floating aluminium structure on gate oxide, one wafer in 25 failed the wafer inspection. The problem was gate oxide damage in the centre of the wafer. The search for the cause in the process flow led to a particular unit where the wafer is

Particle contamination due to a defective ioniser during wet etching

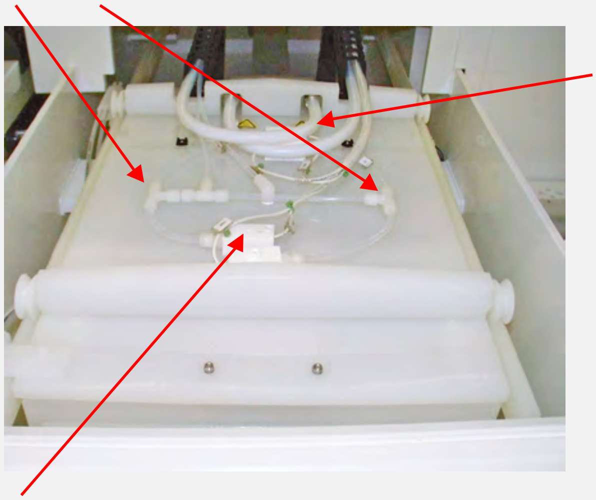


Fig. 9

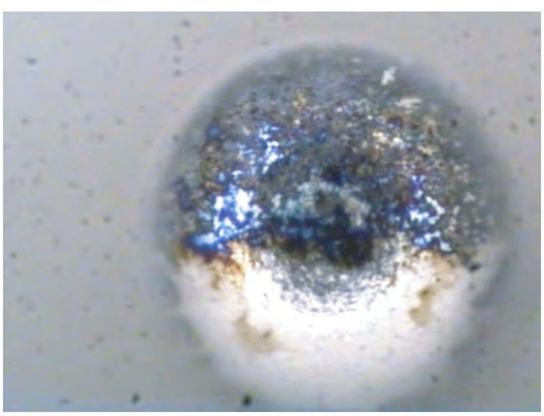


Fig. 9 A Defective ioniser point

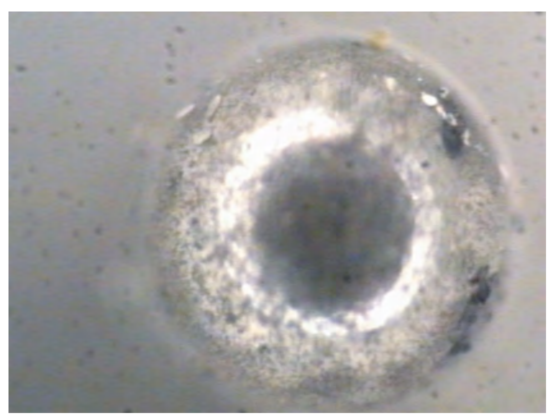


Fig. 8 B Intact point

rinsed with DI water and subsequently dried with oxygen, a so-called rinser-dryer.

Fig. 14 shows some corrective measures to prevent this gate oxide problem. The third measure is perhaps the most elegant. A wafer cassette with 26 slots was available as standard option on the market. In slot 26 a fixed wafer was installed, which shielded the electrostatic field of the teflon carrier.

Serious problems arise when the production lines are halted due to ESD events or when changes in the programme operations occur.

Ionisation systems in semiconductor production

- below the filter cover (Image A)
- in the equipment (Image B)
- in the cassette storage (Image C)

→ Preventive service of the ionisation systems, 3 x per year

(Cleaning of all electrode tips + Control of the discharge times)

Fig. 10

Fig. 10 A

Fig. 10 B

Fig. 10 C

And here the third effect of the electric charges becomes evident: electromagnetic pulses (EMP). These are caused by rapid discharges or load changes. Such pulses can impair the function of microprocessors and cause the computer to crash. This phenomenon explains why cell phones must be switched off in aeroplanes and also in some semiconductor factories.

Example 5: Fig. 15 shows an example from the semiconductor production, where a discharge (ESD) led to an equipment failure. This problem was solved through a good grounding of the cassette indexer.

Conclusion: It is absolutely essential to monitor and discharge all indexers in a wafer factory. Avoiding electric charges by grounding is of course easier and less expensive than installing ionisers. However, grounding measures are only useful in conducting materials.

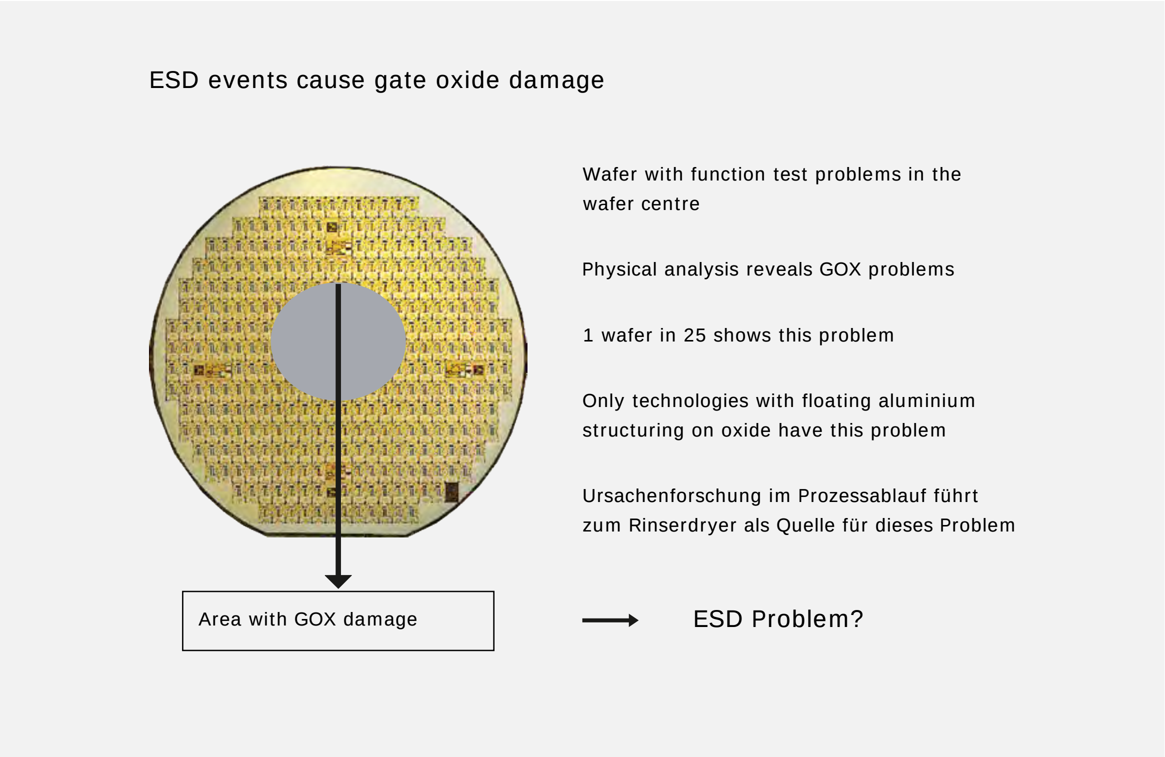

ESD events cause gate oxide damage
Wafer with function test problems in the wafer centre
Physical analysis reveals GOX problems
1 wafer in 25 shows this problem
Only technologies with floating aluminium structuring on oxide have this problem
Ursachenforschung im Prozessablauf führt zum Rinserdryer als Quelle für dieses Problem
Area with GOX damage
ESD Problem?

Fig. 11

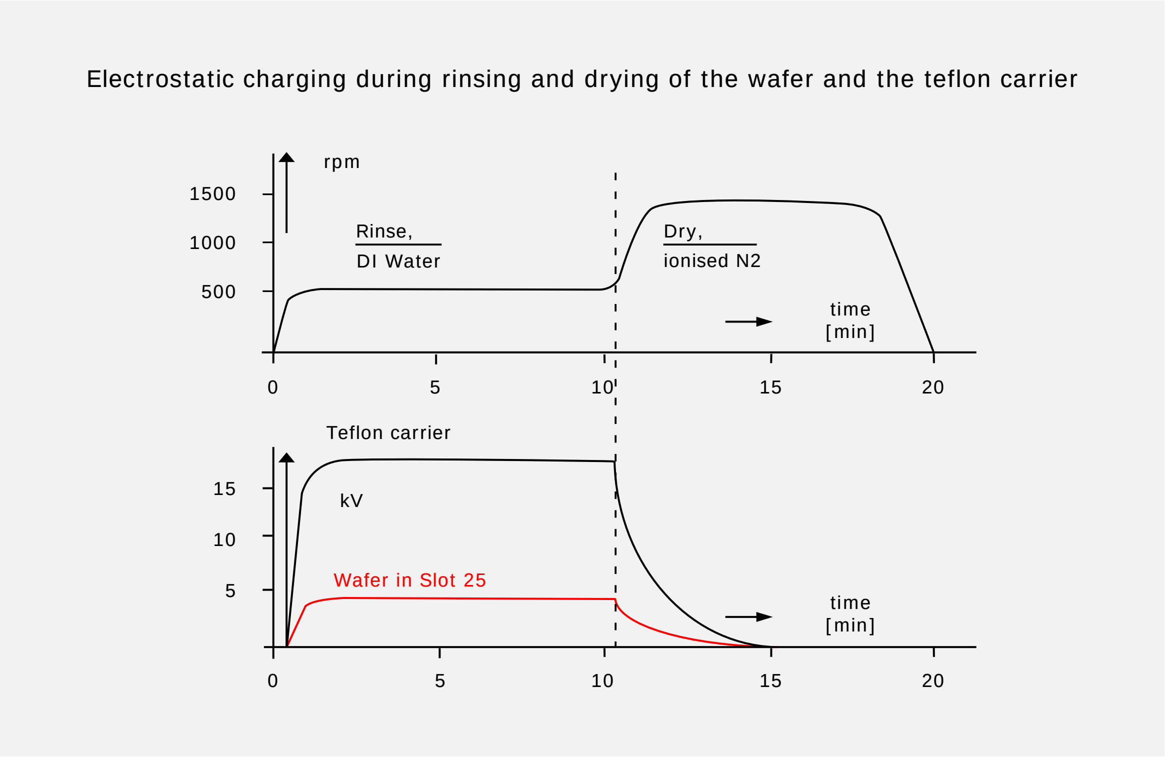
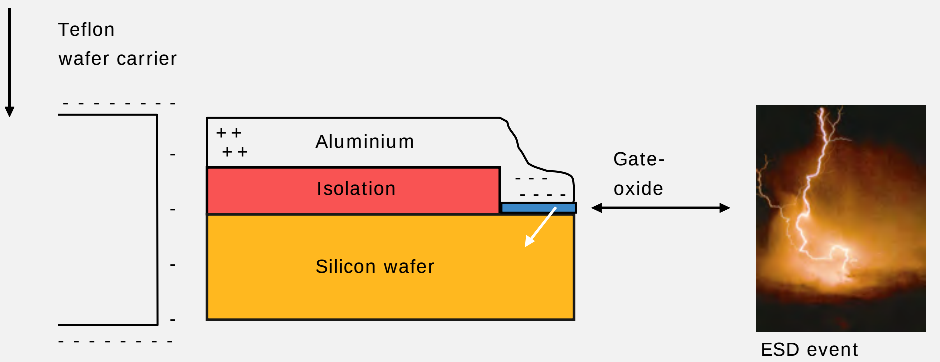

Electrostatic charging during rinsing and drying of the wafer and the teflon carrier
rpm
1500
1000
500
Rinse,
DI Water
Dry,
ionised N2
time
[min]
0
5
10
15
20
Teflon carrier
15
10
5
kV
Wafer in Slot 25
time
[min]
0
5
10
15
20

Fig. 12

ESD events cause gate oxide damage



Difference in charge wafer – carrier: 10 - 15 kV, Distance between wafer and wafer carrier: 5 mm
Charge separation in floating gate, Consequence: gate oxide damage or perforation!!

Fig. 13

All non-conducting materials such as teflon, PVC, PFA, PC, etc. can only be discharged via ionisers.

Ioniser Maintenance

The possibility of reducing the defect density by the use of air ionisers is undisputed. However, it is very important to make sure that the function of ionisers is permanent. This means ensuring regular preventive maintenance and a possible function control by the production monitoring staff.
During the preventive maintenance, the discharge times are measured and, if necessary, re-adjusted, and the ioniser needles are cleaned.

ESD events cause gate oxide damage

Measures to prevent GOX damage by the rinser-dryer

1. Dummy wafers on position 25. Additional handling + extra rinsing process
2. Use of conductive carriers in the rinser-dryer; only possible with H2O rinsing
3. Teflon carrier (non-conductive), with 26 slots. Dummy wafer on position 26

→ ESD shielding!!

Fig. 14

Fig. 16 shows the ioniser monitoring system. The ioniser + controller is connected to the production control systems by means of an FMS interface.

Fig. 17 shows a production hall with installed ionisers and their status:
Red: Ioniser Off
Green: Ioniser On

Only regular, preventive maintenance in conjunction with online monitoring ensure optional functionality of the ionizing devices.

Summary:

Electric charge and discharge phenomena during semiconductor production lead to:

- particle contamination of the silicon wafers and production environment
- a loss of production yield.
- a reduction in quality of the semiconductor structures
- reliability problems of all kinds
- downtimes and failures of the production systems

Corrective measures to prevent electric charges: (see Fig. 18)

- installation of ionisers and their continuous or discontinuous monitoring
- grounding of the production equipment
- if possible, use of conductive materials

Fig. 14 A

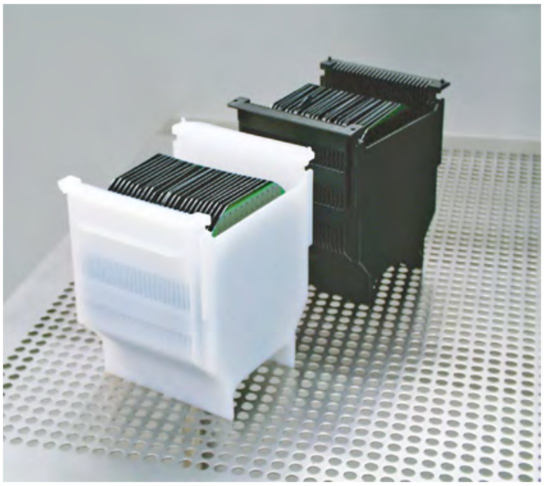


Fig. 14 B

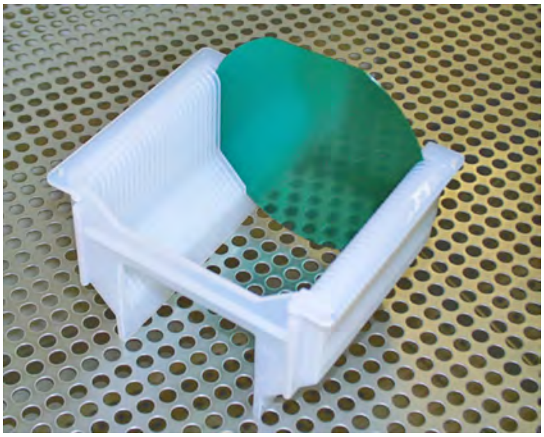


Fig. 14 C

ESD events cause equipment failure / disturbance

The wafer carrier indexer (Image A) of a particle counter (Image B) was not grounded.
The wafer and carrier were charged up to 2 kV when placed on the indexer.
During the contact wafer / wafer handler an ESD event was observed (EMI).
The particle counter was down (reset) for several minutes during each work shift).
Problem was solved by grounding the carrier indexer.

Aim: Monitoring and grounding of all indexers in the wafer factory!

Fig. 15

Fig. 15 A Wafer carrier indexer

Fig. 15 B Surf scan, particle counter

Installation eines Ionisator-Fabmonitoring-Systems

Umhordeplatz in der Diffusion, Handling mit Quarzteilen (Bild A)
Reticle-Kontrolle in der Fotolithografie (Bild B)

Ionisator + Controller + FMS Interface ➡ Leitzentrale: Alarmmeldung

Abb. 16

Fig. 16 A Wafer carrier transfer place in the diffusion
Handling with quartz components

Fig. 16 B Reticle control in photolithography

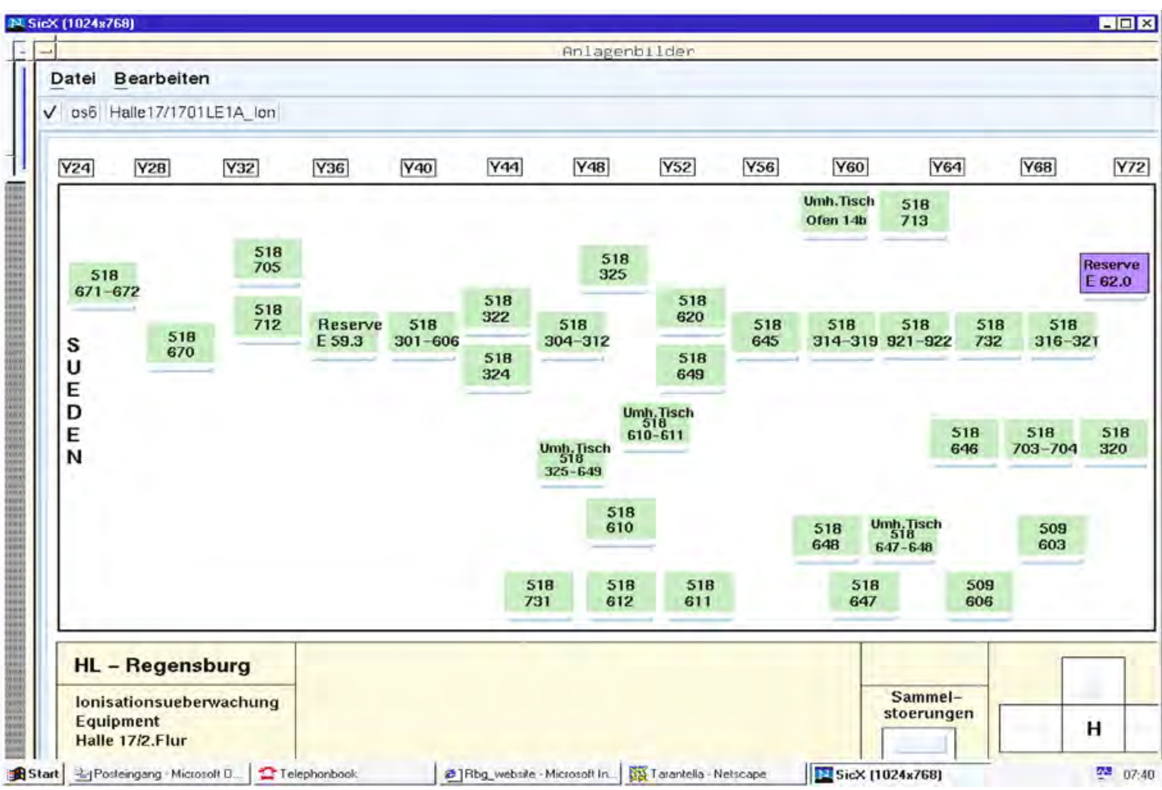


Fig. 17 Ioniser Production Monitoring System

Corrective measures to reduce electric charges in semiconductor production

Summary

Electrostatic charges and discharges during semiconductor production lead to:

- Particle contamination of the Si wafers and the production environment
- Reduction in quality of the semiconductor structure
- Disturbance / failure of the semiconductor equipment

Corrective measures to prevent electric charges are:

- Installation of ionisers and monitoring these
- Grounding of the semiconductor equipment
- Use of conductive materials

Fig. 18

ESD – the invisible lightning

Damage due to electrostatic
discharge and how to avoid it

Fig. 18 A

Charge parameter	Friction parameters for the listed charge parameters Charges through friction in volts			
	Aluminium foil <1 Ohm / square	Graphite glove $< 10^6$ Ohm / square	Non-Amin Film $< 10^9$ Ohm / square	PR glove $< 10^{11}$ Ohm / square
Ouarz	1500	3000	290	3000
Glass	1100	3000	500	900
Wool	200	3000	70	3000
Silk	400	300	70	3000
Aluminium	10	20	50	100
Steel	10	15	20	200
Copper	10	15	35	150
Polyester	200	3000	70	750
Silicon	10	10	20	30
PTFE teflon	1700	3000	3000	3000
FPE teflon	3000	3000	3000	3000

Fig. 19 Charges through friction partners with varied surface resistivity (Ref. 7)

Part II:

Triboelectric Charges generated by Cleanroom Consumables

In cleanroom operations of semiconductor production, surface electric charges pose a major potential danger because the manufactured semiconductor products may already be damaged at relatively low discharge voltages. Moreover, many manufacturing processes that do not take place in immediate proximity to the product may also be affected by surface charges. It is therefore meaningful to look for such processes that lead to surface friction during production, in order to prevent the emergence of charges or to divert these. Triboelectric charges arise especially when handling consumables and cleanroom clothing and always follow the pulse scheme shown in Fig. 20:

1. in cleaning procedures involving wiping (cleaning wipers)
2. when printing forms, operating instructions etc. using laser printers (cleanroom paper)
3. in the context of kinetic friction when wearing work clothes made of synthetic materials (overalls, smocks)
4. when walking on synthetic surfaces (work shoes)

In the second part of this essay, we shall focus on (1) the undesirable effects of triboelectric charges in the context of wiper-based cleaning and (2) in the production of printed matter with laser printers. We will explain how these can be corrected. Furthermore, we shall describe and compare two suitable methods to measure electric charges. These methods make it easier both for manufacturers and users of cleanroom consumables to optimise their selection of suitable materials.

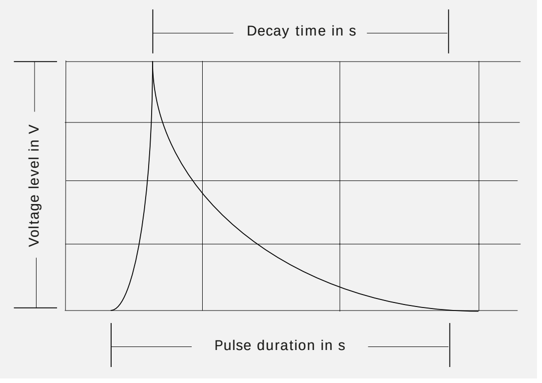


Fig. 20 Pulse scheme for triboelectric charge processes, drop slide method after Ehrler and Corona charging device after Chubb.

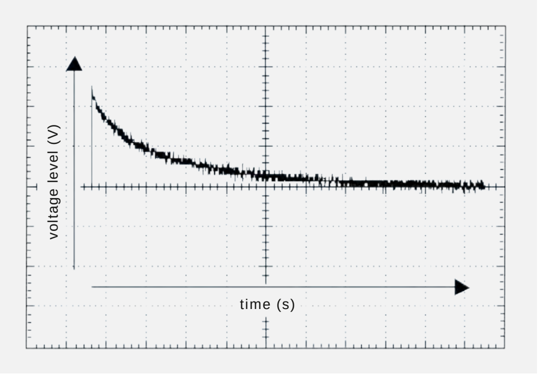


Fig. 21 Charge diagram of a cleanroom wiper in a dry state (Drop slide method after Ehrler).

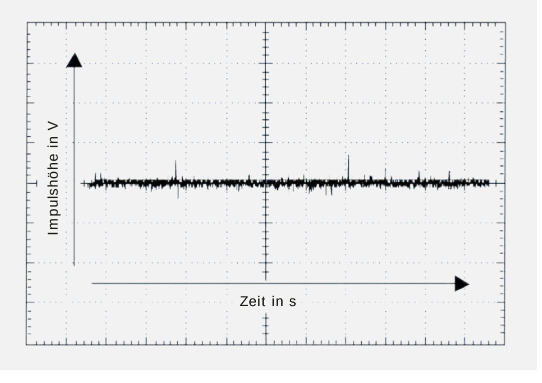


Fig. 22 Charge diagram of the same cleanroom wiper as in Fig. 21, but in a moist state (Drop slide method after Ehrler).

1. Cleanroom Wipers

Triboelectric Charges due to the Wiping Process

As we can gather from Fig. 19, the level of the expected triboelectric charge between two friction partners cannot be exactly predicted. This is also true for wiping processes with a dry wiper on dry surfaces. However, one can be assured that in a wiping process with a completely moist wiper no charging will occur (Fig. 21 and 22).

But not all cleaning processes can be performed with completely moist wipers. When dry or partially dry wipers are used or those that are impregnated with paraffin, there is the risk of triboelectric charge. The following examples illustrate problems that occur repeatedly.

Example 1: To remove oily or greasy substances from a surface, an inflammable solution such as acetone, benzene, isopropyl alcohol etc. is generally used. This method is e.g. typical for the cleaning of printing screens in hybrid circuit printing. The danger consists in the following:

The moistening of a wiper with one of the above mentioned inflammable solutions usually occurs with a spray bottle into the middle of the single- or double-folded or crumpled wiper, which is held in the free hand.

At the time of application, some places of the wiper are saturated with the solvent and the other parts are dry. When during cleaning, dry parts of the cleaning wiper are rubbed against the partly dry surfaces of the printing screens, the solvent-moistened surface areas can be ignited by electric discharge sparks from the dry parts. Fires can occur in this way. For such applications it is therefore advisable to use pre-moistened cleaning wipers or those with reduced chargeability (cotton) or to use non-flammable solvents.

Example 2: Optical glass lenses and also other very smooth surfaces are often cleaned with special wipers consisting of extremely fine threads (microfilaments). The single filaments have a diameter of < 2 µm. With such wipers, even the thinnest contamination layers of oil

and grease down to a thickness of several nm can be quickly and easily removed.
However, the less rough the surfaces of two friction partners, the higher the resulting triboelectric charge will tend to be on the surfaces during the wiping process. Such charged surfaces will attract the particles of the surroundings to a considerable extent until they discharge and, for that reason, the cleanness of the surface achieved by the wiping procedure is often of short duration.
This can be counteracted by moistening the wipers a little with deionised water. However, the wiper must never be wet. It should be in a state which can be described as damp. That is less than moist but more than dry. This low moisture level is attainable in practice only by spray moistening (not by splash moistening).

Example 3: Wipers containing paraffin, which are especially used in the circuit board industry in order to remove particles from surfaces, can give these circuit boards very high triboelectric charges – especially when the wipers consist of polyester nonwovens or fabrics. Voltage levels of almost 900 V and decay times of max 200 s have been measured on such surfaces when using polyester wipers. There is a risk of attracting particles from the ambient air and a subsequent contamination. Here it is recommended to use coarse-meshed cotton wipers waxed with paraffin.

Example 4: “Antistatic wipers” are usually presaturated with film-forming polymer dispensions. During wiping, a transfer of the chemical substance takes place from the wiper to the surface. Here the transferred substances create a moist microclimate which is intended to reduce the chargeability of such surfaces. Unfortunately, the substance sometimes dries out, thus forming crystals, and the crystals pass into the atmosphere.
Such wipers are also problematic for use in cleanrooms because of the molecular contamination (AMC) related to them.

To determine whether the movement speed in the wiping processes or the speed of the paper feeder in the printer has an impact on the level of the surface charge, a cleaning wiper was moved with the aid of a pneumatically driven linear motor over a previously discharged plexiglass surface.

The results were as follows:

velocity (cm / s)	**Surface charge (V)**
10	1830
25	751
50	335

Fig. 23 Surface charge depending upon the friction velocity

Slow wiping movements cause a higher charge than fast movements.

Summary of cleaning wipers in a dry state when delivered

- In the dry state, knits have a generally somewhat lower triboelectric charging tendency than nonwoven materials (Fig. 36-39).

- As in common in manufacturing, adding a non-ionic surfactant can greatly influence the charging characteristics of a cleanroom wiper. It can even cause a change in polarity (Fig. 26). However, one must always take into consideration that an excess of surfactant on the surfaces that are to be cleaned can leave undesirable residues, which affect the desired surface cleanness.

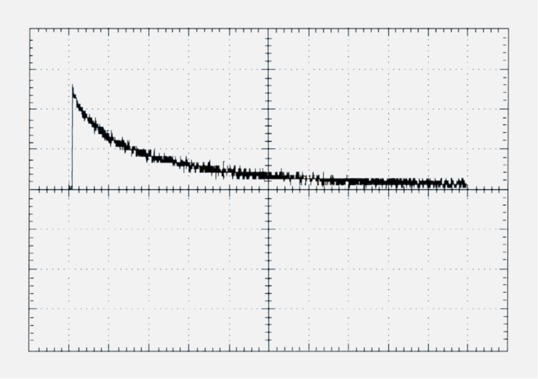


Fig. 24 PES knit without added chemicals, (+8636V : 195s).

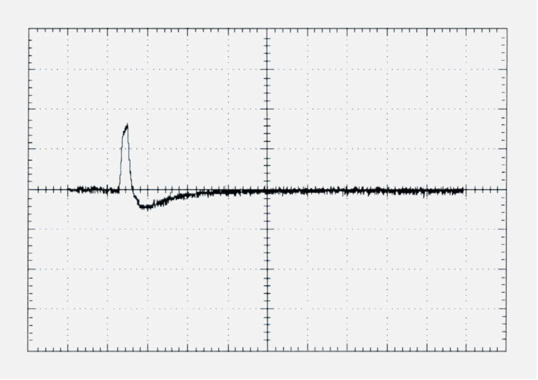


Fig. 25 PES knit, washed and hydrophilically equipped (+530V : 0.19s).

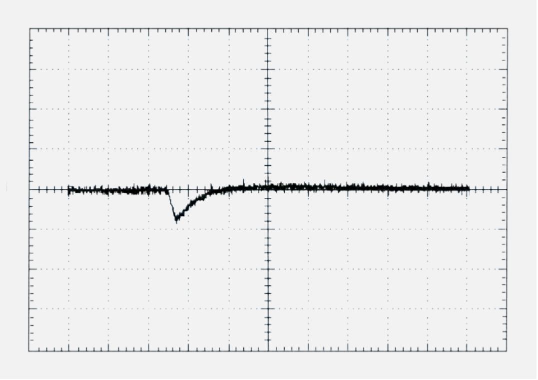


Fig. 26 PES knit, washed and hydrophilically equipped, different surfactant than in Fig. 8 (-241V : 0.8s).

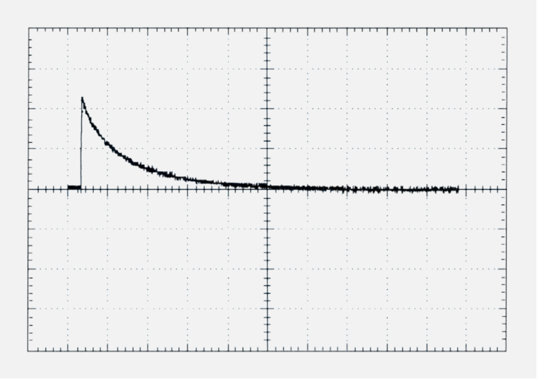


Fig. 27 nonwoven material consisting of a PES cellulose blend (+3876V : 62s).

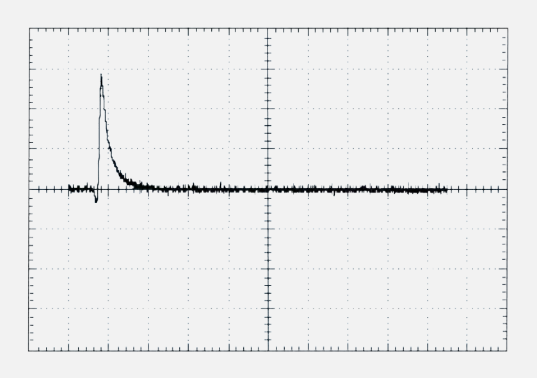


Fig. 28 nonwoven wiper as in Fig. 11 but half of the sample moistened with solvent (+938V : 0.75s).

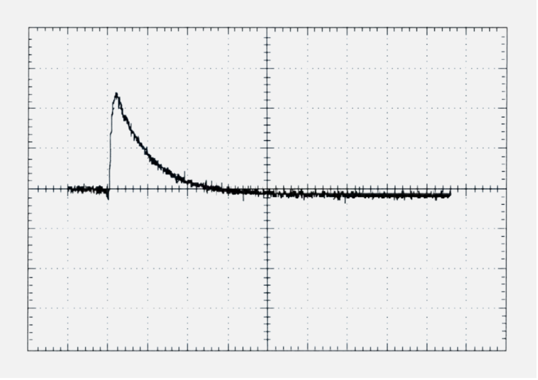


Fig. 29 cleanroom paper with polymer coating (+796V : 1.4s)

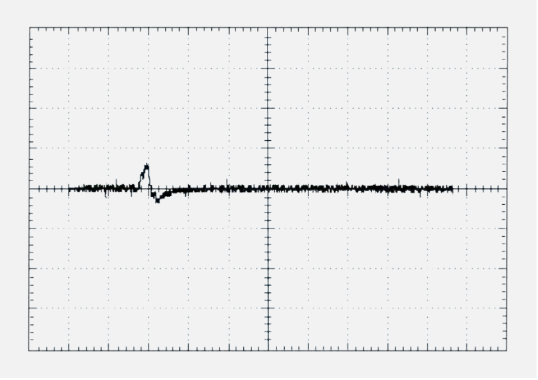


Fig. 30 cleanroom paper as in Fig. 13 but after a brief immersion in 0.1% NaCl solution and subsequent drying.

- The charging characteristics of the cleanroom wipers available on the global market differ from each other considerably (Fig. 36, 37, 38 and 39).

- A higher degree of cleanness and/or a better washing out-condition sometimes leads to an obviously higher charging tendency of the wiper made of knit materials. This, however, depends on the basis material which is used (polyester or polyamide).

- Cleanroom wipers in a dry state can reach peak charges of over 6000 volts with a wiping way-length of only 100 mm. It is therefore useful to choose suitable cleanroom wipers if an occasional or constant use of the wipers in a dry state is planned or if through evaporation during the work phase a dry state can occur.

- Cleanroom wipers, which are used in a solvent-saturated state, are often only partially saturated. The dry parts of the surface of the wipers have the charging characteristics of dry wipers (Fig. 28). This fact should be considered in every operator training course.

- So-called antistatic wipers, which are furnished with film-forming polymer dispersions, should not be used in cleanroom operations.

- Slow wiping results in higher charge voltages than fast wiping and not vice versa (Fig. 23).

- Triboelectric-charged surfaces can often be discharged with a wiper saturated with isopropyl alcohol and DI water.

2. Cleanroom Paper

Due to electric charges of the paper, operators of photocopiers or printers occasionally have their problems with the faultless feed and paper transport in the printer. This phenomenon is especially prevalent in the winter months when rooms are heated and the humidity is very low. Double or multiple feeds and paper jamming are the unpleasant consequences of dryness.

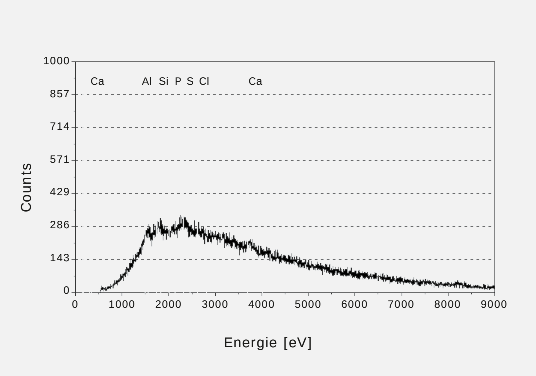


Fig. 31 low ion cleanroom paper (EDX analysis)

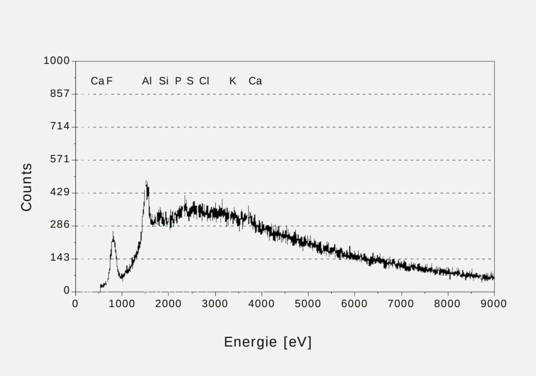


Fig. 32 Cleanroom paper with two distinct peaks (Al und Fl) (EDX analysis)

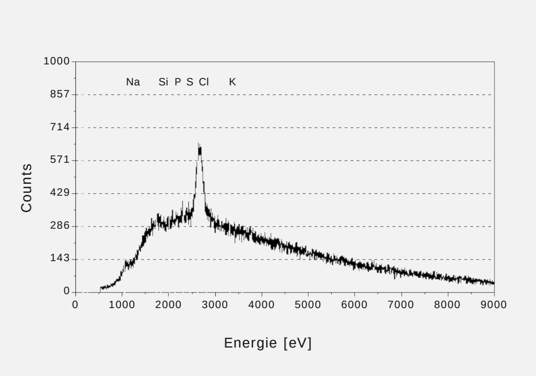


Fig. 33 Cleanroom paper immersed in 2% NaCl solution and dried (EDX analysis)

Decay time measuring station JCI - 155

Apparatus for measuring the electric charge capacity after Chubb

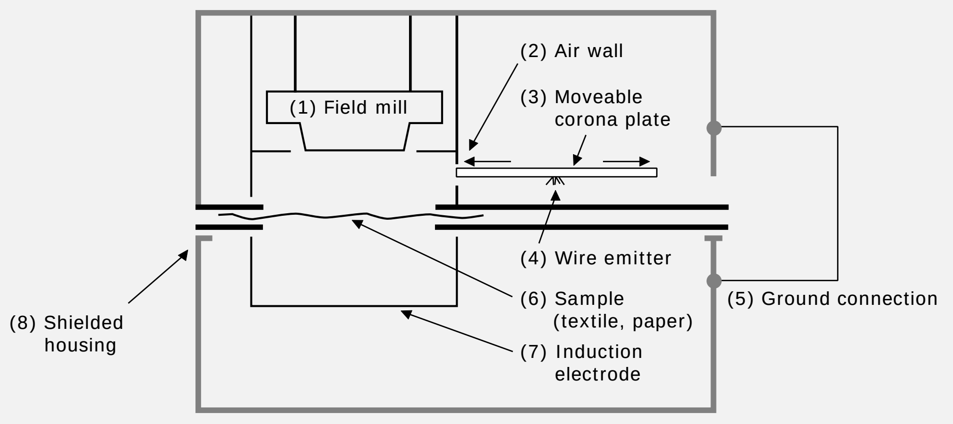


Fig. 34

Drop slide after Ehrler

Device to measure the triboelectric charge of flexible surface structures

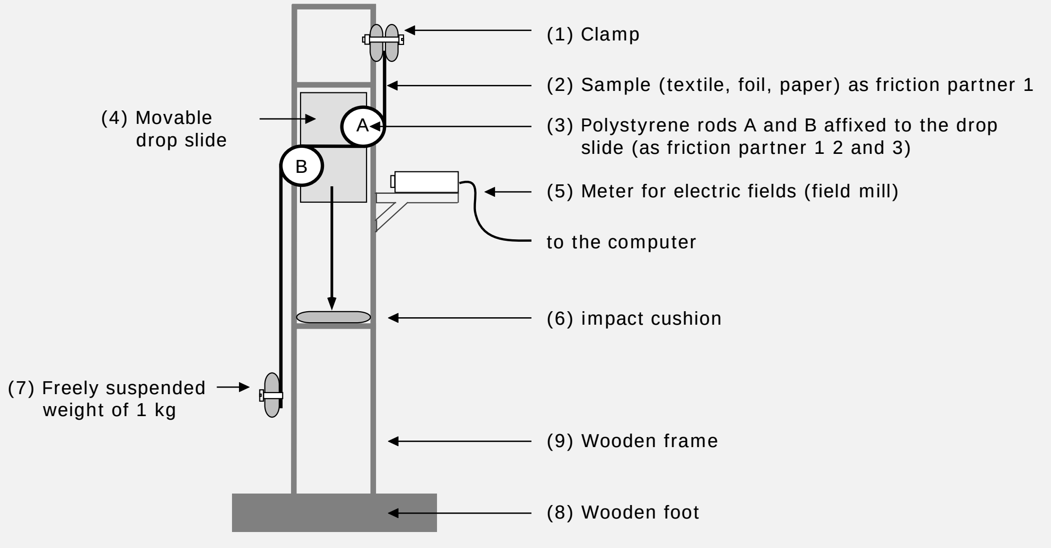


Fig. 35

In cleanroom connected production tracts photocopiers and printers are sometimes operated in an air-conditioned environment of only about 38% humidity. In this production environment cleanroom paper is always used. There are quite significant differences between standard copy paper and cleanroom paper. In principle, these make cleanroom papers more prone to paper jamming in a dry environment. If one is aware of the physical principles underlying this situation, one can take appropriate countermeasures.

The following parameters are an absolute priority in the requirement profile of cleanroom paper for the cleanroom engineer in, for example, semiconductor production:

- low particle release
  and thus automatically
- low ion release

In this regard it must always be noted that when determining the quality of cleanroom consumables,it is not their content that is important, but rather how much of it is released during use. (Ref. 8).This means in practice:

It is not the ion content that is critical for the practical applications of a cleanroom paper, but rather the release of ions during use. However, this occurs almost exclusively in the context of particle release. In production processes that could be adversely affected by ion contamination it is therefore very important to use cleanroom paper that has been decontaminated on the cutting edges.
The following properties are normally subordinate but not unimportant:

- low-level triboelectricity
- high toner adhesion
- high tensile strength
- good paper-feeding properties

In order to fulfil the two first-named requirements, some manufacturers provide the surfaces of cleanroom papers with a polyelastomer coating which binds the particles on the paper surface and thus greatly reduces particle emission. To our knowledge, only one manufacturer offers papers in which the cutting edges are additionally decontaminated. However, that is where most particles are found. The more polyelastomer applied to the surface, the less particle attrition caused by the surface friction during the operation and as a consequence the less particle emission during handling. On the other hand there is always a certain increase in the triboelectric chargeability and thus electrostatic inhibition of the sliding mechanism in the paper feeder.

The coating of cleanroom papers has significant effects on their triboelectric surface charge during the printing process. To prove this, a device for measuring surface charge based on the principle of a field mill was fixed above the paper stack in a laser printer. During the printing operation, as the diagrams in Fig. 43 and 44 show, the cleanroom papers with a latex coating had a considerably higher charge through the transport in the printer than those with a PVA coating.

Slide Inhibition

The cause for problems with the unimpeded transport of the paper in the printer or in the copy machine is usually that the slide inhibition is too high between the sheets of paper in the stack. Several factors can contribute to this:

- the surface adhesion is too high due to triboelectric surface charging, especially if the humidity of the environment is relatively low.
- too low discharge of the process-related corona charge of the paper in the printer during the paper transport.
- the adjustment of the pressure setting of the paper drawer of the printer or copier is too high.
- the friction coefficient between the sheets of paper is too high (surface roughness).
- insufficient hardening of the polyelastomer coating applied to the paper(very rare).

The following material characteristics of the paper as well as the process parameters are decisive for the faultless transport of the paper in the printer or photocopier:

- Surface roughness
- Friction velocity
- Pressure setting
- Adhesion
- Material moistness
- Density
- Temperature
- Triboelectric chargeability
- Pre-charging related to the process
- Electric discharge of the paper during the paper transport

The triboelectric chargeability of the paper is therefore only one of many factors which determine the parameter slide inhibition. In analysing the causes of too high slide inhibition, it is not sufficient to explain the problem e.g. by measuring the surface resistivity of the papers. Much more often, device-specific rather than triboelectric parameters cause jamming in the paper transport.

It is, however, probable that in triboelectrically charged papers there is a clear association between surface resistivity and decay time of the charge pulses. Both the essay of Malinverni (Ref. 7) and the results of diverse tests in the Clear & Clean Research Laboratory, but also the research by Curt Raschke (Ref. 3), confirm this phenomenon. This shows that the chargeability of papers significantly decreases as the proportion of chlorine in the paper increases (see diagrams 29 and 30).

A method especially suited to roughly ascertain the ion content of cleanroom papers is energy dispersive X-ray analysis (EDX),using a scanning electron microscope. This is evident in Fig. 31 to Fig. 33. Whereas there are no visible peaks in Fig. 31, in the paper of a non-European manufacturer shown in Fig. 32 there is a clear aluminium peak and also a fluorine peak. If a paper of the quality as in Fig. 31 is immersed for several minutes in a 1% NaCl solution and then dried and analysed by means of EDX there is in the diagram a prominent chlorine peak (Fig. 33). The charge level and the decay time are then considerably less than in the paper shown in Fig. 31 (see the charge diagram in Fig. 30 compared to the diagram in Fig. 29.)

For cleanroom papers one may thus have to accept the alternatives:

- higher ion content
  or
- higher triboelectric chargeability.

For the above-mentioned reasons, in the open cleanrooms of semiconductor production, many cleanroom engineers prefer papers that have a higher ion content, but which are decontaminated on the cut edges.

Coloured Cleanroom Papers

Cleanroom papers are mainly used for operation protocols in the production of semiconductors or pharmaceuticals. Another application is the fabrication of cleanroom-suitable copies of operating manuals for the machines and equipment set up in the cleanroom. Some users prefer the colour coding of individual papers or chapters within the protocols and therefore use different coloured papers. Such papers must be dyed in a vat during the paper production. For the dyeing process there are colours that contain metal ions and are relatively lightfast and those which contain less ions and are less lightfast.

As already mentioned, the ion content of papers for use in semiconductor manufacturing is uncritical as long as no particles detach from the paper which then transport the metal ions into the production environment. Generally speaking, however, the use of different coloured papers should be avoided because this leads to an increase of stock items and is not really necessary. It is possible to find the desired pages in the operation protocol even without colour-marked pages.

Test Results for Cleanroom Wipers (Knits)

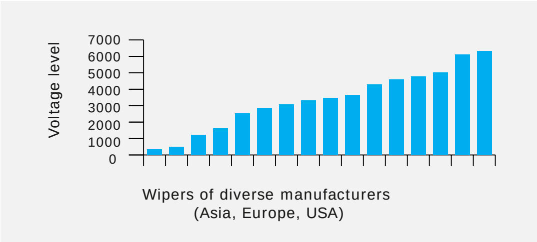


Fig. 36

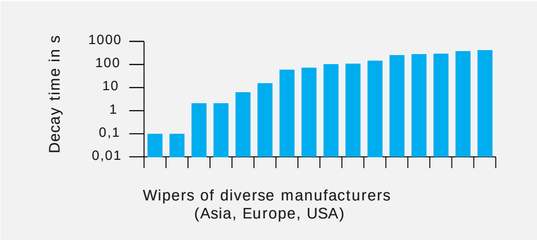


Fig. 37

Test Results for Cleanroom Wipers (Nonwovens)

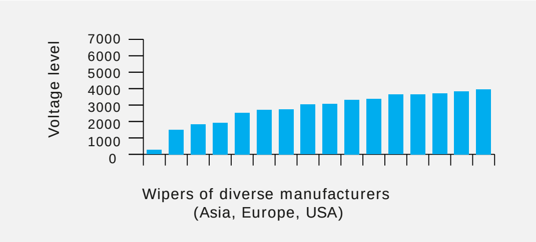


Fig. 38

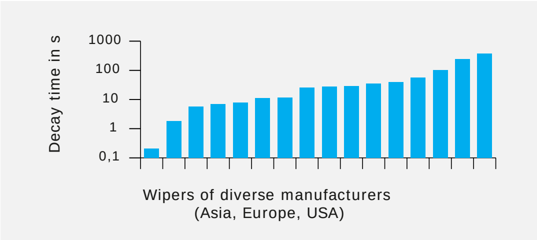


Fig. 39

Test Results for Cleanroom Papers

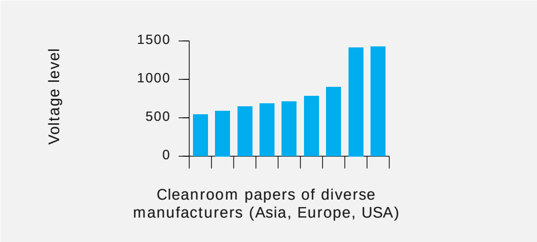


Fig. 40

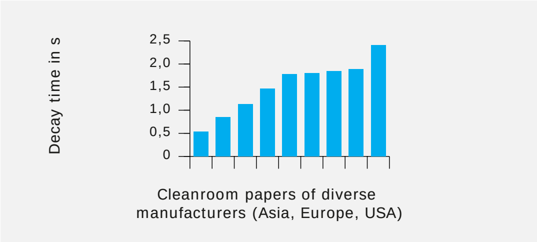


Fig. 41

Summary Cleanroom Paper

- Although the climatic conditions were the same, considerable differences in the pulse decay time could be determined between the different brand papers. The reasons for this are the different densities, surface characteristics, polymer coating and ion components in the paper.

- If a standard cleanroom paper is briefly immersed in a 0.1%igen NaCl solution and then dried, the charge level and the decay time are considerably less than the non-immersed standard cleanroom paper. (Fig. 29 and 30)

- The charge characteristics of the major cleanroom papers on the world market (Ref. 8)vary considerable, but to a less extent than in cleaning wipers. The charge level, measured with the drop slide after Ehrler, varies in the paper with the highest and lowest charge tendency in a ratio of 1:3. For the pulse decay time the ratio is 1:5.

Comparative Tests

We first wanted to assess the chargeability of cleanroom wipers and papers through surface friction through a practical test. The experiment was designed to simulate the charge relationships in wiper-based cleaning procedures or in paper transport. It was therefore necessary to design an apparatus with which it is possible to elicit a triboelectric charge and to measure it, always under the same physical and environmental conditions. In this context, the triboelectric drop slide after Ehrler (Fig. 35 and 45), which was developed in the Institute of Textile Technology and Process Engineering in Denkendorf, seemed to us to be the appropriate instrument. We built the device according to the specifications of Dr. Peter Ehrler and his staff, Ms. Schmeer-Lioe and Mr. Mavely, whom we owe valuable information.

We also purchased a device made by the British company JCI (see Fig. 34 and 46), which can accommodate flexible sheets and provides these with a corona charge. The decay of this charge is then measured by means of a field mill and recorded as a graph (see Fig. 42). This device is characterised by its ease of use and good reproducibility.

Description of the Decay Time Measuring Station JCI-155

In a metal housing consisting of an upper and a lower part there is a recess with the dimensions 55 x 65 mm. The sample (6) is clamped between the upper and lower part of the metal housing in such a way that it is fixed like a membrane but is not drawn taut. After the assembled system begins operation, a horizontally mounted corona plate, which has an emitter in its centre (wire bundle), moves above the sample and causes its electric charge. After the sample has been charged, the corona plate moves back to its initial position within 0.02 sec, and the decaying surface charge is measured by the field mill above the sample and stored on the memory card of a computer.

Description of the Drop Slide after Ehrler

Due to the low chargeability of the material wood, the drop slide after Ehrler consists of a vertically constructed wooden frame in which – likewise made of wood –there is a vertically guided drop slide (4). Firmly connected to the drop slide are two polystyrene rods (3) A and B with a diameter of 15 mm. Instead of polystyrene a different polymer could be used here. The drop slide is locked in its initial position in the upper part of the wooden frame. When operated, it can be electrically unlocked and then falls onto the impact cushion (6).

	Ehrler system		**Chubb system**			
	Voltage level in kV	Decay time to 0 kV in sec.	Voltage level in kV	Decay time to 0 kV in sec.	Quotient Voltage level Ehrler/Chubb	Quotient Decay time Ehrler/Chub
Microfibre knit	3.4	479	2.4	> 1000	1.41	0.47
Polyester knit	3.5	251	2.2	45	1.59	5.57
PES / cellulose-nonwoven	3.7	78	1.8	3.5	2.05	22.30
Viscose nonwoven	3.7	1.2	1.1	0.9	3.36	1.33

Fig. 42 Voltage levels and decay times in comparison: the Ehrler and Chubb systems

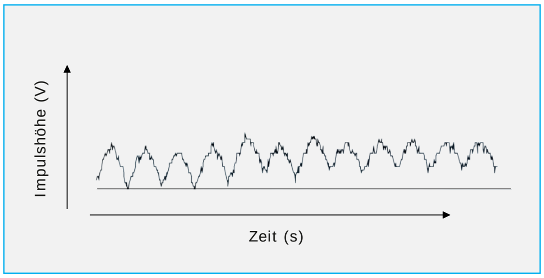


Fig. 43 Charge pulses during paper transport: cleanroom papers coated with polyvinyl alcohol

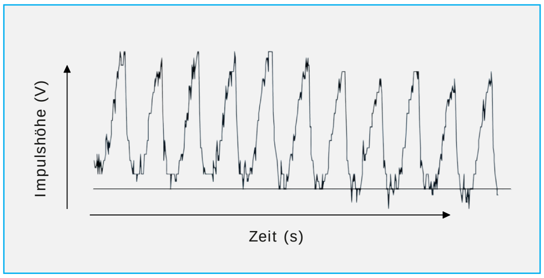


Fig. 44 Charge pulses during paper transport: cleanroom papers coated with latex

The cleanroom wiper or paper that is to be analysed (2) is fixed in the clamping device (1) which is located at the top part of the wooden frame. Then the paper is carefully placed around the polystyrene rods without causing any friction which could generate unwanted electric charges. A weight (7) is clamped to the free end of the paper which alone with the aid of gravitational forces ensures the close contact between the paper and the polystyrene rods. After the insertion of the sample in the drop slide is completed and the field mill (5) and the downstream equipment were turned on, the actual test begins.

Performance of the Tests

From each cleaning wiper or paper, five samples were cut and stored for 12 hours in a test climate of 40% relH at +22° C. Then the samples were placed one after the other in the drop slide or in the JCI measuring station, where they were charged and measured. The devices were located in the climate chamber. The charges arising on the cleaning wiper or the paper upon operation of the devices and the subsequent decay phases were registered on an oscillograph or as technical data (Fig. 36 to 39). The data were analysed and tabulated. Using this method, an overview was provided about the possible electrostatic chargeability of the cleanroom wipers and the cleanroom papers of different manufacturers under usual humidity conditions in cleanrooms.

There are fundamental difference in construction between the drop slide after Ehrler and the corona charging device after Chubb, so that in the measurements There are different results in the voltage levels and in the decay times (see Fig. 42). The difference may possibly be explained by the fact that in the drop slide after Ehrler the sample is charged on both sides and in the corona charging device after Chubb only on one side.

Fig. 45 Triboelectric drop slide after Ehrler

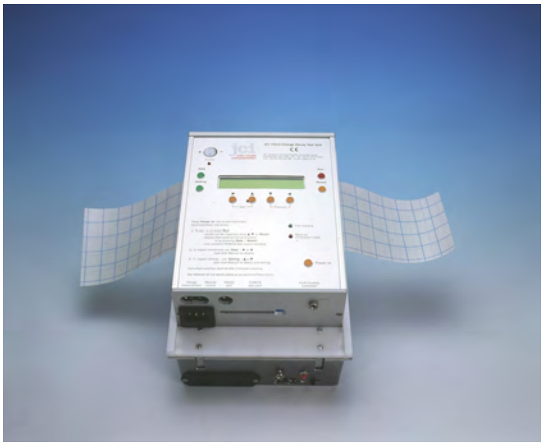


Fig. 46 Corona charging device after Chubb

The test data for the same materials differ between the two systems Ehrler and Chubb, but in triboelectric charge and discharge phenomena and times we must always consider that we never measure on physically and chemically pure surfaces. Rather, in the molecular sense, each textile and paper is already "pre-coated". The advantages of the corona charging device after Chubb are its ease of use and its uncomplicated, fast electronic data processing.

Notes to the Charge Diagrams

In Fig. 36 to 41 a series of very interesting charge diagrams are shown, which support the conclusions put forth in the summary. The diagram in Fig. 20 shows the principle course of all subsequent diagrams: (Fig. 24 to 30).

When the drop slide falls, the test sample is spontaneously charged. A subsequent decay phase follows. The various cleanroom wipers and papers on the market show considerable differences in the measured voltage levels and in the decay times. The higher these two values are, the less is the „triboelectric worth" of the relevant product. Fig. 27 shows a „standard" diagram of a polyester knit out of which all of the chemicals were removed which would have normally been added to make the wiping material capable of absorbing water. The drop slide test showed a resulting voltage level for it of 8636 V with a decay time of 195 s. Fig. 26 shows clearly that adding another surfactant to the wiper in Fig. 25 not only causes a reduction of the charge voltage level but also can cause a change in the charge polarity. In this way, it is possible in the production of high-tech wipers to select the addition of a surfactant so that the voltage level can be reduced considerably - even to zero. However, one must take into consideration that by adding surfactants one usually adds ions, which are not desirable, to the wiper as well. This is also true for so-called non-ionic surfactants. The choice of the right surfactant in the right amount is therefore very significant.

In Fig 22 it was already shown that a moist wiper does not produce a charge during the wiping process. This occasionally leads to careless handling of such wipers, which although they are moistened prior to each cleaning procedure, are not, however, saturated homogeneously over the whole surface. The remaining dry places on the wiper still have a residual triboelectric effect. This fact is apparent in the diagrams in Fig. 27 and Fig. 28. Fig. 27 shows the charge diagram of a dry nonwoven wiper made of equal parts of polyester and cellulose fibres. Fig. 28 shows the charge diagram of the same wiper, but in a partly moistened state.

Part III:

Physical Basics of Triboelectricity

If two electrically neutral surfaces made of any material are completely laid over each other at a normal ambient temperature, then a charging transfer is generated over and beyond the boundaries of the surfaces until the potential balance is achieved. If the two surfaces are then separated, the same quantity of electric charge excess exists on each surface, but it is of opposite polarity. This change is known as „electrostatic charging". In principle, these processes are relevant to both electrically conductive materials and insulators.

How do these charging and discharging processes occur? On the surface of an insulator (e.g. polyester) there are surface states with longer resting times of electrons. Such surface states are found on surfaces of synthetic materials, in particular where there are defects in the crystal lattice structure. Synthetic materials which have been exposed to a process of thermal forming show both crystalline and amorphous zones. At the transitional junctures of the crystalline to the amorphous there are defects in the form of incomplete macromolecular chains which interfere with the electric surface homogeneity, thus forming crystalline defects and in this way having an increased readiness for a charging transfer. The surface charge density is therefore at first approximation proportional to the difference of the electron emission work functions of two contacting solid surfaces. The electron emission work function is a material-specific quantity. It corresponds to the energy which is necessary to free an electron, e.g. with the aid of electrostatic fields or photons out of the crystal lattice to which it is bound. The level of a triboelectric charge generation, however, results not only from the difference of the surface charge densities but also from the density and distribution of the above mentioned surface states per surface unit. With that we come to the well-known triboelectric series, which is commonly thought to make possible a classification of different synthetic materials according to their charging tendency by a particular friction partner. This series is based theoretically on the electron emission work function of different synthetic materials. However, one must take into consideration that theory and practice can be far apart here, because the amount of „electric pollution“ of the surfaces modifies the surface state density to a large extent. Thus, in practice, considerable deviation from the triboelectric series and even a change in polarity can be expected. Bauser drew an interesting energy diagram showing the electron transfer between two surfaces (a metal-synthetic material transfer), shown in Fig. 47. The synthetic material is described by three parameters:

1. electron emission work function WK
2. ionisation energy I and
3. electron affinity A.

The metal is indicated by the electron emission work function WM. The broken double lines define energy zones within which a conduction band exists. Depending on the material, these conduction bands can vary greatly. The filled-in black or blank circles denote the different surface states before contact (black) and after contact (white) with the other material. The potential VS is produced by the occupied surface states. The proportion of the space charge is characterised by the extent that these states are occupied and is given by the energy level between the Fermi level and the conduction band. The band bending for a magnitude of VD corresponds to the space charge forming under the surface. The energy level X indicates the extent to which these states are occupied. The cause of the charge transfer between two surfaces is that all of the surface states are occupied up to the amount of the Fermi level and a redistribution of the charges takes place.

In practice, electrostatic effects are produced by the cyclical contact and separation of synthetic surfaces. For example, such oscillating contact- and separation-cycles result e.g. from walking with rubber soles on a synthetic floor. The shoe soles make surface contact with the floor and a charge redistribution occurs. When the shoe sole subsequently lifts off the floor an excess charge is produced both on the shoe sole and on the floor.

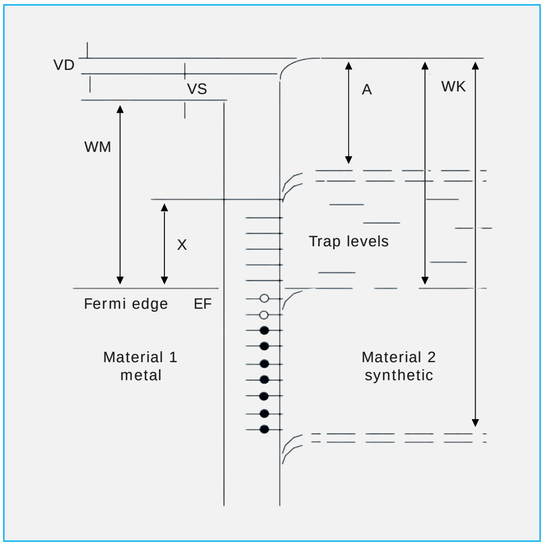


Fig. 47 Energy diagram of the charge transfer after Bauser. Meaning of the indices: W1, W2 – electron emission work function of the two materials 1 and 2, I-ionisation energy, A - electron affinity of material 2, EF – Fermi level.

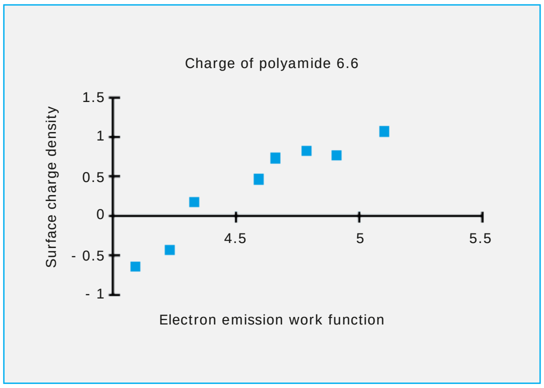


Fig. 48 In 1967, R.G. Arridge drew this well-known diagram about surface charge density in elementary charges per surface unit relative to the electron work function of various metals WM. This diagram shows that e.g. the electron work function for polyamide 6.6 is about 4.4 eV.

At first this charge will balance out over the remaining contact surface between the shoe sole and the floor. This will ensue to the last point of contact. If the transfer resistance exceeds at this point about 1011 Ohm, then the charge neutralisation cannot be completed and a surface charge remains on the shoe sole and the floor. The situation is similar in a wiping cleaning procedure where there are considerably more points of contact between the friction partners than in the simple touching of the two in a stationary contact state. Thus, in general, friction generates a considerably greater charge.

The excess charge of just separated surfaces is discharged more or less quickly depending on the surrounding conditions. Decisive for the discharge time is the conduction resistance. This term includes all electric resistivity between the charged surface and the ground. In this context it is often assumed that the ambient air, the moister it is, is a finite electric resistor and modifies the conduction resistance. This is only true to a limited extent. Even moist air has an almost infinite electrical resistivity. The influence of moist air on the surface resistivity is caused on the one hand by the absorption and storage of water molecules in the molecular structure of the relevant material surface and also partly by the formation of a hydrogen bond. Furthermore, ionic conductivity can occur through the solution of mineral salts in a moist surface layer - especially with paper products but also with wipers containing cellulose. Thus, the hygroscopicity of a material determines its surface resistance to a great extent.

Surface Resistance

Meanwhile, another past assumption has also been proved wrong: the assumption that there is a relation between surface resistance and the chargeability of a material. Malinverni has clearly pointed out in his essay “Surface Resistivity: Why?” (7) that there is no proven relation here. In order to prove its absence, a series of different materials (quartz, glass, wool, silk, aluminium foil, steel, copper, polyester, silicon chip (polished), PTFE teflon, FPE teflon) with surface resistances of 1 Ohm/square to 1013 Ohm/square were tested using testing apparatus after Baumgärtner (12,13).

Fig. 19 shows the peak charges in Volt by rubbing the above mentioned charging partners with four selected friction partners.

Lodevicus Hermans was senior lead engineer for cleanroom technology at Infineon AG Regensburg. He ist now freelance consultant for the Cleanroom Industry

Win Labuda is CEO Technology of Clear & Clean GmbH in Lübeck.

References

1. Meß- und Überwachungstechnik zur Elektrostatik im Rahmen der Qualitätssicherung in Reinen Arbeitsbereichen (Measurement and monitoring techniques for electrostatics in the context of quality assurance in clean working areas), Thomas Sebald, VDI-Berichte No. 1095 – from 1994

2. Test method to assess the suitability of materials and surfaces to avoid problems from static electricity by measurement of capacitance loading, J.N.Chubb, JCI – 10//2001

3. Tribo-Electricity, “Background” toner deposition and the surface chemistry of some papers. Curt R. Raschke, Adressograph Corp. Warrensville Heights, Ohio, USA

4. Elektrostatische Ladungen – Ursachen und Beseitigung (Electrostatic Discharge - Causes and Remedies). Günter Lüttgens, Pierre Boschung - expert Verlag Grafenau, Württ.

5. British Journal of Applied Physics, 18-1967, R.G. Arridge

6. Dechema-Monographien Vol. 72, H. Bauser, Verlag Chemie Weinheim -1974

7. Surface Resistivity: why? - Grace Italiana Spa. Tagungsband 2 – ESD-Forum 1991 - Pierpaolo Malinverni, VP-Verlag Herrenberg

8. Evaluating wiping materials used in cleanrooms and other controlled environments, T. Textor, T. Bahners, E. Schollmeyer, Deutsches Textil-forschungszentrum Nord

West e.V., Krefeld, Germany - Institute of Essen-Duisburg University, 41st WFK Detergency Conference, Düsseldorf, May 2003

9. Elektrostatik, ein häufig unterschätzter Qualitätsfaktor in der Reinraumtechnik (Electrostatics, an often underestimated quality factor of cleanroom technology), Thomas Sebald, VDI- Berichte No. 919 - from 1992

10. Untersuchung der triboelektrischen Eigenschaften von Verpackungsfolien (Study of the triboelectric properties of packaging films) Tagungsband 2 -ESD Forum 1991 -R. Gärtner, H. Schmeer, VP-Verlag Herrenberg

11. Ladungsverteilung auf Isolierstoff Oberflächen bei elektrostatischer Aufladung in Luft (Charge distribution on insulating surfaces with static electricity in air). - Dietrich Königstein, Dissertation at the Bundeswehr University in Hamburg.

12. Electrostatic measurement for process control, H. Baumgärtner, EOS-ESD Symposium, EOS-6, Oct 1984

13. ESD-analysis of masking tape operations, H. Baumgärtner, EOS-ESD Symposium, EOS-7, Sept 1985

14. Das elektrostatische Verhalten als funktionale Eigenschaft und als Qualitätsmerkmal textiler Flächengebilde (Electrostatic behaviour as a functional characteristic and quality characteristic of textile fabrics), Ehrler, P., Schmeer-Lioe, G.,Textil-Praxis International 46 (1991)

15. Maßnahmen zur Einhaltung eines unkritischen elektrostatischen Verhaltens bei technischen und funktionalen Mehrweg-Textilien (Measures to maintain noncritical electrostatic behaviour in technical and functional reusable textiles), Institut für Textil- und Verfahrenstechnik Denkendorf, Forschungsbericht, AIF-Forschungsvorhaben No.10580, 1998

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