The cleanroom consumables paper, wipers, and clothing constitute the largest throughput of surface materials in a cleanroom. A cleanroom of the semiconductor industry with an open structure has an annual demand of wipers and paper products, which - counting both sides of the materials - amounts to a surface of over 200 000 m². *The surfaces of these materials are more or less triboelectrically chargeable. Static charges represent a potential danger for all semiconductor production. The materials in use on the market show great differences in their charge capability.*

Triboelectric Effects during the Application of HiTech Wipers and Paper Products

Win Labuda
Clear & Clean - Research Laboratory
(dedicated to Dr. Peter Ehrler)

The following paper is an introduction to the fundamental principles of triboelectricity and deals with the triboelectrical charging of *cleanroom wipers* and *cleanroom paper products*. In addition, a proven method for measuring the triboelectricity of surface products will be presented and the results of a whole series of products on the global market will be published here for the first time.

Fundamental physical Principles

Lüttgens, Boschung, and Sebald [1, 2, 4] have commented in their papers and lectures on the fundamental physical principles of triboelectricity in practice. A repetition in the context of this paper follows for reasons of clarification.

After a rubbing movement with a dry wiper over a worktop, e.g. of polyester, the observer notices at best a cleaning effect. In reality, however, much more has taken place: both surfaces have changed electrically.

If two electrically neutral surfaces of any material whatever come into contact with each other at normal temperatures, 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 *electrical charge excess* exists on each surface, but it is of opposite polarity. This charge is commonly called *electrostatic charging*. These processes are in principle 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 distinguish solid surfaces where there are defects in the crystal lattice structure, e.g. of the surface of a synthetic material. 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 electrical 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 workfunctions of two contacting solid surfaces. The electron emission workfunction 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 surface charge density 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 tendency to be either positively or negatively charged by a particular friction partner. This series is based theoretically on the electron emission workfunction of different synthetic materials. However, one must take into consideration that theory and practice can be far apart, 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. 1. Here the synthetic material is described in three quantities: emission workfunction WK, ionization energy I and electron affinity A. The metal is indicated by the electron emission workfunction WM. The broken double lines define energy zones, inside 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). The potential VS is produced by the occupied surface states. The proportion of the space charge is characterized 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

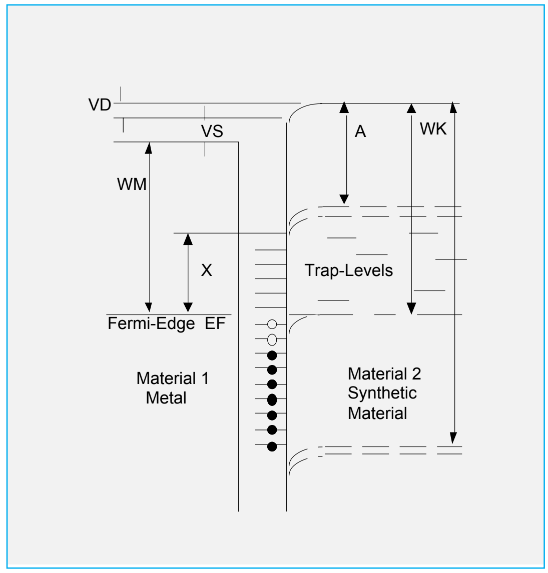

Fig. 1 Energy diagram of the charge-transfer after Bauser. Meaning of the indices: W1, W2 - workfunction of the two materials 1 and 2; I-ionization energy; A- electron affinity of material 2; EF - Fermi level

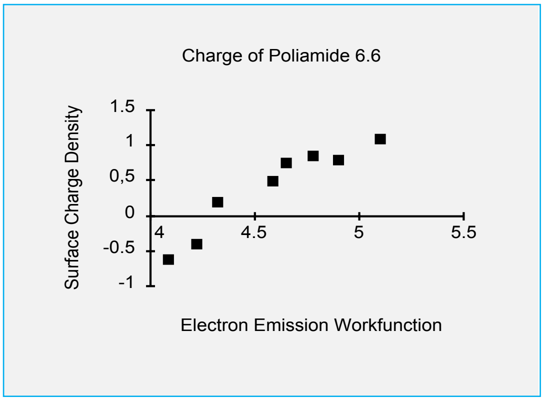

Fig. 2 R.G. Arridge drew this well-known diagram about surface charge density in elementary charges per surface unit relative to the electron workfunction of various metals WM. We can assume from it that e.g. the electron workfunction for poliamide 6.6 is about 4.4 eV.

the surface states are filled up to the amount of the Fermi-level and a redistribution of the charges takes place.

Practical Consequences

In practice, electrostatic effects are produced by the cyclical contact and separation of synthetic surfaces. For example, such oscillating contact- and separation-cycles result 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. 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 this point of about 1011 Ohm, then the charge neutralization cannot be completed and a surface charge remains on the shoe sole and the floor.

The situation is similar in the dry wiping process for the purpose of cleaning by wiping. There are, however, considerably more points of contact between the friction partners than in the simple touching of the two in a stationary contact state. Thus, friction produces in general a considerably greater charge.

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The excess charge of just separated surfaces is discharged more or less quickly depending on the surrounding conditions. Determining for the discharge time is the conduction resistance. This concept includes all electrical resistivity between the charged surface and

Charge partner	Friction partner for the listed charge partner Charges through friction in Volt			
	Aluminium-foil < 1 Ohm/square	Graphite-glove < 10^6 Ohm/square	Non-Amin-film < 10^9 Ohm/square	PE-glove < 10^{11} Ohm/square
Quarz	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

Table 3 Peak charges through friction partner with varied surface resistivity

the ground. In this context it is often assumed that the surrounding air, the more moist it is, is a finite electrical resistor and modifies the conduction resistance. This is only true to a limited degree. Even moist air has an almost infinite electrical resistivity. Moist air influences the surface resistance by taking up water molecules in the molecular structure of the relevant material-surface on the one hand 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 hygroscopability of a material determines its surface resistance to a great extent.

Surface Resistance

Another assumption from the past 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, aluminum foil, steel, copper, polyester, silicon chip (polished), PTFE-Teflon, FPE-Teflon) with surface resistivity of 1 Ohm/square to 1013 Ohm/square were tested with testing apparatus after Baumgärtner [10, 11]. Table 3 shows the peak charges in Volt by rubbing the above mentioned charging partner with four selected friction partners.

Cleanroom Wipers

Triboelectric Charges through the Wiping Process

As we can gather from Table 3, the level of the expected triboelectric charge between a charging- and friction partner cannot be exactly predicted. This is also true for wiping processes with a wiper on surfaces. However, one can be assured that in a wiping process with a moist wiper no charging will occur (Fig. 4, 5). But because not all cleaning processes can be implemented moist, an acute danger of a charge buildup and in individual cases even a potential danger for people exists when the wipers used are dry or half-dry.

Whenever the task is to remove oily or greasy substances from a surface, an inflammable solution such as aceton, benzine, isopropyl alcohol etc. is put to use in practice. For example, this is typical for the cleaning of printing screens in hybrid-circuit printing. Thus the potential danger lies in the following:

The moistening of a wiper with one of the the above mentioned inflammable solutions usually occurs with a spray bottle into the middle of the single- or double-folded wiper, which is held in the free hand of the operator. At the time of application some places of the wiper are saturated with the solvent and the other parts are dry. The solvent vaporizes in a relatively short time. In cleaning large screens for hybrid-circuit printing greater quantities of solvents are often applied and spread out extensively.

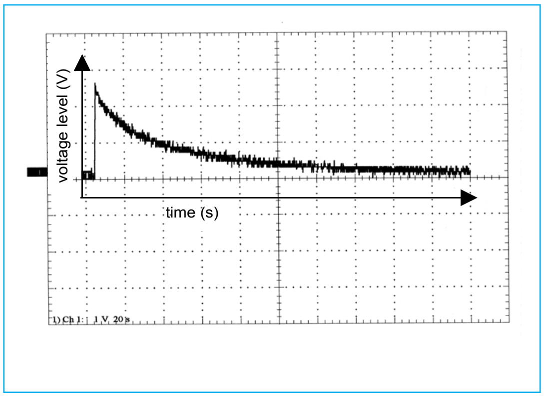

Fig. 4 Charge diagram of a cleanroom wiper in a dry state (Drop slide method after Ehrler)

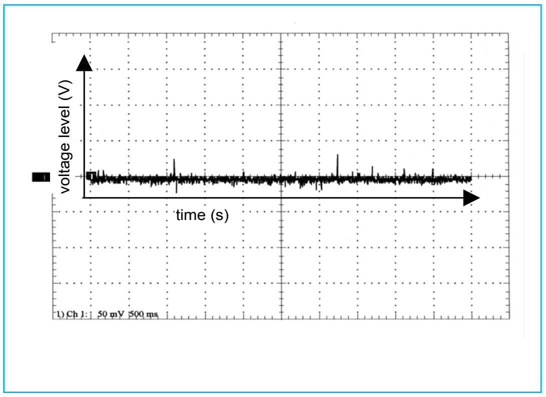

Fig. 5 Charge diagram of the same cleanroom wiper in a moist state (Drop slide after Ehrler)

If a portion of the solvent has dried and the dry places on the wiper rub against the partly dry screen surfaces, then the parts of the surface that have remained moist can be ignited by electrical discharge sparks. Dangerous fires can occur in this way. For such cases it is useful to deliver the wipers in a moist condition and to use those with reduced chargeability.

Optical glass lenses are often cleaned with special wipers consisting of extremely fine threads which have a diameter of not more than 2 µm. With such wipers even the thinnest contamination layers down to a thickness of several nm can be quickly and effortlessly removed. However, the less rough the surfaces of two friction partners, the higher the resulting triboelectric charge on the surfaces will be. Such charged surfaces will attract the particles of the surroundings to a considerable extent until they discharge and, for that reason, the desired cleanness of the surface is of short duration. This can be counteracted by moistening the wipes a little with deionized water. However, the wiper must never be moist. It should be in a state which can be described as damp. That is less than moist but more than dry.

A similar problem arises in removing powder and grainy dust particles from critical surfaces. Often they may not be removed in a moist condition because of a reaction between the moisture in the wiper and the substance which is to be removed. Here it is necessary to use special wipers with a very small charging propensity and, in addition, to carry out the wiping process very slowly. The higher the speed of wiping, the higher the expected triboelectric charges will be as well.

Wipers containing paraffin, which are especially used in the circuit board industry in order to remove dust from surfaces, can give these surfaces very high triboelectric charges - especially when they consist of polyester nonwovens or fabrics. Voltage levels of max 882V and decay times of max 187 s were measured on such wipers using the same measuring instruments as are described later.

Cleanroom Paper

Occasionally operators of photocopiers or printers have their problems with the faultless feed and delivery of paper. This phenomenon is especially prevalent in the winter months when rooms are heated and the humidity is very low. Double or multiple feeds are the unpleasant consequences of dryness. 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 does not have knowledge of several technical correlations and does not take useful countermeasures.

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

- low particle release and
- low ion release

The features below are normally subordinate but not unimportant:

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

In order to fulfill the two first-named requirements, some manufacturers coat the surfaces of cleanroom papers with a polyelastomer, which binds the particles on the paper surface and greatly reduces particle emission. The more polyelastomer applied, the less - within limits - the characteristic values of particle production (caused by the surface friction during the operation) and particle emission (caused by the handling). On the other hand there is an increased triboelectric chargeability and therewith an electrostatic determined slide inhibition in the paper feed and delivery.

Slide Inhibition

The cause for problems with the continuous feed and delivery of the paper in the printer or in the copy machine is usually that the slide inhibition between the sheets of paper lying over each other in the stack is too high. There are several reasons for this:

- 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
- the surface adhesion because of electrostatic contact charging is too high
- too little discharge of the Corona charge buildup of the paper, due to operating conditions, after the printing process

The following material characteristics of the paper as well as the process parameters determine the faultless feed and delivery of the paper in the printer or photocopier:

- Surface roughness
- Friction speed
- Pressure setting
- Adhesion
- Material-moistness
- Density
- Temperature
- Triboelectric chargeability
- Precharging due to the process
- Electric discharge of the paper before leaving the printer

The triboelectric chargeability of the paper is therefore only one of many influences which determine the parameter slide inhibition. In analysing slide inhibition which is too high, it is not enough to want to solve the problem by measuring the surface resistance. Experience shows much more often that the printer- or copier-device-specific parameters rather than the triboelectric ones of the paper cause jamming in the feed and delivery of the paper in the printer or photocopier.

It is probable, however, that with triboelectrically charged papers a clear correlation between surface resistance and the decay time of the charge voltage exists. Both the essay by Malinverni [7] and the results of our own experiments, but also the paper by Curt Raschke confirm this phenomenon. Thereby it appears that the chargeability of paper clearly decreases according to the proportion of its chlorine content. To which extent chlorine ions modify the chargeability either of the paper mass or possibly of the mass of the polymer coating or of both is to be tested. However, such measuring should also include additional elements such as sodium, for example, and should not only apply to the element chlorine.

Both evaluations (Fig. 6) with the energy dispersive x-ray analysis (EDX) show such variable ion concentrations, whereas the paper with the manufacturers code C-GA-G has a voltage level of only +685V, and also a relatively low decay time of 1,13s - out of which in the first approximation a charge integral according to ((IH x ITA):2) = 387 results. (IH =voltage level, ITA =charge decay time)

The paper with the code B-BC-U shows a voltage level of + 785 V but only 0,54 s decay

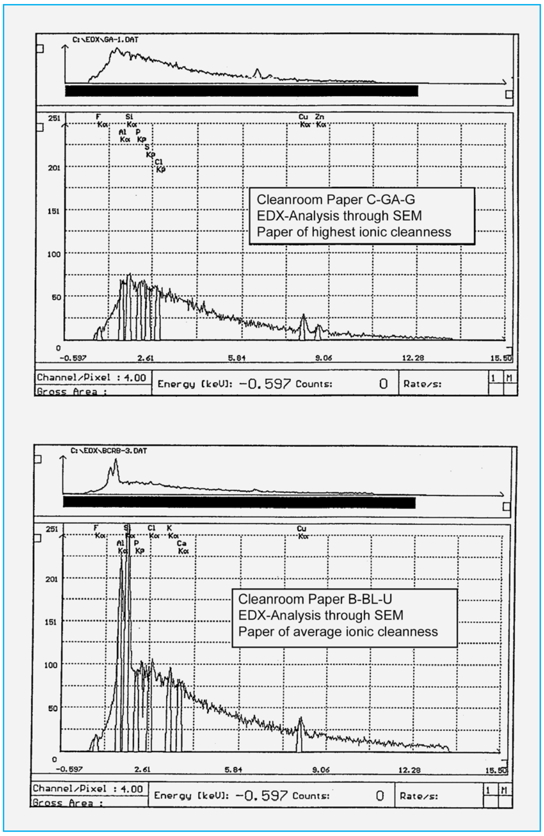

Fig. 6 Evaluation of the energy dispersive x-ray analysis

time. In first approximation this results in a charge integral of only 211.
The paper with the clearly higher proportion of ions shows thus only about 50 % of the charge integral of the cleaner paper in ionic terms.

If one looks at the difference between the charge diagrams in figures 17 and 18, where the level of the voltage was reduced by a short immersion in a 0,1 % NaCl-solution and then drying, the indications increase that ionic cleaner papers have longer discharge times than those with a higher proportion of ions. It is not clear what influence the other species besides the chlorine ions have.

Thus, with cleanroom papers, it is necessary to take a serious look at the possible alternatives:

- a higher proportion of ions or
- higher chargeability.

Comparative Tests

of the chargeability and discharge of various products of cleanroom wipers and papers

We wanted to subject the chargeability of cleanroom wipers and papers through surface friction to a practical examination. The experiment was supposed to simulate the charging conditions of the wiping process or that of paper feed and delivery. It was therefore necessary to devise an apparatus with which it would be possible to bring about a surface friction, always under the same physical and environmental conditions, and to measure this electrical charge which was so produced. In this context, the triboelectric drop slide, developed by the Institute of Textile and Process-engineering Technology in Denkendorf, seemed to us to be the suitable instrument. We built the device according to the instructions of Dr. Peter Ehrler and his colleagues Ms. Schmeer-Lioe and Mr. Mavely, for whose valuable advice we are thankful.

To operate the drop slide after Ehrler the following equipment is used:

Equipment

- drop slide after Ehrler (own construction)
- Temperature and humidity chamber - Fabr. Rumed
- Field intensity gage JCI 140 CF after the field mill principle
- Oscilloscope, Tektronix with a memory device for 2500 pixel type THS 710
- Texas Instruments Personal Computer Extensa 450 T
- Hewlett-Packard-Inkjet-Printer Deskjet 320
- Tektronix-Software WSTR 31 -
- Cables, (plug connections, adapters)

The Drop Slide after Ehrler

Description

Because of the low electrical chargeability of the material wood, the drop slide after Ehrler consists of a vertically constructed wooden frame, in which a vertically operated drop slide - also wooden - is located. Two polystyrol rods (3) A and B with a diameter of 12 mm are firmly attached to the drop slide. In its initial position the drop slide is locked in the upper part of the wooden frame. To start operation it can be released electrically. Then it falls down onto the collision cushion (6).

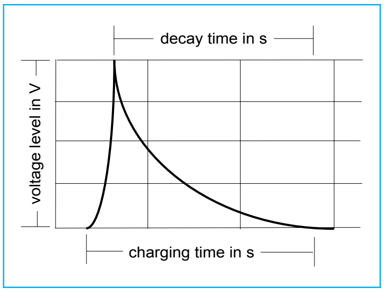

Fig. 7 Charge diagram as it is shown upon operation of the drop slide after Ehrler on the memory oscilloscope

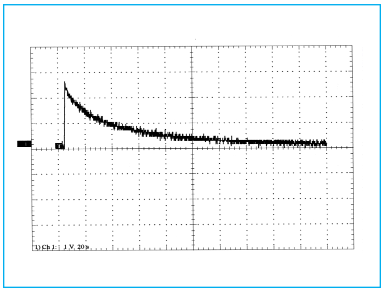

Fig. 8 Standard charge diagram of a washed polyester-knit without surfactant application
(+8638 V with 195 s decay time)

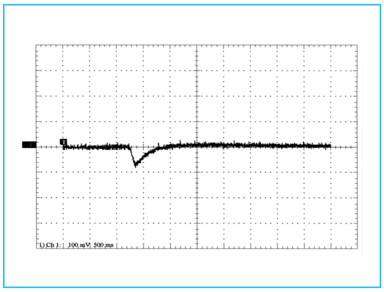

Fig. 9 Charge diagram of the same knit as in Fig. 8, but furnished with surfactant
(-241 V:802 ms)

The wiper or paper which is to be analyzed is fastened to a grounded clamping device, which is located at the top of the wooden frame. Afterwards the paper is carefully put around the polystyrol rods, without causing any friction, so to avoid producing undesirable electric charges. On the free end of the paper a weight (7) is clamped, which - only with the assistance of the force of gravity - guarantees the intense contact between the paper and the two polystyrol rods. After the sample material has been put into the drop slide and both the electric field measuring device (5) and the subsequent instruments have been switched on, the actual testing begins.

The Implementation of the Tests

Five test samples of each paper and wiping material cut to the measurements of 50 x 300 mm were put into a temperature and humidity chamber for 12 hours of 40 % relH at +22° C. Afterwards the samples - still in the test climate - were subsequently put into the drop slide, charged, and measured. The drop slide was thereby in the climate chamber. The spontaneous charges on the wipers or paper upon operation of the drop slide and the subsequent decay phases were registered on an oscillograph. (see the following figures). The oscillograms were evaluated and the resulting data was recorded in tables. In this way a survey was written about the possible electrostatic chargeability of both the cleanroom wipers and the cleanroom papers of various manufacturers under the usual cleanroom humidity conditions.

Charge Diagrams

Below a series of our most interesting charge diagrams are shown, which support the conclusions put forth in the summary. The diagram in figure 7 shows the principle course of all subsequent diagrams:

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 voltage level and the decay time. The higher these two values are, the less is the „triboelectric worth“ of the relevant product.

Figure 8 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

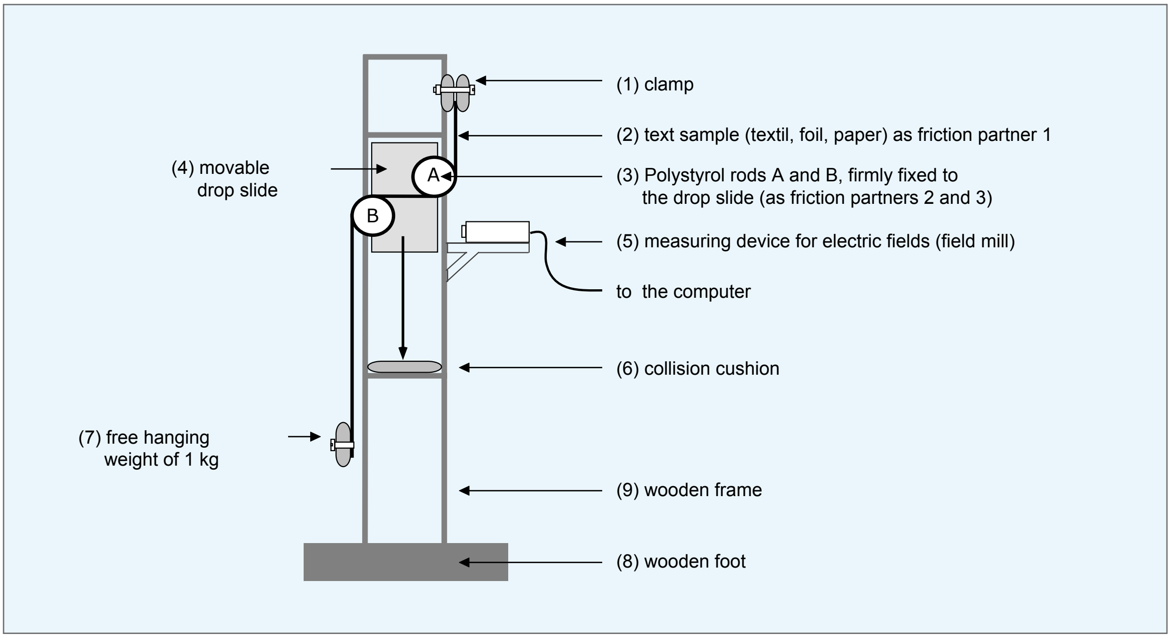

Fig. 10 Drop Slide after Ehrler to measure the triboelectricity of porous surfaces (Scheme)

showed a result for it of 8636 V voltage level with a decay time of 195 s.

Fig. 12 shows clearly that adding another surfactant to the wiper 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 to select the surfactant addition 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 especially true for so-called non-ionic surfactants. The choice of the right surfactant in the right amount is therefore very significant. This is one of the areas where the qualities of the well-known designers of high-tech wipers can be clearly distinguished.

In Fig. 5 it was already shown that a moist wiper does not produce a charge during the wiping process. This fact, however, leads occasionally to careless handling of such wipers. It is true that they are moistened before each cleaning process, but they are not however, saturated homogenously over the whole surface. The places which have stayed dry still have a residual triboelectric effect. This

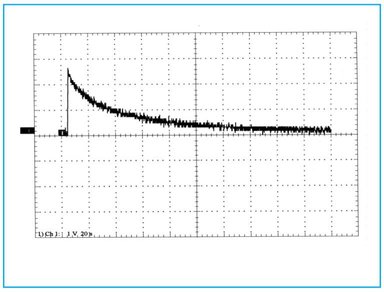

Fig. 11 Standard charge diagram, PES-knit, washed
(+8638 V: 195 s)

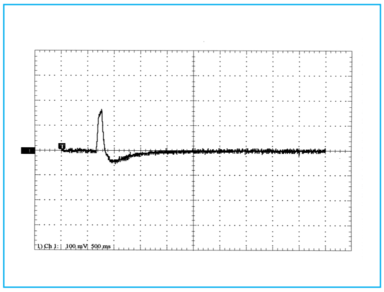

Fig. 12 Comparison to Fig. 11: Charge diagram, PES knit, washed and furnished with surfactant
(+530 V: 188 ms/ -149 V: 1,6 s)
(enlarged to a scale of 1:10)

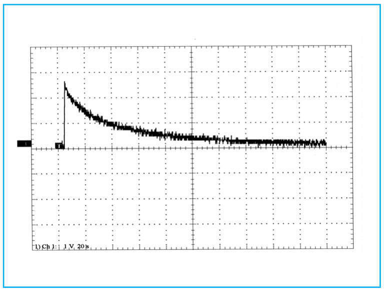

Fig. 13 Standard charge diagram. PES knit, washed (+ 8638 V: 195 s)

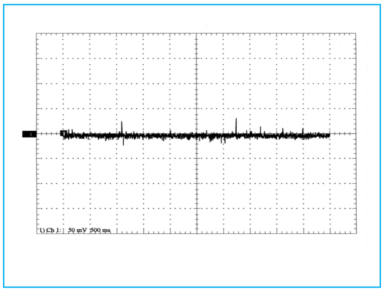

Fig. 14 Comparison to Fig. 13: Charge diagram, PES-knit, moistened with deionized water
(no charge, 0 V: 0 s)

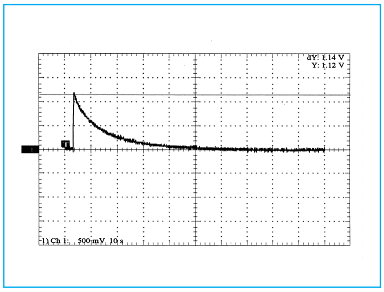

Fig. 15 Charge diagram, nonwoven material consisting of 50:50 PES-cellulose
(+3876 V: 62,1 s)

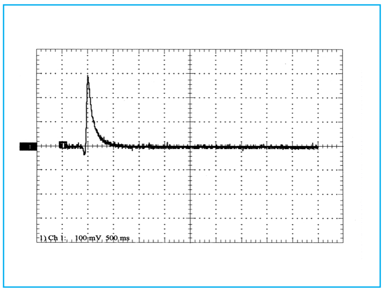

Fig. 16 Charge diagram, the same material as in Fig. 15, but half of the sample wet
(+938 V: 750 ms)
(enlarged to a scale of 1:5)

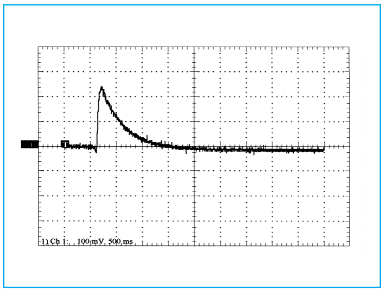

Fig. 17 Charge diagram, standard cleanroom paper with polymer coating
(+796 V: 1,43 s)

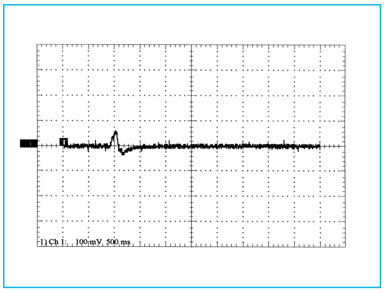

Fig. 18 Charge diagram, the same paper as in Fig. 17, but after a brief immersion in 0,1 % NaCl solution and drying
(+181 V: 171 ms)

fact can be ascertained from figures 15 and 16. Fig. 15 shows the charge diagram of a dry nonwoven wiper made out of equal parts of polyester and cellulose fibres. Fig. 16 deals with the charge diagram of the same wiper, but in a partly moistened state.

Test Results

The results of the tests are presented in the following section and are subdivided as follows:

Cleanroom Wipers

1 Knit materials of all data (Figures 19 to 22)

2 nonwoven materials of all data (Figures 23 to 26)

Cleanroom Papers

3 Papers of all data (Figures 27 and 28)

Summary of the final Results

4 Knit materials, nonwoven materials, paper (Figures 29 to 31)

(We ask for your understanding that the manufacturers and the type description of the tested products have been codified for legal reasons of fair competition.)

Summary

1. Cleanroom Wipers

1.1. In general, knit materials have a somewhat smaller charging tendency than nonwoven materials.

Test Results for Cleanroom Wipers (Knit):

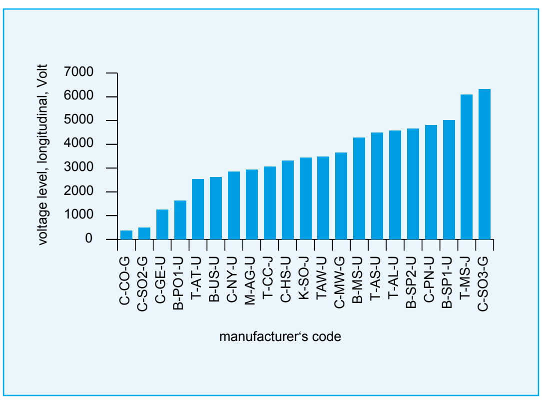

Fig. 19 Test results for the voltage level of various cleanroom knit wipers by longitudinal friction

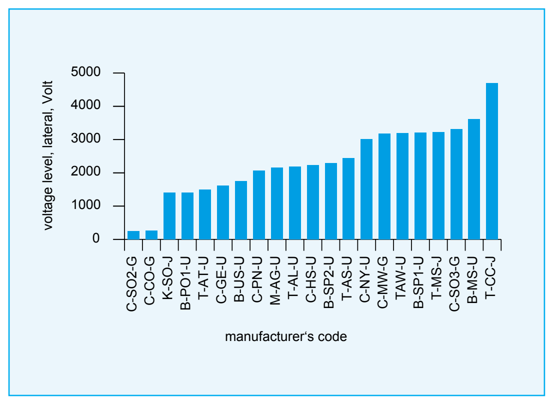

Fig. 20 Test results for the voltage level of various cleanroom knit wipers by lateral friction

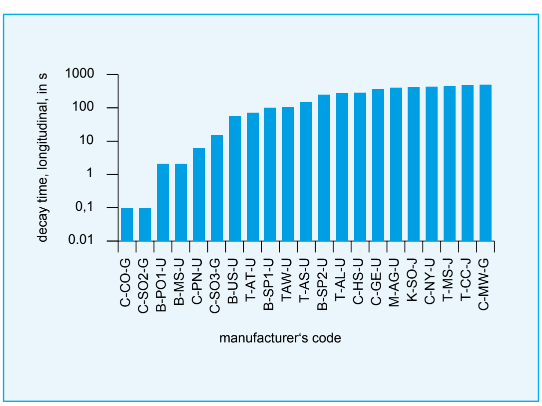

Fig. 21 Test results for the decay time of various cleanroom knit wipers by longitudinal friction

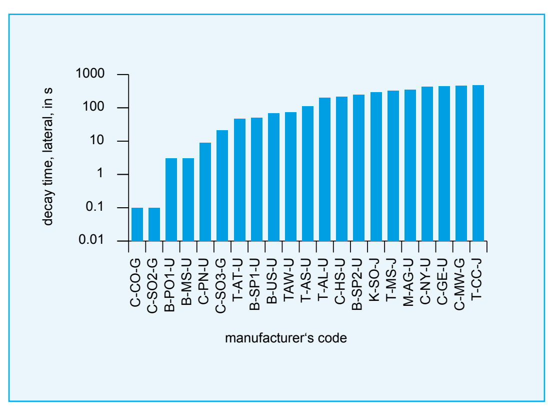

Fig. 22 Test results for the decay time of various cleanroom knit wipers by lateral friction

1.2. Adding a non-ionic surfactant can greatly influence the charging characteristics of a cleanroom wiper. It can even cause a change in polarity (Fig. 9).

1.3. The charging characteristics of the cleanroom wipers available on the global market differ from each other greatly. The variation of chargeability among nonwoven materials between the material with the highest charging tendency in comparison to the one with the lowest is a ratio of 1:8. For the decay time it is, however, 1:2000. With knitted materials the ratio is even 1:20 for the voltage level and 1:5000 for the decay time.

1.4. A higher degree of cleanness or rather 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, polimide or polypropylene).

1.5. Cleanroom wipers 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.

Test Results for Cleanroom Wipers (Nonwoven):

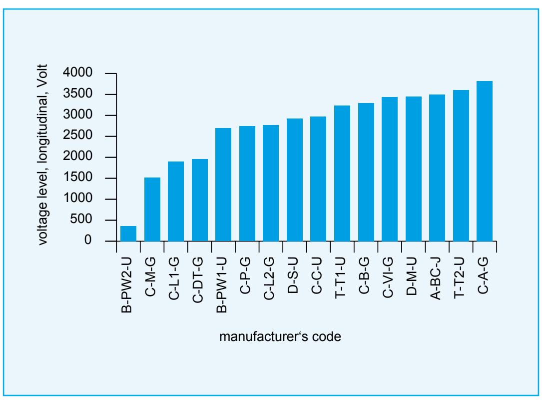

Fig. 23 Test results for the voltage level of various cleanroom nonwoven wipers by longitudinal friction

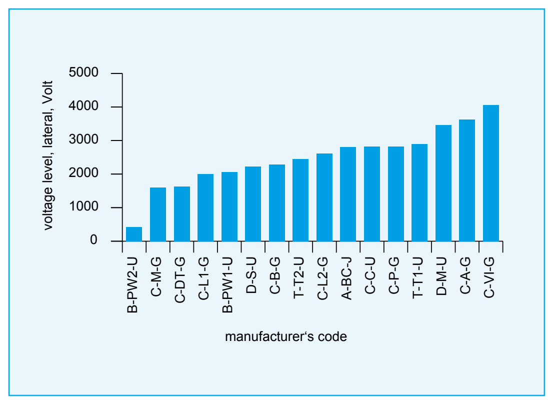

Fig. 24 Test results for the voltage level of various cleanroom nonwoven wipers by lateral friction

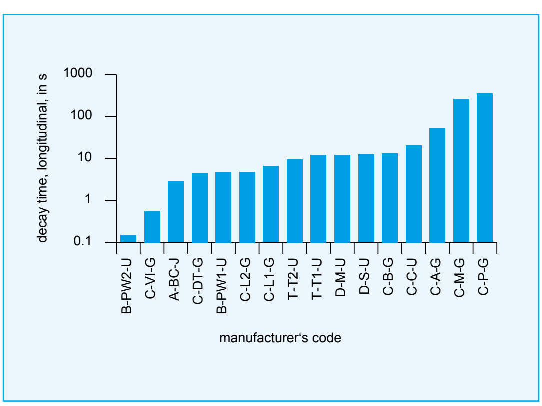

Fig. 25 Test results for the decay time of various cleanroom nonwoven wipers by longitudinal friction

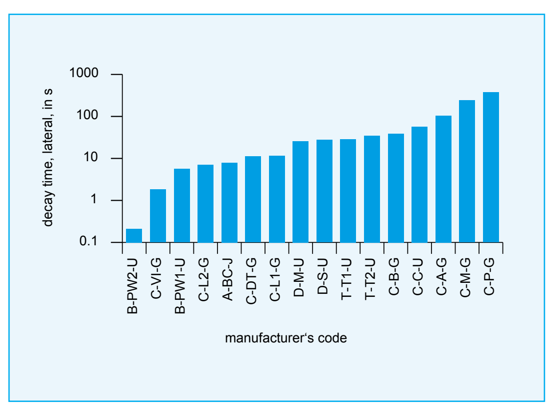

Fig. 26 Test results for the decay time of various cleanroom nonwoven wipers by lateral friction

1.6. 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. 16). This fact should be considered in every operator training course.

2. Cleanroom Papers

2.1. Under the same climatic conditions considerable variations in the charge decay time among the different products could be ascertained. The exact causes of that are still to be determined. Density, surface composition, polymer application, and ionic components can be modified to get more information about the mechanics of decay times

2.2. If a standard cleanroom paper is dipped briefly in a 0,1 % NaCl solution and then dried, the chargeability and the decay time are considerably less than with an undipped standard cleanroom paper.

2.3. The charging characteristics of cleanroom papers available on the global market vary less among each other than those of wipers. The chargeability of the paper with the highest charging tendency compared to the one with the least charging tendency varies in a ratio of 1:3. For the charge decay time the ratio is 1:5.

Summary of the Final Results

In order to compare the parameters voltage level and decay time for the test samples, the charge index must be determined. This occurs in the first approximation by multiplying the mean voltage level and the mean decay time and then dividing the product by two. In this way an index value is determined which considers both the voltage level and the decay time, and from this a useful comparison of the various test samples can be made.

Acknowledgements

I wish to express my deep appreciation of the extensive analytical laboratory contribution of Mrs. Yuko Labuda and Mr. Sven Siegmann in the framework of this essay. I am grateful to Mr. Gärtner and Mr. Sebald for their support. A very special thanks to Dr. Peter Ehrler because he impressed the principle of the drop slide on us already in 1985. With his assistance we could carry out these instructive experiments.

Translation: Carol Oberschmidt

Test Results for Cleanroom Papers:

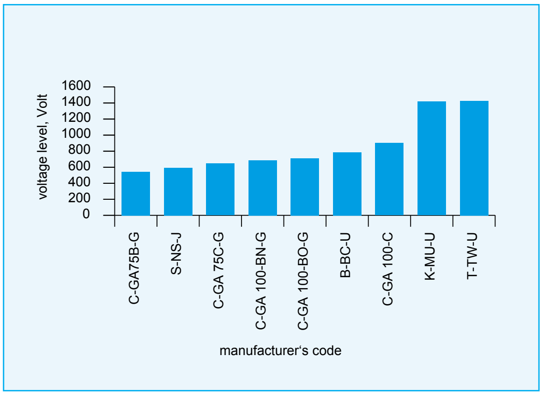

Fig. 27 Test results for the voltage level of various cleanroom papers

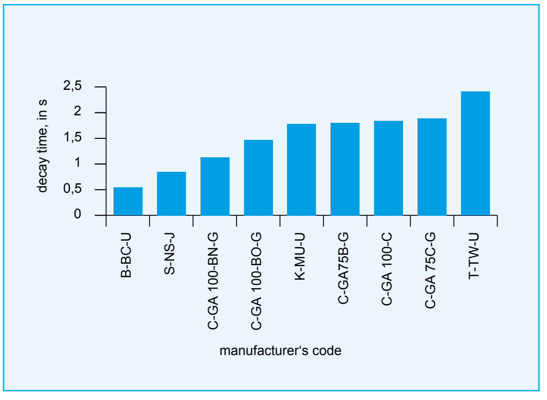

Fig. 28 Test results for the decay time of various cleanroom papers

Summary of the Final Results:

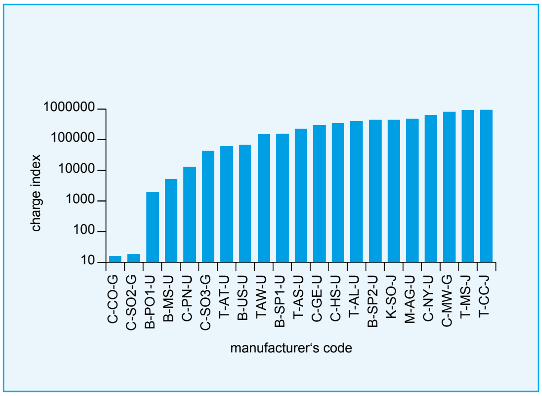

Fig. 29 Charge index for various cleanroom *knit wipers*

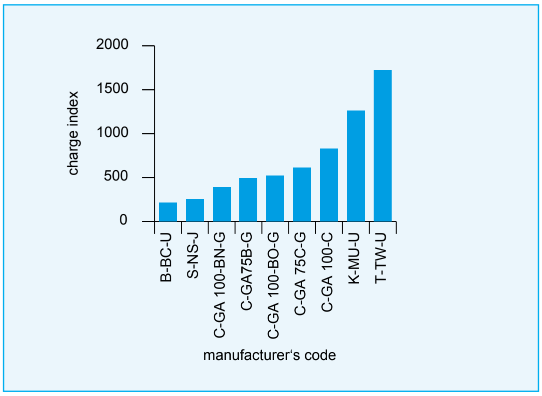

Fig. 30 Charge index for various cleanroom *papers*

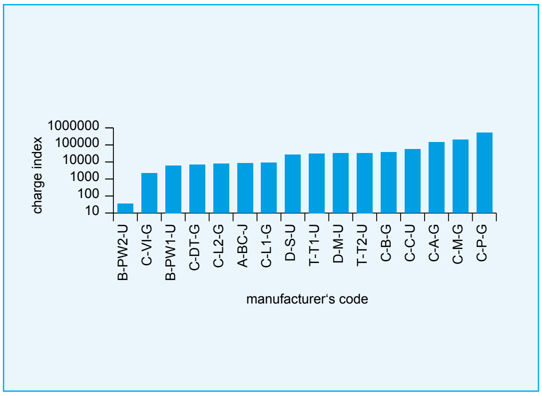

Fig. 31 Charge index for various cleanroom *nonwoven* wipers

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