



Indicator plate
before a moist wiping
procedure

Indicator plate
after a moist wiping
procedure

Win Labuda

Cleanroom Consumables

Aspects, Test Methods, Discussion

Clear & Clean Research Laboratory
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Front: The C&C indicator plate (Patent DE 10016832A1) is a simple testing device that works in conjunction with a stereo microscope to visualize chemical residue, transfer of debris and particulate deposits. The plate is a useful and inexpensive tool for an assessment of the usability of cleanroom consumables (Literature: Win Labuda, Stefan Haupt - Visualisierung von Mikro-Verunreinigungen. (Visualization of Micro Contamination / ReinRaumTechnik 2-2017)

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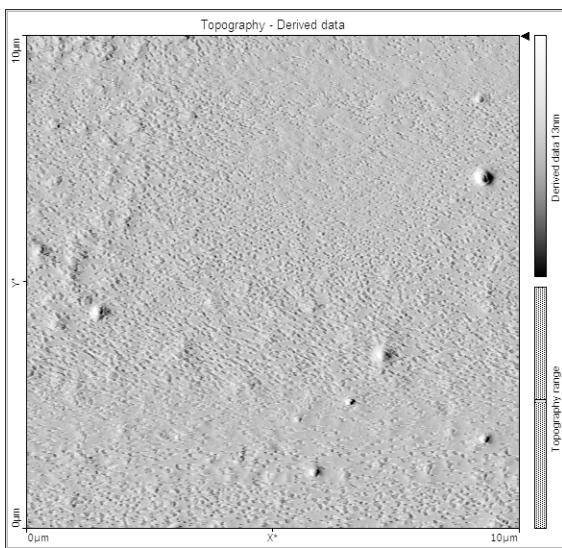


Fig. 2 AFM-10 x 10 μm scan after moist wiping with cleanroom cleaning cloth. Several particles are embedded in atmospheric condensate, Naio-Nanosurf AFM

Undoubtedly, the group of consumables for the cleanroom-bound HiTech industries is of application-technical as well as technological importance. Cleanroom supplies are now a billion dollar business worldwide. This fact alone is a clear indication of a well-functioning industry, without which the spectacular achievements of the semiconductor and pharmaceutical industries in recent decades could not have been realized. It has probably escaped the attention of many of us that the total surface area of consumables such as overalls, wipes and gloves that passes through a larger clean room is in excess of 4 Million square feet per annum. Quality assurance is therefore a primary concern of cleanroom-bound industries. In this context also the recent relocation of cleanroom consumables manufacturers from Europe and the US to China, Malaysia and Thailand requires our attention. The sourcing of consumables from local manufacturing companies overthere and the sale of these products under long-established brand names in Europe and the US raise a number of issues regarding the hygiene, quality and storage of such products. The installation of a continuous quality monitoring at the foreign production sites with unrestricted access to their quality data is a definite requirement waiting for a solution. Without appropriate agreements with the indigenous manufacturers in these countries, certification of such products by European test-houses is virtually useless. The findings and suggestions in this essay reflect the experience of a cleanroom consumables manufacturer with 40 years of manufacturing experience in Germany. They could serve as a guide to building an effective quality assurance system for ccleanroom consumables. In addition, the present work deals with cleanroom consumables in terms of their various applications, test methods and the simulation technologies used.

Part 1 - Aspects

The material group of cleanroom consumables includes clothing, gloves, cleaning wipers and sticks, paper and notebooks, breathing masks, shoes, mop systems and packaging materials. For reasons of space, however, only the particle release of gloves, wipers, and workers and their clothing are discussed in this essay.

The saying goes pure production processes require pure consumable materials. This seems plausible at first glance. Just how pure the material for a specific production process must be, however, cannot be answered clearly as yet. Due to this uncertainty, a large portion of the cleanroom consumable material is carefully decontaminated as manufactured. In some cases, manufacturing processes have a comparatively high degree of purity. But despite relatively clean production or careful decontamination, there are always traces of contamination on the surfaces of the consumables. Theoretically they

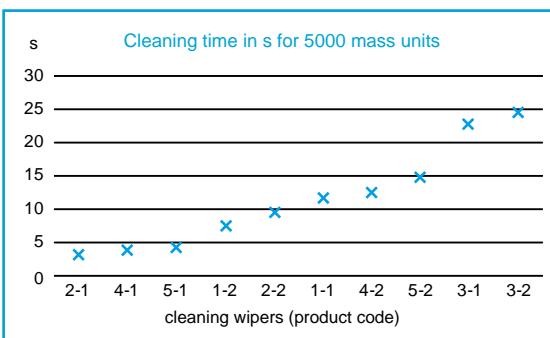


Fig. 3 Diagram: specific cleaning time for ten arbitrarily selected cleaning wipers.

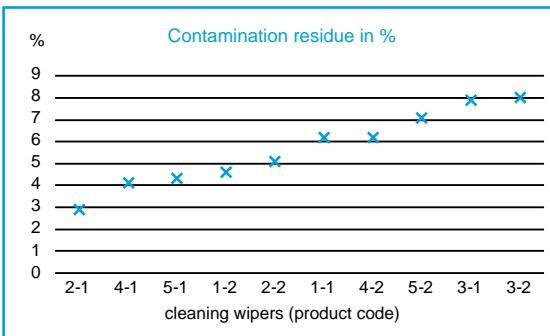


Fig. 4 Diagram: maximum cleaning performance (as an impurity residue) for ten arbitrarily selected cleaning wipers.

could reach the sensitive core areas of the process and reduce the process yield. This essay is dedicated to the interrelations between cleanroom consumable material contamination and suspected process risks. First, here are some examples to illustrate the concept of contamination:

- When dust particles get inside watches, a running inhibition occurs and the clocks will stop.
- If there are thin grease films or particles on the lenses of a camera, but in particular on the photosensitive surfaces of the image sensors, the image quality will suffer.
- If particles, germs and other foreign substances are present on wafers during chip manufacture, precarious failure situations may occur during the control of aircraft, motor vehicles or medical devices.

The above-mentioned function-impeding foreign substances are generally referred to as contamination. We distinguish between particulate, film, gaseous and liquid contamination. In this paper we are mainly concerned with particulate and film contamination. It is known that particulate and film contamination are associated with each other in most cases. Where particles are present, there are usually contaminating films in which they are embedded or to which they adhere.

If we had to assess the quality of the cleanroom consumables offered today without the aid of measuring and testing technologies, then simple logic speaks for the existing consumables. Semiconductor and pharmaceutical industries have developed impressively over the last quarter of the century, using the respective material. In truth, the two branches of industry today determine our entire life. Consumable materials that reduce process yield, practically no longer exist. It would be noticed immediately by Defect Engineering in the High-Tech industries and replaced by higher quality consumables [12, 13]. And, most importantly, the consumables portfolio is so diverse that today almost every quality requirement can be fulfilled.

Only a small minority

From experience we can say that only a small minority of users have problems with using the currently available cleanroom consumables. A large part of what is written in this essay primarily concerns this small user circle. For this reason, the major part of the measurement and simulation technique described below is not found in the well-known manufacturers of microchips, or in normal pharmaceutical operations or, for example, in the operations of implant manufacturers. However, the situation is different in the international space industry and the American space agency NASA, where there are well-equipped laboratories for the purity determination and qualification of the cleanroom consumables as well as the surface cleanliness. The manufacturers of lithography systems for the manufacture of semiconductor products also pay close attention to

the surface cleanliness of cleanroom consumables. However, there are only three of them worldwide.

On the other hand, most cleanroom consumables users rely on the manufacturers' advice in terms of consumable material selection and thus appear to be generally satisfied. The fact is that, to our knowledge, there are very few suppliers worldwide that maintain an extensive quality and testing laboratory for cleanroom consumables and technically adequately trained employees to be able to advise even in more complex applications.

In the area of cleaning wipers, we notice the following material-ranking order of complexity of the user application and demand:

- 1: cellulose wipers
- 2: polyester cellulose nonwovens
- 3: polyester or polyamide knits
- 4: micro-fibre precision cleaning wipers.

The two significant improvement expectations of users are: lower particle release during application and lower release of film and gaseous contamination. It is only afterwards that parameters such as liquid absorption, cleaning efficiency, electrostatic chargeability etc. are ranked in the evaluation scale. However, there is a certain absurdity in this area:

While the purchasing departments of the users have in recent decades negotiated ever more favourable prices for the consumables, the purchased cleaning efficiency (wipers, swabs, mops) found less attention. The diagrams (fig. 3, 4) show the conspicuous differences in cleaning of internationally traded cleaning wipers measured in the laboratory. The users' purchasing departments or even maintenance staff usually do not notice when a 10% cheaper cleaning wiper has a 20% lower cleaning effectiveness than the previous product. Due to the ever increasing expenditure for cleaning-time (Labour-cost), there may be a manifold increase in the effective price per cleaning operation if the cleaning effectiveness data of the wipers remains unconsidered.

The cleanroom consumable market in statistics

In order to assess the possibility of implementing newly developed test methods internationally, it is worth taking a look at the geographical distribution of the leading technology markets. If these markets do not want to accept new or sophisticated test methods at all, then it will be quite impossible to implement them. The increase in demand for cleanroom consumables has largely taken place in Asia in the past decade [17]. By the end of 2015, the Asian consumables demand had grown from 3.7 (2011) to 4.6 billion US\$. With only US\$ 1.5 billion forecast for European and U.S. demand taken together, it is unlikely that the Asian technologists will sacrifice their existing quality assurance systems based on the IEST-recommended practices in exchange for new European conceptions. For this, there should at least be a valid reason,

especially since the production yields of the Asian semiconductor industry are, as is well known, often close to 98%. In such a comfortable position, consumables for cleanroom facilities play rather a subordinate role.

Purity and contamination

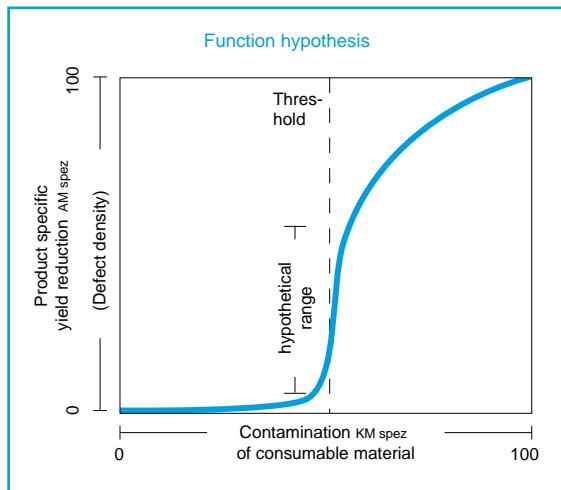


Fig. 5 Contamination volume and process yield reduction by the consumable material

Purity is characterised by the amount of contamination, the excess of which affects the functionality of a system [14] (fig.5). From this, the individual process-relatedness of all purity systems can be derived. With this hypothesis, we relate the following variables:

KM tot.

Process-related total contamination

KM Spec.

Product-related contamination

PA tot.

Process yield

AM Spec.

Product-related yield reduction

The process yield is, among other things, a function of the effective amount of contamination, but because the total contamination quantity is constituted of different single contaminations, the contamination amount and the process yield are at best the variables that are most accessible to measure.

Cleaning, regular cleaning maintenance and purity monitoring have the purpose in a production under cleanroom conditions to ensure the optimum process yield. Therefore, one could come to the premature conclusion: the purer the consumption material, the higher the process yield. However, a link between consumables purity and process yield is not described in the reference literature. What however is plausible is that with increasing consumption material contamination, the process yield decreases after exceeding a certain contaminant mass. It is also conceivable that this function is linked to a process-specific threshold.

A further complication for the establishment of an integral purity system in modern high-tech production is that the dissemination routes of contamination in the production environments are difficult to follow. This also applies to chemical (ACC) and molecular (AMC) contamination [15]. These are essentially determined by the ambient temperature, fluctuating electric fields, relative humidity, forced air currents, changing temporary resting places, different morphology of the particles as well as the surface characteristics and, last but not least, a proper operator handling. In addition, there is basically no correlation between air and surface cleanliness [20]. From all of this, it is found that an allocation of consumable-related contamination to the process yield reduction is not feasible for reasons of principle.

Manufacturing process as a cybernetic system

For example, if we consider a production process as a flexible cybernetic system, we define process-compatible materials, process steps, target values and maximum actual values, all of which are oriented on a one goal – on the continuous production of a product with optimised process yield on the basis of a certain cost per unit.

The operators' choice of the process steps, the determination of the target values and the choice of the auxiliary materials are based on their own process experience as well as benchmarking with suppliers or competitors. They are oriented on the respective technical state of the systems and materials. If, therefore, a consumable material has a certain regular contaminant delivery, this is just part of the process and not an emergency. The process goal is never endangered by the regular contamination release of a planned consumable material. The potential danger for process continuity is rather from possible catastrophic events, which can dramatically increase the effective contamination. This would happen, for example, if a glove manufacturer accidentally delivered powdered gloves instead of cleanroom gloves, and this remains unnoticed. Such an incident can lead to contamination peaks in production, which may also become process-relevant. Such incidents are, however, extremely rare and can hardly be prevented. Once a process-oriented „material mix“ of consumables has been established in a production, the process manager has to decide whether the existing material mix or the change to a cheaper consumable product has a potentially more favourable effect on the production costs.

Process-specific contamination barrier

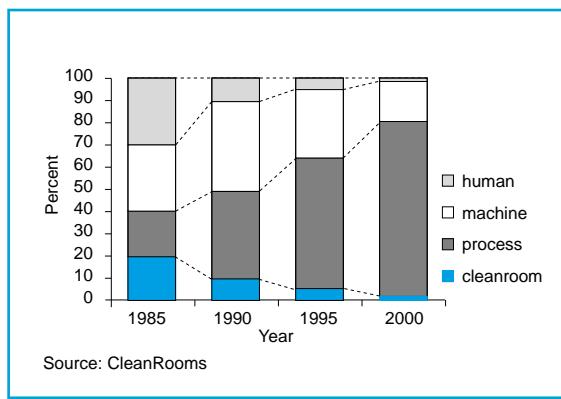


Fig. 6 Sources of wafer contamination over time

Process-relevant in our context is defined as such contamination which reaches the manufactured product and contributes to the reduction of the process yield. Since 1985, the share of cleanroom-generated contamination on wafers has declined from 20% to less than 2.5% in chip manufacturing [16] (fig. 6). This reduction also includes consumable-material-induced contamination.

The particle propagation is limited by the process-specific contamination barrier on the way from the cleanroom consumable material surfaces to the yield-sensitive core areas of the process [13, 14]. In a semiconductor manufacturing process, for example, the process-specific contamination barrier consists of the hermetic process (SMIF), the laminar airflow and the type, number and duration of rinsing and etching processes in the process plus the regular cleaning of cleanroom surfaces [24]. The spherical dissemination of the existing particle accumulations leads to a reduction in the contamination density. This especially applies to the increase in spatial distance between the production environment and the core area.

Particulate contamination

The particles residing on the consumable material can be grouped into motion-induced material fragments, such as from formatting processes, material abrasion due to transport and manufacturing friction such as rubber abrasion and dusts from blow-air drying of textile fabrics, particulate detergents and process water residues. In addition to the particle groups mentioned, there are special ones which require separate observation. These are the oligomers, macromolecules with a low chain length, emerging from the polymer surfaces at temperatures of + 180 °C. In addition, there is the group of microorganisms or biotic particles. This group plays a major role in medicine and hygiene: they are viruses, bacteria and their toxins as well as fungi and spores. Another very special particle group is pollen with its pronounced growth potential.

Oligomer particle contamination

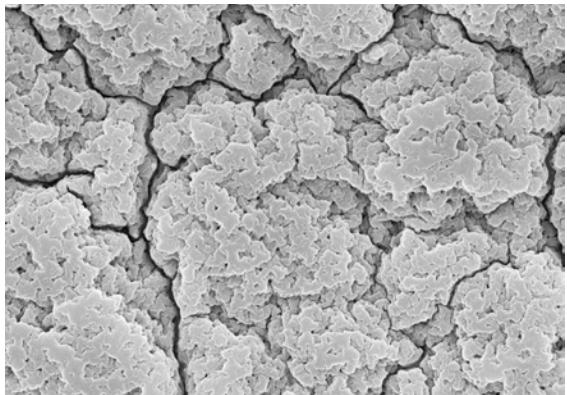


Fig. 7 Surface of a nitrile glove, decontaminated, small amount of particles, SEM 3100x, rugged microstructure

In researching the causes of particulate contamination by cleanroom consumable material, one particle group requires special attention. If we are talking about particle contamination in our context, we are almost always referring to particles that either reach the consumable material from the outside or are fragments of it. Oligomers are particles which come to the surface from the interior space of the fiber materials, such as polyester and polyamide. Oligomers are macromolecules consisting of 10 to 30 units with the same structure. When they have more units, they are referred to as polymer. Sub-units are monomers, dimers, trimers, etc. in this paper we focus exclusively on the trimers of group c [G-T] 3. They form the largest share of all subunits at 77%. The percentage of the oligomers in the mass of the polyester yarn of cleanroom wipers is between 1 and 4% [31], depending on the author. Oligomers occur more frequently at temperatures higher than 180 °C. After their emergence from the yarn, the oligomer particles adhere to the yarn surfaces (Fig. 8) and can be removed therefrom, for example by liquid extraction. A mass fraction of 1% appears to be low when viewed superficially. However, with respect to the square meter of knitted polyester fabric with a surface mass of say 250 g, 2.5 g of oligomers are attached as particles to the yarn surfaces. From an assumed average particle volume of $0.125 \mu\text{m}^3$ and a total oligomer mass of 2.5 g per m², there results 1.5×10^{10} oligomer particles per m² or 8×10^8 of oligomer particles on the yarn surfaces of a cleaning wiper of 23 x 23 cm in size. This is a serious quantity of particulate matter, whose exit from the textile must be prevented as much as possible.

Biotic particulate contamination

In the context of the cleanroom consumable material, this type of contamination does not play a significant role for many users. However, sterile but also pyrogen-free consumable materials are a prerequisite for use in consumable material applications in medicine and the pharmaceutical industry. The sterilisation of cleanroom clothing, gloves, cloths, swabs and other parts is nowadays carried out mostly by gamma irradiation of the consumables by cobalt 60 radiators with a

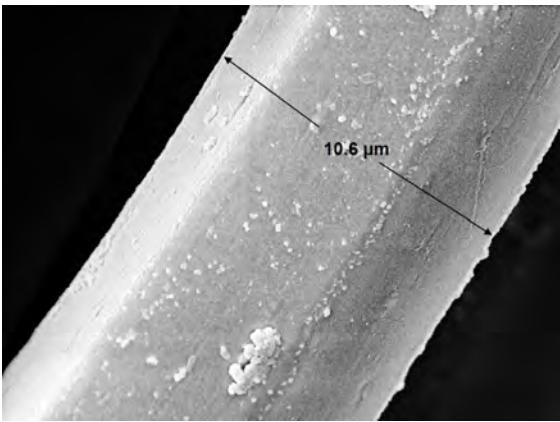


Fig. 8 Polyester oligomers on the fibril surface of a polyester knitted wiper, SEM 6500x

radiation dose interval of 25 Gray. For a number of applications, however, it is necessary that the wipers used are not only disinfected, but are instead made sterile and also pyrogen-free during their manufacture.

- Disinfection means a condition in which, using a given test method, a maximum of 10 germs survive in one million (CFU).

- Sterilisation, on the other hand, means that out of one million CFU, no more than one may show growth.

The „colony-forming unit“ (CFU) refers to the number of microorganisms that are located at a reasonable distribution density with distribution as uniform as possible on a culture medium gel so that the colonies formed are visible with the naked eye.

Pyrogens are inflammatory substances that can produce fever, for example, during parenteral administration (injection). A distinction is made between bacterial and viral pyrogens as well as pyrogens of non-bacterial origin.

Endotoxins are a subgroup of the pyrogens. They are a class of chemical compounds that can cause unwanted physiological reactions in humans, such as endotoxin-induced sepsis, microcirculation disorders, and coagulopathies by activating blood clotting and fibrinolysis.

Film contamination

On surfaces of cleanroom consumables there is also film contamination, in addition to the particulate matter. The following section applies exclusively to contamination of this kind. In or on it, however, particles can also be present.

We distinguish between:

- Contact contamination
Fingerprints, adhesives, dyes, or grease residues
- Distributed contamination
Smearing by contact, pressure and movement, cleaning procedures by wiping

Product	reale Freisetzung	nach Spezifikation	simulierte Freisetzung
Clean- room wipers	into the air	IEST-RP-CC004.3	into the di-water max. 12.000 part.
improvement:		LabudaFulling Test	into the air max. 200 part.
Cleanroom gloves	into the air	IEST-RP-CC005.4	into the di-water max. 700 part.
improvement:		C&C-Manu-Stretch-Test	into the air max. 100 part.

Table 1 The problem of simulation, particle release, real and simulated, Part/cm², particles > 0.5 μm

Table 2 Comparison of test methods for cleanroom consumables

Material	Test Method ASTM / IEST	Alternative Test Method
Cleanroom gloves	IEST-RP-CC005.4	C&C-ManuStretch Test
Clean- room wipers	ASTM-395 (Gelboflex) IEST-RP-CC004.3	Labuda-Fulling Test C&C-Transfer-Test
Cleanroom garments	IEST-RP-CC003.4 (Helmke-Drum) ASTM F51-68 (Suction Method)	

- Emitted contamination
Breathing, coughing, sneezing, engine exhausts
- Air-to-surface contamination
Water vapor sedimentation, gas residues, dust particles

Cleaning-by-wiping-operations are carried out, for example, in the clean work environment with the aid of wiping means (cleaning wipers, swabs, mops) which contain non-volatile residues from their production processes. This process results in a cleaning-typical exchange of substances: on the one hand, there is a reduction in the contamination mass on the object surface, and at the same time there is a transfer of ingredients from the wiping materials to the object surface.

Film contamination of surfaces is best characterised by the fingerprint, which is known to everyone. Fingerprints consist of surface fat of the epidermis. This contains tallow gland fat, esterified fatty acids, waxes, glycerol and unsaponifiable fats such as cholesterol. As a result of repeated contacts, in particular with material surfaces, there are, especially on the fingertips, skin cells, foreign particles but such as, but not only, bacteria, viruses and fungi.

The generally accepted active avoidance strategy is the wearing of gloves [37]. Fingerprints are an aesthetic as well as a hygienic problem. Every day large amounts are spent worldwide for the removal of fingerprints. The success criterion of the performed cleaning procedures is usually the reduction of the visibility of the impressions. However, in many cases, there are also visually no longer recognisable contaminant residues in the mass range of a few nanograms. These can have undesirable effects on the functionality of technical systems as well as on the transmission of pathogenic micro-organisms. Since 1998, we know that the smallest bacteria in Tyrolean lakes have a mass of about 8×10^{-15} g.

In experiments on the material transfer of precision cleaning wipers during wiping cleaning procedures, we measured a mass increase of $0.5 - 1.7 \times 10^{-7}$ g / cm² (fig. 28).

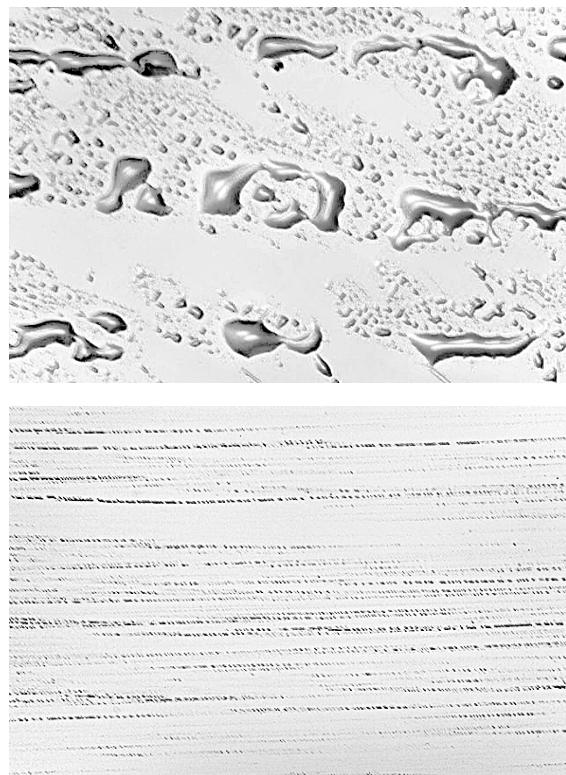


Fig. 9 Removing a fingerprint by wiping – before and after wiping, top: Fingerprint in differential interference contrast (section); below: still visible residues, Zeiss-DIC, photo microscope III

The increase in mass thus corresponds to about 10^7 bacteria / cm². This (hypothetical) transfer quantity can be quite relevant, for example, in view of the rules which many states have committed to comply with in order to protect planetary purity [28].

Film contamination of functional surfaces is known not to be limited to fingerprints. We know of a large number of functionality-limiting film contaminants. With regard to cleanroom consumables, the following products, in particular, can be considered as sources of non-volatile contamination: gloves, wipers, swabs, mops, clothing, packaging and adhesive materials. Film contamination can, for example, affect the following technical parameters: the adhesive forces of area connections of the adhesive joining technique and of lacquers, the contrast transmission of lenses and objectives, the functionality of mirror systems of laser technology. However, chemical residues can also lead to cross-contamination by outgassing and to condensation from the gas phase of the residues. The contamination may be both product-inherently reinforced by excipients or else externally. The latter is, for example, the case with cleaning wipers whose cleaning efficiency is very often modified by the use of solvents.

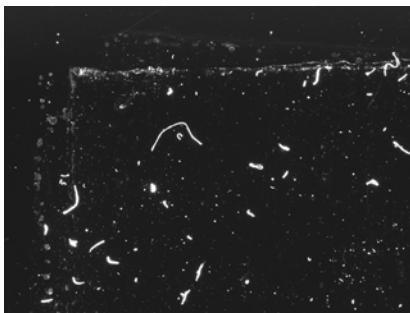


Fig. 10 Cleanroom wiper 1, after drying on the indicator plate, (cellulose-polyester nonwoven), Zeiss AxioZoom V16, 24x

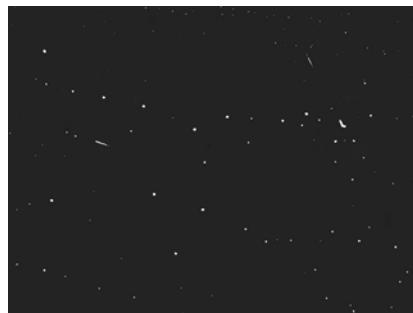


Fig. 11 Cleanroom wiper 2, with n Hexane after wiping motion and subsequent drying

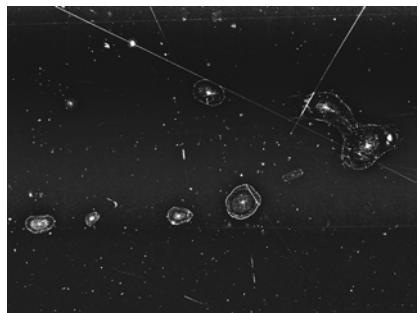


Fig. 12 Cleanroom wiper 3, with a mixture of Isopropylic alcohol and DI water, after wiping motion and subsequent drying

Presaturated cleaning wipers

In this context we are also concerned with the topic of contamination of object surfaces when using presaturated cleaning wipers. These are, for example, wipers made of polypropylene non-woven materials or alternatively of polyester or polyamide-knitted fabrics. Such wipers are provided in sealed plastic bags or plastic buckets which are mostly filled with a mixture of isopropyl alcohol and di-water. The bags are provided with an adhesive flap, which is to be closed after each single-wiper-removal. The wet-wiper buckets have a lid allowing pressure closure. We have tested three different brands of such wipers as to their respective residue left on the indicator plate after a wiping motion. In the first experiment, we placed a section of a moist cellulose-polyester nonwoven wiper on the C&C-indicator plate without weighing it down and let it dry (fig. 10). In the second and third tests (fig. 11, 12), we wiped with the respective moist wiper over the indicator plate. We assumed that after wiping no non-volatile residues would appear on the surface of the indicator plate, if they were not already present in the wiper.

However, on the basis of the test results, we must assume that all tested cleaning wipers contain non-volatile residues and release them onto the object surface during wiping. The residue mass after wiping was, however, significantly lower than if it was just layed flat onto the plate and allowed to dry.

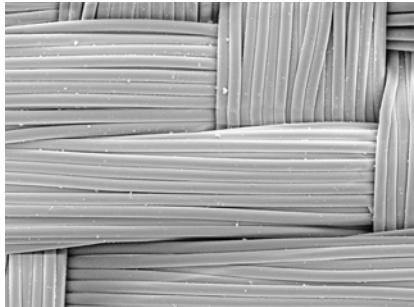


Fig. 13 Cleanroom gown, particulate standard contamination, yarn intersections, SEM 225x

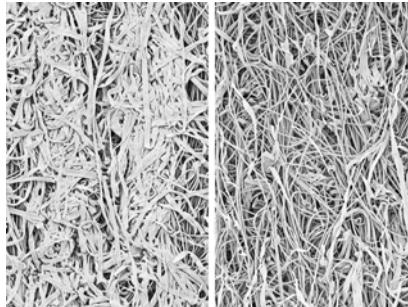


Fig. 14 Surface of polyester cellulose wipers, (left A side - more cellulose, right B side - more polyester fibres), SEM 40x

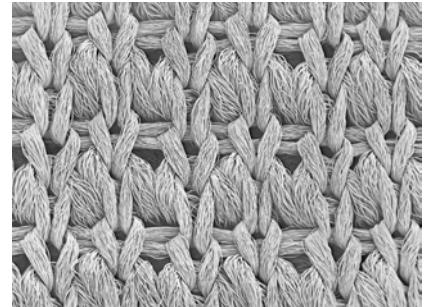


Fig. 16 Surface polyester knitted fabric Sibis™, application-adapted stitch pattern, SEM 25x

Part II - Test Methods

Reality and simulation of particle release

The real-world particle release in connection with the use of cleanroom consumables is neither foreseeable nor traceable [2]. We therefore try to simulate them by means of properly designed test devices. But whatever we measure and no matter how accurately we do this, we lack a reference data of the first order to the production process for the determined data. That could be the production yield alone. As long as we cannot relate the particle release from the cleanroom consumables to the production yield, all we do is pure speculation. Whether 10^3 or 10^5 particles are released from a glove during the operation per unit of time is only relevant if this quantity of particles either entails a reduction of the production yield or a risk to people or the environment.

In view of this correlation deficit, the premium consumable manufacturers and high-volume users of cleanroom consumables have tacitly agreed on a second-order reference. This is how they proceed according to the method of comparative quality assessment. In order to ensure the innocuousness of the use of certain cleanroom consumable materials, the handling-induced contamination of consumable material, which is known to be used without problems in processes with an optimised production yield, is analytically determined. The contamination data determined in this way then serve as a guide for comparable or newly developed products.

However, this process is not without problems. If, for example, we would like to determine how many particles are released from the surface of cleanroom consumable materials in a dry state, this seems to be very simple: a dry clean-room wiper is moved mechanically. Part of the particles adhering to it dissolve, and the released particles are counted by means of air particle counters. However, there is a problem: the particle adhesion is not only dependent on the mechanical deformation of the wiper surface. It is also determined by the respective ambient temperature, the relative humidity, the effective van der Waals forces, the electrical surface charge and the chemical contents of the wiper [11]. The number of released particles thus markedly varies depending on the ambient parameters mentioned. This applies to all test methods mentioned in this review, which are based on the motion-induced release of airborne particles from material surfaces. The influence of environmental parameters on particle adhesion has long been known and described [22, 23].

If we now carry out the experiment described above with a wiper presaturated with a solvent instead of a dry wiper, the physical conditions for the simulation change completely: the direct measurement of the particle flow by means of air particle counters is not possible, the electric surface charge and van der Waals forces are almost eliminated by the liquid content in the wiper. Moreover, when the wiper is wet, hardly any particles are released into the environment. Many par-

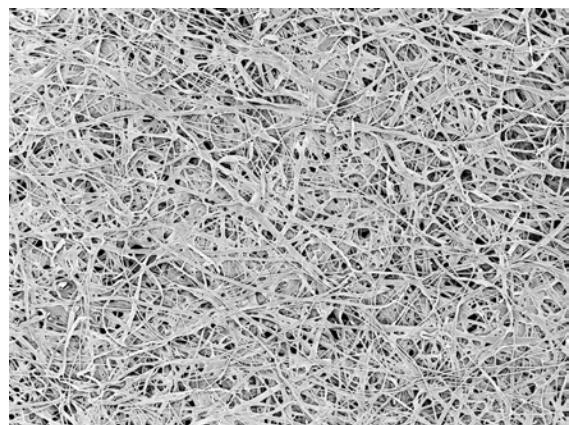


Fig. 16 Surface cellulose nonwoven DRYTech™ for cleaning purposes, SEM 30x

ticles have separated from their resting places on the outer yarn surface. They are suspended into the liquid medium. If the amount of liquid in the wiper decreases, for example by evaporation, so that their state has changed from „wet“ to „moist“, the particle adhesion changes and follows the laws of liquid-bridge adhesion [1]. Between dry, wet and solvent-saturated textile surfaces, there are innumerable transition states with regard to particle mobility. Not a single, but a multitude of physical states are now determinants of adhesion, each of which may be calculable, but they are practically unmanageable in their diversity.

The consequence from this example: We can design our test conditions to refer to given ambient conditions of temperature, humidity, and electrical charge, but the possible number of variables greatly reduces the likelihood of a true relationship between the material condition and the test result. Even a careful preconditioning of test specimens can only help to a certain extent.

Plausible simulation parameters

As a plausible simulation of cleaning by wiping, the focus of our analysis is not on the detection of the particle emission of the wiper into the environment (Gelbo Flex method), nor is it on the detection of the quantity of particles which, after immersion, passes into a test liquid (IEST-RP-CC 004.3 method):

The only practical-relevant parameter is the contamination adherent to the object surface after the cleaning procedure has been carried out. However, for this parameter of central importance, thus far no plausible and at the same time affordable test system has been offered. It need be a system that would make the interesting particle size range of $0.1 - 2 \mu\text{m}$ plus the chemical components of surface films metrologically accessible.

The simulation of the various material applications should be based on models that are as simple and realistic as possible. To simulate particle release during use, in the case described below we use handling-typical movements, with which the use of a consumable material can be simulated in a realistic manner. As a suitable example, we select the product cleanroom gloves in conjunction with the C&C-ManuStretch test (see fig. 21 on page 23).

We defined the movement of opening the clenched fist to the extended hand in order to bring the handling-induced particle release. This movement sequence takes place at a defined distance above the probe of an air particle counter. An arm support device is used for this purpose. Thus the basic prerequisites for a plausible method with direct particle detection seem to be given, if there were not any environmental influences on the particle adhesion. These have to be examined

and documented for the different measuring locations. The proof of the functionality of measuring and test systems is the plausibility of their results. This can be expressed statistically by the coefficient of variation, which is independent of the unit of measure of the random variables as a relative scattering measure. The variation coefficient v of a measurement series of variables is calculated from $s = \text{standard deviation of the data divided by its mean value } x$ transversely. In the partly porous, partly elastic materials of many of the cleanroom consumable materials, we assume that a test method with a secured coefficient of variation of up to 30% is plausible, although in some cases we have accepted values of 50%. The test methods described below relate exclusively to the simulation of particle scattering during use, but not to that of particle abrasion or surface transfer of film contamination. For this purpose, there are other test methods that are adequately described in the reference literature [4].

Analysis of endotoxin particles

In order to render pyrogens harmless in textile structures, such as cleaning mops or other structures, a temperature control with a specific temperature profile is normally carried out. The success of this treatment is then examined. There are established procedures for the testing of remaining pyrogens: Rabbit test: The increase in the body temperature of rabbits after intravenous injection of the pyrogens is measured.

Limulus test (LAL test): It is about 100 times more sensitive than the rabbit test, but only affects the endotoxin of gram-negative bacteria. The test is already indicated at a lower limit of 100 gram-negative bacteria per ml.

EndoLisa test: Based on a bacteriophage protein by means of which the endotoxin of gram-negative bacteria is bound quantitatively to a microtiter plate. Thereafter, a washing process is carried out for the removal of interfering substances of the sample matrix. The endotoxin content can be determined by means of the recombinant factor C and a fluorescent substrate.

ImmuStick: In July 2016, the Fraunhofer Institute for Interfacial Engineering and Biotechnology (IGB) presented a test strip „ImmuStick“ [34] to detect bacteria, fungi and viruses on surfaces quickly and without elaborate equipment. It is necessary for the detection of small pyrogen traces. A test strip is dripped with a fluid prepared by the test laboratory, which could be enriched with pyrogens. A color reaction of the test strip indicates a positive result. This stick would allow simple lab tests of products for the medical and pharmaceutical industries. The market launch of the test strip is still pending.

Analysis of oligomer particles

Depending on the production history of the yarns used, more or less oligomers may be attached to the fibrils of a raw fabric. For example, it is important to know the particulate state of the knitted fabrics before and after the knitting because further treatment steps of their duration depend on the measured particle volume. Since the oligomer exit from the polyester surface is directly dependent on the temperature profile of the various processing steps, the comparative oligomer inventory may be the reason for influencing the processing temperature in preliminary stages of the production in order to reduce the decontamination of the finished knitted fabrics. It is also advantageous to distinguish between oligomer and other particles. A correspondingly accurate analysis can serve well here. For this purpose, the oligomers must first be separated from the fibrils of the yarn by immersion of the test specimen in cold analytical dioxane. It is particularly important to adjust the separation times of the oligomers to the mesh count of the knitted fabric concerned and to ensure that the same time of analysis is observed for each measurement. We recommend performing the quantitative oligomer determination with the aid of UV spectroscopy at a wavelength of 240 and 254 nm, respectively. For these wavelengths, a peak as well as a calibration curve [31] were obtained. However, it is also possible to determine the oligomers by means of thin-layer chromatography according to Valk, Stein and Dugal (silica gel plate 0.5 mm, eluent chloroform / ether = 9:1) or by means of HPLC chromatography [31].

Reality and simulation of film contamination

On the polyester or polyester-poliamide yarns, which constitute a large part of the cleaning wipers, swabs and clothing, as well as some gloves, the following chemical non-volatile residues can be found: silicone oil, DOP plasticisers, surfactants and spinning oil residues as well as amides. During the cleaning-by-wiping-procedure, in connection with the use of solvents, the above-mentioned chemical residues dissolve from the yarn surfaces and reach the object surfaces by means of liquid distribution of solvent fractions. Chemical residues can significantly affect the functionality of semiconductor circuits, memory boards, laser systems, optical glasses, and many other technical systems. In order to estimate how many mass units from the various consumable materials may reach the object surfaces during cleaning-by-wiping-procedures, the mass of residues contained in the textile structure is generally determined according to method ASTM E1560-11 or on cleanroom gloves according to the ASTM method E1731. In practice, however, this test approach has repeatedly been the cause of gross evaluation errors. For example, if before decontamination 1.6 g and after 0.6 g of non-volatile residue are contained in a wiper of the total mass of 8 grams, this corresponds approximately to a mass of 10^{-3} g/cm² of wiper surface. On the cleaned surface of a quartz scale, however, we measure only 10^{-7} g/cm² of residue, i.e., the 10,000th part of the residue contained in the wiper. This explains better

than anything the insufficient plausibility of some of the test approaches that are still in use. Up to now, it has not been easy to determine the mass which comes to a surface from the wiper during the wiping process. However, it is obvious that the mass of the residue on the object surface does not correspond to the mass in the textile structure. This means that the contaminant mass of the wiper does not at all imply the contaminant mass on the object surfaces that we actually want to know.

Gaseous contamination (VOCs)

The outgassing of organic compounds (VOC = volatile organic compounds) from the internal and external structures of cleanroom consumable materials into the ambient air is also related to the film contamination on the object surfaces [48]. The phenomenon and its measurement technology is described under the term „outgassing“ in sheet 17 of the guideline VDI 2083 [39] and also in DIN ISO 16000 ff. In particular, the products: clothing, gloves, wipers, swabs, film packaging, filter materials but also humans are known for their release of molecular contaminants into the surrounding atmosphere. For the manufacture of semiconductors, phthalates, amines, siloxanes, boron, ammonia, organic phosphates and some condensable organic substances are described as critical [40]. For the aerospace industry, outgassing is definitely a critical parameter [41].

Determination of the volatile organics from the consumable materials is now mostly carried out by means of thermal desorption with subsequent gas chromatography and FID (flame ionization detector) or mass spectrometric analysis. This method is relatively accurate but not feasible for most users - because of the expenditure of the instruments in the six-digit range. One might think that the problem could be solved by certification at one of the many professional certification companies. However, a certificate is a kind of temporally-limited-validity-information, as long as the produc-

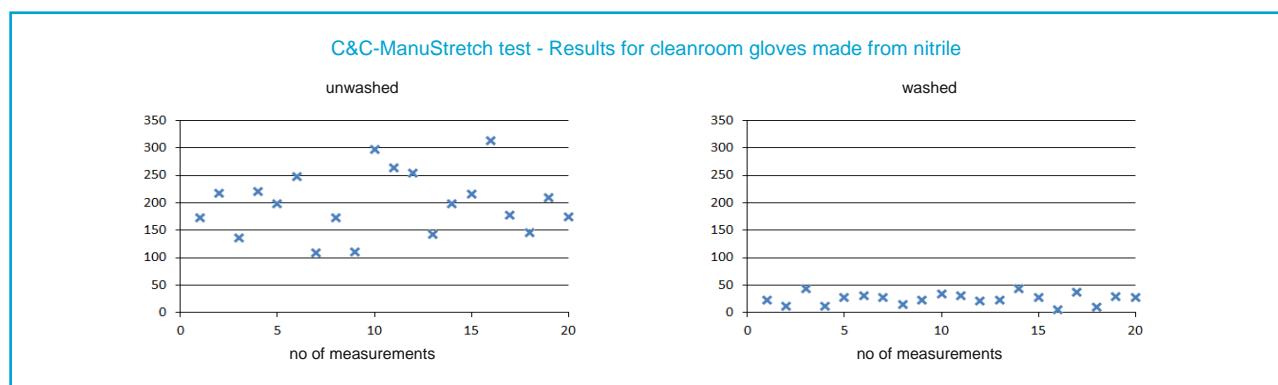


Fig. 17 Results: C&C-ManuStretch test for the particle release of washed and unwashed nitrile gloves
(for description see page 23)

tion quality is not continuously monitored and the production data obtained in a reliably documented way. Otherwise no one can know whether the certified data is still relevant even four weeks after the certificate issue. This threat applies in particular to foreign manufacturing companies not under indigenous jurisdiction.

The outgassing of materials is often simulated with the aid of a hermetically sealed test chamber, which can be heated up to 400 °C, into which the test specimens are inserted. As is the case with many other tests of cleanroom consumables, it is normally not proposed to carry out tests which are not consistent with the ordinary stress-profile of the material. In this case, the test temperature is e.g. increased from +22 °C to +90 °C, which increases the outgassing rate of the test specimen by approximately 100 times. [42] As already mentioned elsewhere in this document, the test data deviating so much from the operating data always involves the risk that costly but unnecessary safety precautions are taken as part of a general avoidance strategy. However: If there is no outgassing at operating temperature generally no further measures are required, even if the outgassing becomes noticeable at higher temperatures or under high-vacuum conditions.

The essential disadvantage of determining the outgassing as a sum parameter, for example, by means of quartz balances, is the absence of more specific material data. On the other hand, it makes sense for many users to determine whether the outgassing is at all in a critical mass range, in such cases determining the total outgassing of a material sample can make sense.

Scialdone and Montoya, US NASA, therefore describe in their 2002 essay [43] a relatively simple device (MOLIDEP) for determining mass loss by vacuum using a quartz balance and a residual gas analyser.

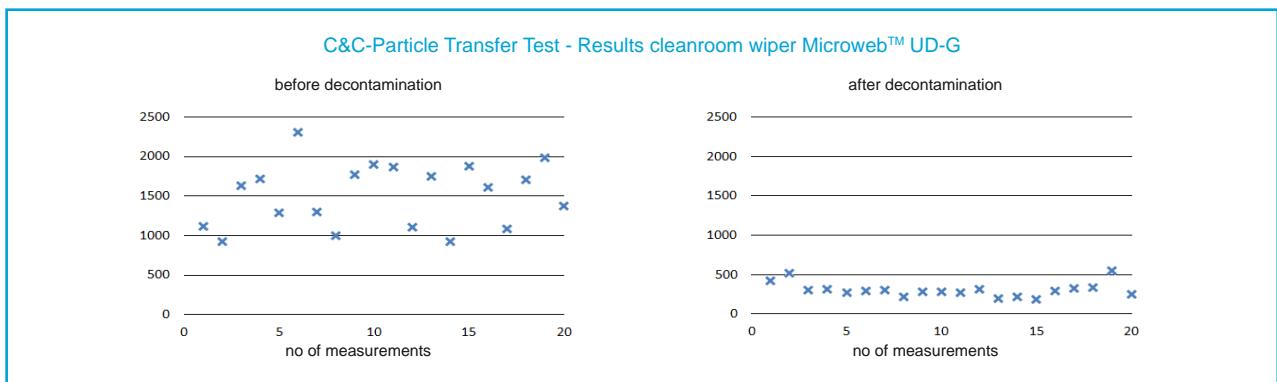


Abb. 18 Results: Particle Transfer Test cleanroom Wiper Microweb™ before and after decontamination (for description see page 27)

The future of the outgassing determination of materials is guided by the development of highly sensitive gas-chromatographic columns using MEMS technology. Jinhai Sun et al. describe in their essay [44] a 6 m long column with internal dimensions of $100 \times 100 \mu\text{m}$, which was produced with the aid of the „Deep Reactive Ion Etching“ (DRIE) technology.

The developers have long struggled to make the outgassing determination accessible to larger user groups by presenting significantly smaller and more affordable systems than before, which can be operated in production surroundings or even mobile. In principle, they use two methods: the measurement of the sum parameter total outgassing with the aid of a quartz and the measurement of individual VOCs using MEMS (micro-electro-mechanical systems).

Recently, first MEMS-based miniature gas chromatographs and gas analysers have appeared on the American market with resolutions to date still in the medium ppm range and in the second case at 1 ppm at prices of several thousand dollars. [45, 46]

S. Zampoli et al. of the Istituto per la Microelettronica e i Microsistemi in Bologna, Italy describe in their work [47] a MEMS-based μ -gas chromatograph for sub-ppb concentrations for the analysis of complex VOC mixtures. The developers have used 3 independent MEMS units for this purpose and achieve with their system sensitivities of 0.1 ppb.

Long term, we can expect ever smaller and yet more sensitive analysers for the determination of the outgassing of clean room consumables.

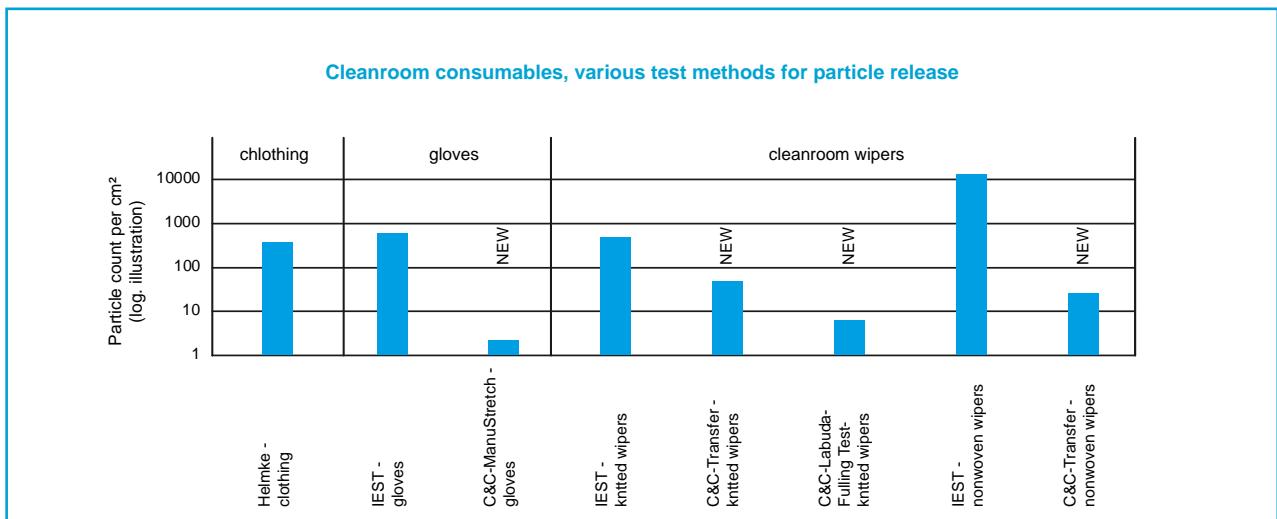


Fig. 19 As can be seen from the differing results, not all of the above test methods can be realistic.

ToF / SIMS secondary ion mass spectrometry

The time-of-flight secondary ion mass spectrometry is an analytical method for the high-resolution chemical characterisation of solid surfaces. The method allows the analysis of the states of the three upper molecular layers and thus can serve, among other things, to identify surface contamination. Three cleaning wipers (here with the designations RRT 1, RRT 3 and RRT 4) were scrubbed experimentally in the saturation states dry, acetone-moist and propanol-moist over pure aluminium surfaces of low roughness. Thereafter, residues from the polyester matrix could be detected on all nine substrates analysed. Erucamide traces (13-docosenamide) were found on the aluminium substrate in question after the wiping procedure on such wipers which had come into direct contact with packaging material made from polyethylene on the aluminium surface. The substance belongs to the group of waxes, which are often used as lubricants in foil production. In addition, with the wiper RRT 1, sulfate traces such as dodecyl benzene sulfonate were found. Mineral oil and surfactant traces could not be found, which surprised us. However, a quantitative assessment of the possible contamination with the method is only possible to a limited extent.

Drop shape analysis

This test method is a well-known and possibly the most powerful yet unspecific analysis tool for the determination of contaminants on solid surfaces. It functions by comparative measurement of the contact angle of the lying fluid droplet. It was found that on the contact angle on surfaces on which previously a dry wiping operation with a knit-type wiper had taken place was less than the contact angle of pure surfaces. This may be interpreted as a reference to the transfer of film contamination from the knitted fabric to the test surfaces. For surfaces wiped with a moistened wiper the contact angle difference averaged even higher. Also the drop-penetration-time of di-water drops into knitted wipers and nonwovens is a good measure for their surface-purity as well as for their fluid absorbance.

The C&C Indicator plate test

A flattened wiper section of the dimensions say, 35 x 35 mm is placed onto a Clear & Clean Indicator plate, which is a clean, dark-coloured glass plate of 50 x 50 mm (alt. 150 x 50 mm) in size. A number of drops of an analytically pure solvent (e.g., acetone, alternatively isopropanol, n-hexane etc.) are added to the wiper section by means of a glass pipette, until it is completely soaked. The amount of solvent added should be such that it does not spread beyond the edge of the wiper and about kept even with the upper plane of it. After the solvent-evaporation in many cases a solid residue is formed on the indicator plate, mostly in the edge areas of the wiper section. This visually differs from the dark background of the plate when using an oblique illumination (fig. 20). If the indicator plate is mounted on the boom of a suitable microscope, the solid residue of spin finish and other chemicals can be visualised and photographed. With some experience – the quantity

Caution with „practice tests“

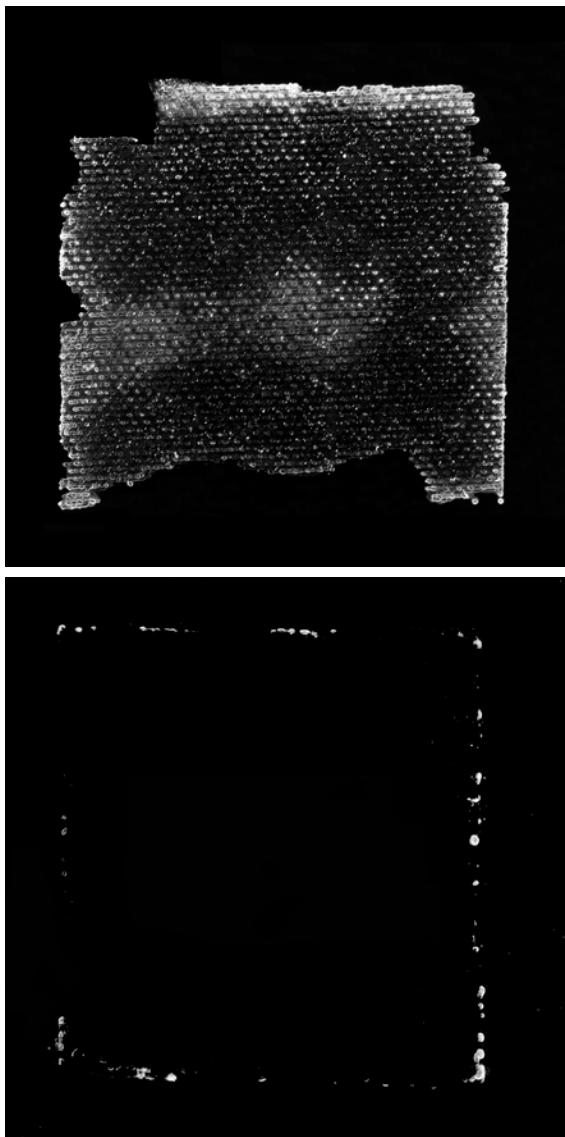


Fig. 20 Non-volatile residue (NVR) of cleaning wipers. Chemical residue from a cleanroom wiper after drying on Clear & Clean indicator plate, top: after acetone immersion, below: after 2-propanol immersion

can be estimated in general categories [51].

The indicator plate is one of the most versatile, cost-effective and lightest test devices for the microscopic visualisation of both particulate and film contamination. It is also suitable for rapid general assessment of the purity of solvents as well as of the cleaning efficiency of various wipers and cleaning agents on different surfaces.

In cleanroom operations, the task is at times to check the functionality of a consumable, and, if necessary, to choose an alternative one. If, for example, one wish to ascertain how many particles dissolve from a cleaning wiper due to the applied mechanical stress (e.g. multiple folding, controlled wiping) and enter the environment, it is by no means sufficient to provide one or two test specimens only for a reliable general quality statement. This also applies to cleanroom gloves and other consumable materials. The reason for this is the principally inhomogeneous structure of rubber, textile- and paper-materials such as those of polyester-cellulose or knitted wipers, latex, vinyl- or nitrile gloves and cleanroom-paper. For measuring series of 24 individual measurements, for example, for the parameter particle release, differences of the individual measured data were found in the ratio of max. 1:5. Thus only a larger number of individual measurements of 12 or 24 sample drawings can lead to a plausible measurement result for consumables. If the variation coefficient of the measured individual values is in excess of 30% then one must think twice about the plausibility of the measurement method. Practice-oriented test methods such as manual crimping, pulling and compressing wipers over a particle probe or rubbing both hands while wearing gloves are completely unsuitable test methods which simulate the mechanical stressing of the materials during their application in a non-realistic manner.

Since, however, normally no special equipment is available to the cleanroom personnel for testing these products, so-called „practice tests“ are often found to lead to insufficiently plausible test results, which nevertheless play a certain role in the selection of consumables. On the other hand „practice tests“ are in a way important because, for example, there is a difference in the number of released particles whether only smooth surfaces are cleaned in a certain cleanroom-bound-production or smooth surfaces with a sharp-edged hole structure.

In this essay we describe simulation in the sense of the reproducible physical experiment based on excercising the actual physical work. It is recommended using only such methods to test consumables with which use-identical physical work is applied. Alternatively, one can have the test-system examined at an institute's test centre.

With the Schöttle/Labuda Fulling Simulator (fig. 26) we simulate, for example, the mechanical deformation of cleaning

wipers during their application and measure the resulting particle release. This is because the mechanisms of particle delivery from the real system (e.g., cleaning wiper,s gloves, clothing) are too complex to allow an exact solution of the motion equation. In such system, the validation of the relevant simulation model is of great importance. Here, the causes for so many implausible results are found. The best example of this is the much abused IEST immersion method with its deviant simulation model (the simulation of air particle release by dipping and moving the test specimen in DI water. This is followed by the determination of the quantity of particles released into the DI water.) Deformation type, deformation work and reproducibility of the stress application are decisive for a verifiable test result.

Simple testing instruments for more security

Before turning to a number of simple testing technologies for cleanroom consumables, we would like to make a few fundamental comments on the current situation of the measurement and testing technology available to cleanroom operators. In principle, the operators must be able to rely on the fact that the specifications for cleanroom consumables are adhered to by their manufacturers. The problem lies in the recent geographic change of the production sites.

About until the Millennium almost exclusively U.S. manufacturers, as well as some Japanese and few Europeans who produced cleanroom consumables in their native countries. The upcoming competition and reduced price level in China, Malaysia and Thailand however, had forced many of these either to build production sites in the Asian countries, or to buy consumables overthere. In the meantime, however, European importers had been looking for foreign sources of supply in order to undercut the American consumable manufacturers in price. And there are some hints that meanwhile the American manufacturers buy large parts of their production in Asia and manufacture a lesser percentage of their cleanroom consumables in their own country. It is a natural consequence of all this that the quality monitoring of such products is not always secured or at least not clearly communicated. The importers of cleanroom consumables cannot be expected to guarantee quality monitoring of packaged products and so the problem is often neglected. In this situation, it is certainly meaningful for some consumers to have the necessary tools at hand which can be used to quickly identify gross manufacturing errors of the cleanroom consumable materials possibly originating from sources in East Asian Countries.

For this we recommend the following tools for the performance of the C&C-Transfer-Test:

- Trinocular stereo or reflected light microscope (Motic)
- Digital camera (Motic)

- Illuminated lighting lamp or white light-emitting diode illumination
- Set of indicator plates with metal base (Clear & Clean, type CC 900, CC 901 or equivalent CCI-von-Kahlden type)
- Small pneumatic vertical press
- Compressor for a pressure from 1-5 bar with time-delay switch

With this simple set of tools it is possible to carry out a whole series of basic tests. The stereo microscope allows the viewing of surfaces and edges of cleaning wipers, the seams of cleanroom clothing, the mechanical manufacturing quality of swabs, contaminated surfaces of cleanroom gloves and much more. With a microscope-adapted digital camera and the appropriate software, all this can even be photographically documented. With the aid of the Transfer-plate and a bezel light, it is possible to view particle deposits and also to count them automatically with suitable software. If a solvent droplet is applied on to the Transfer-plate, it is very easy to see whether a solvent has a high degree of chemical purity after evaporation. If a fingerprint is applied to the Transfer-plate, it is not difficult to estimate the cleaning efficiency of a particular wiper when cleaning the plate with it. If a small section of a wiper is placed onto the transfer-plate and is moistened with a solvent, it is possible, after evaporation and the building of visible residue on the plate, to determine whether there is any chemical residue in the wiper. If a small pneumatic press with a nominal pressure of, for example, 3 to 5 bar is pressed for 10 seconds on a cleaning wiper placed on an indicator plate, the free accumulated quantity of particles of the wiper can then be estimated microscopically, and it can also detect whether the wiper contains chemical residue. This is a test that has been similarly described for cleanroom gloves.

Particle release from cleanroom gloves

When working with cleanroom gloves, particles are continuously released from the surface of the gloves due to the motion-induced material deformation. Five types of cleanroom gloves are in practical use: Vinyl, Latex, Nitrile and Polyethylene and Polyurethane gloves. The most popular test method for cleanroom gloves is the IEST method RP-CC005.4, it is also known as the „Liquid agitation particle generation test“. This test-method, however, does not properly simulate the particle release of the gloves in their dry state of use.

Gloves: IEST immersion test

Test method IEST-RP-CC005.4 (Oct. 2013)

This test method stipulates to hold the glove test sample for the „grey value“ determination in a clean work environment by means of a gripping forceps over a carefully decontaminated beaker. The beaker should be of 2000 ml volume and should be filled with 750 ml of 0.2 µm filtered DI water of 18M-Ohm so that excess DI water flows into the beaker. The sample, which is now wetted both externally and internally by

DI water, is left in the beaker. The beaker with the glove inside is fixed onto a 2-axis shaker with a shaking stroke of 1.9 to 2.5 cm and is shaken for a duration of 10 minutes. The glove is then removed and disposed of. The particle-laden DI water is analysed by a liquid particle counter or microscopically. In this test method, for example, an average of 700 particles > 0.5 µm/cm² glove area is measured for a Nitrile glove. The glove surface area in cm² is determined by mass comparison of a material cutout of the dimensions 50 × 50 mm. For Vinyl and Latex gloves it is slightly less, while the open-pore PU nonwoven-gloves release more particles.

A cleanroom glove of size XXL has a surface area of about 680 cm². This results in a total quantity of 476,000 particles > 0.5 µm, which are released into the DI water during this test. The method is easy to carry out, but it does not at all simulate the particle release from the gloves in the real (dry) state of use. The respective test results are therefore not close to being realistic. The erstwhile developers of the IEST test method had in the 1980s apparently decided to evade the uncertainties of particle adhesion caused by the ever changing surface charges. Given the choice, they agreed on a less plausible, but more stable parameter: the particle release into a liquid medium.

Gloves: C&C-ManuStretch test

C&C-ManuStretch test (fig. 21)

For the purpose of testing the motion-induced particle release of cleanroom gloves, an alternative method has been developed by the Clear & Clean Research Laboratory which corresponds within broad limits to how users handle cleanroom gloves. Like all test methods based on the release of particles on surfaces, also this method is subject to the imponderable effects of humidity, temperature and static electricity in the storage or testing environment. However, these restrictions also apply to the tested material. The quantity of released airborne particles can be determined by means of an air particle counter according to the test. For this purpose, the following test operation was defined:

The hand clothed with a cleanroom glove is clenched to the fist and opened to the maximum possible width within one second. This is done twelve times within twelve seconds. The arm of

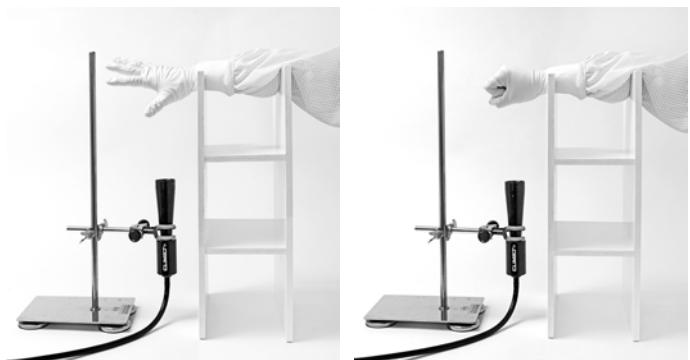


Fig. 21 C&C-ManuStretch test for the determination of particle release of gloves

the examiner rests during the test on a specially created arm rest in a fixed distance above the probe plane of a counter for airborne particles. The method is considered plausible if the variation coefficient of the ten count variables is within 50%. To exclude any outliers from the calculation, we take from a series of 24 random values both the 2 upper and lower ones from the calculation. In case of 36 random values, the 3 upper and 3 lower ones are disregarded.

In the case of testing cleanroom-compatible Nitrile gloves, an average of 78 particles $> 0.5 \mu\text{m}$ was obtained on the base of 1440 individual measurements and after subtracting the two maximum and minimum values. We will make further series of measurements to determine whether and how much the relative ambient humidity affects the electrical surface charge of the glove film and thus the particle release, or whether the surface charge deteriorates in the wearing state of the gloves.

Testing of particle release induced by the use of cleaning wipers

The aim of every cleaning by wiping procedure is to create a system-compatible clean state of object surfaces. At the same time, however, a small mass of contamination is transferred to the object surface originating from the ingredients of the cleaning wipers textile structures. These are mostly particles, spin-finish, surfactant and solvent residues from the auxiliary materials used during the spinning and knitting processes of the textile materials. In some cases, the remaining contaminant residue on the object surface affects their functionality only slightly or not at all, but in others such residue severely limits them. This can be the case when cleaning optical systems, electron optics and laser equipment, but also with plasma etching systems of semiconductor manufacture, the production processes of adhesive technology and in the preparation for automatic painting processes.

A large percentage of cleaning wipers are used in a partially moistened state - namely, if a solvent is applied to the center of the wiper before the cleaning-procedure is carried out. A possibly just as large percentage of the wipers are already delivered in the solvent-soaked condition (wet wipers). A percentage of cleaning wipers are used for wiping off liquid spills. After a moist cleaning procedure, different amounts of particles remain on the surface of the object than after a dry cleaning or dry wiping of object surfaces. None of the test methods described below is suitable for simulating the mentioned influences on the respective state of purity of the object surface. It is therefore advisable to select a test method which promises the best possible conclusion about the success of the respective cleaning procedure. Unfortunately, few useful and affordable measuring systems are available for the determination of particulate surface cleanliness. Up to now, the determination of the number of particles, which is released from the cloth by various methods and then quantitatively determined, is basically helpful. Unfortunately, these methods are usually

Cleaning wipers: IEST immersion test

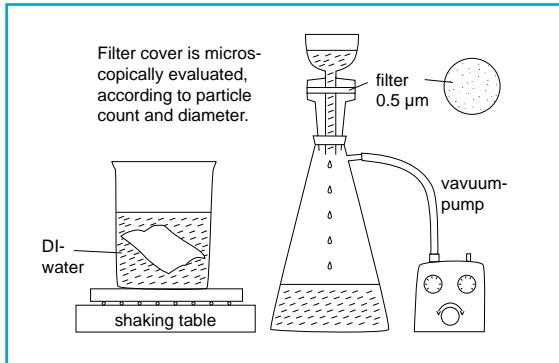


Fig. 22 Test scheme for cleaning wipers according to method IEST-RP-CC004.3 (immersion method)

not realistic, for only very few particles per cm^2 are found on a carefully wiped glass plate. However, testing a wiper according to the method IEST RP-CC004.3, we find millions of them.

Test method IEST-RP-CC004.3 (fig.22)

The particle release of clean room wipers into a liquid medium is subject to different physical laws than the one into surrounding air. In the di-water, the adhesive forces between particles and the yarn surfaces are virtually eliminated. The particles dissolve in large numbers from the surface of the filament after the sample is immersed and find their way into the liquid medium unobstructed. This is also the reason for the exceptionally large amounts of particles released during this test. The test method foresees that, after a grey-value measurement has taken place, a plastic container of 4-liter capacity filled with 600 ml of test liquid, (optionally DI water, DI water-isopropyl alcohol mixture or DI water-surfactant mixture) would be fixed on a 2-axis shaker with 10-13 mm shaking stroke. The cleanroom wiper (test specimen) is then given into the container with the test liquid so that it is completely covered. The test specimen is shaken at 500 rpm for 5 minutes. It is then removed from the container, allowed to drain for 30 s and disposed of. The particles present in the test liquid are analysed by means of a liquid particle counter or microscopically after filtration through a 0.5 μm Millipore-filter.

Cleaning wipers: Gelbo Flex test

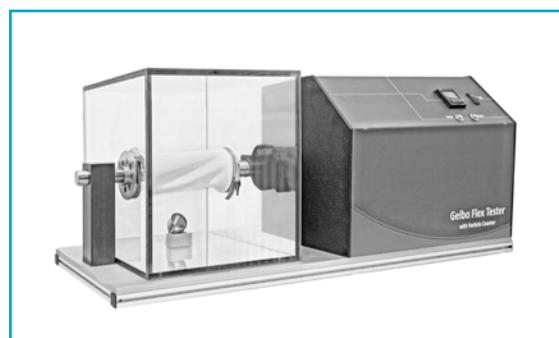


Fig. 23 Flex tester after Gelbo

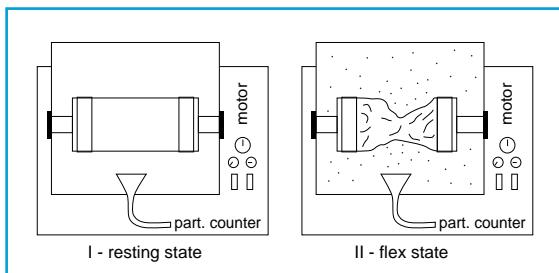


Fig. 24 Scheme Flextester according to Gelbo in two states

Gelbo Flex test method according to ASTM-395 or DIN EN ISO 9073-10 (fig. 23, 24)

The modified Gelbo Flex test according to DIN EN ISO 9073-10 is a method intended for the detection of the motion-induced particle release from cleaning wipers, paper or films. According to this, the test specimen is located in an on all sides closed chamber which is ventilated by clean air and in which at least the conditions of the cleanroom class 3 according to ISO 14644-1 (2014) should be complied with. The formatted test piece (cleaning wiper, plastic film or paper) is fixed by means of clips on to two oppositely disposed, rotationally mounted disks. The disks are rotated (flexed) relative to one another. At the same time, the spacing of the disks from each other is cyclically changed. In this case, particles released from the surface of the test specimen arrive in the peripheral environment thereof and, if they enter the intake air stream of a particle counters probe, they are counted and classified according to their Feret diameter.

The Gelbo Flex simulator provides excellent service in the flex durability testing of plastic foils and other surface-measured materials for the simulation of processes with higher amounts of mechanical work. However, it is not suitable for the testing tasks which require the simulation of very little mechanical stress, such as quarter-folding a cleaning wiper. For such minimal operation, the device renders an excess of mechanical

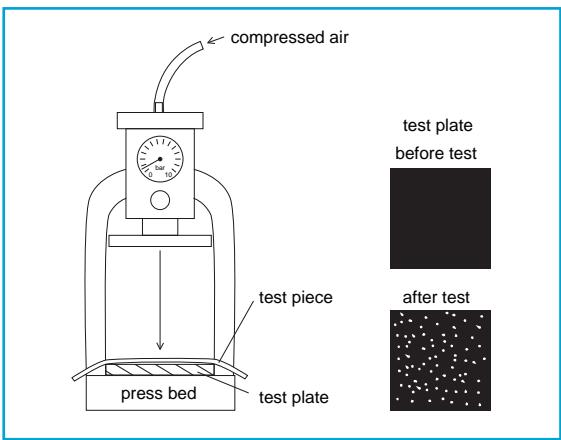


Fig. 25 Test scheme for the particle transfer test

Cleanroom wipers: C&C-fulling test

work - much more than is required to simulate the folding procedure. In addition, the simulators sharp-edged mounting clamps lead to handling problems during the mounting of the test specimen. During the test specimens attachment-procedure relatively large amounts of particles could be sheared off, which can impair the subsequent measurement result. In addition, the device does not provide a channeled particle current from the test specimen because of the torsional movement towards and away from the isokinetic probe of the air particle counter. The effective distance between the surface of the test specimen and the plane of the isokinetic probe alternates during the simulation which leads to a turbulent airflow pattern with all its known consequences concerning the counting of particles in an air flow. For the reasons mentioned above, it seemed appropriate to develop a simulator in which the disadvantages mentioned regarding the Gelbo Flex simulator were largely taken into account. This is the Fulling simulator according to Schöttle and Labuda (fig. 26).

C&C-Labuda Fulling Test (fig. 26, 27)

With the fulling simulator Mk1 - according to Schöttle/Labuda - it is possible to simulate the specific particle release during the application of cleaning wipers in their dry handling phase. For this purpose, a wiper section with the dimensions of 220 × 50 mm under a defined tensile load is wrapped around the circumference angle of 180° by a fulling mandrel of 2.8 mm diameter and is moved back and forth a set number of times. The fulling mandrel is arranged just above the isokinetic probe of an air particle counter. In this process, the textile material is milled and the released particles are counted by a particle counter and recorded and classified according to Feret diameter. Thus, the device was designed to be a useful replacement of the Gelbo Flex tester, when the task is to simulate small and very small amounts of mechanical work, like the quarter-folding of a wiper. This simulation model simulates the mechanical process of folding, without however resulting in uncontrolled changes in the distance of the test specimen relative to the particle probe, as is the case with the Gelbo



Fig. 26 Fulling simulator Mk I after Schöttle/Labuda

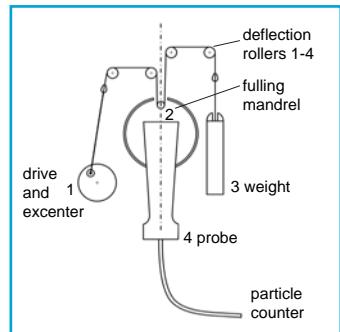


Fig. 27 Test scheme for the La-buda Fulling Test, particle release from dry cleanroom wiper

Flex system. In addition, all this can be done with an energy input comparable to folding and crumpling a wiper. Even with this test method, however, the influences of material moisture and electric fields on the particle adhesion forces must not be neglected. And also: even with this machine the mechanical work rendered may exceed the one of quarter folding a wiper. A number of experiments are planned which should allow a deeper insight into the mechanics of simulating the real forces to take effect on a cleaning wiper during the various stages of its use.

Cleanroom wipers: C&C-transfer test

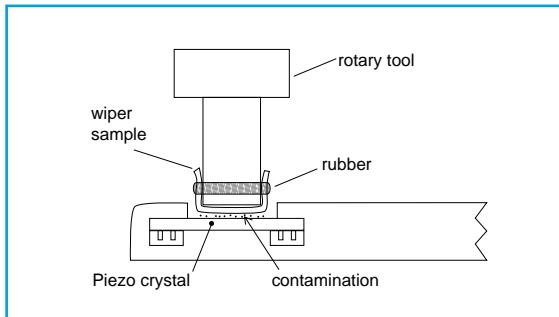


Fig. 28 Test scheme C&C-mass transfer test before and after removal of contamination

C&C-Mass Transfer Test - Experimental

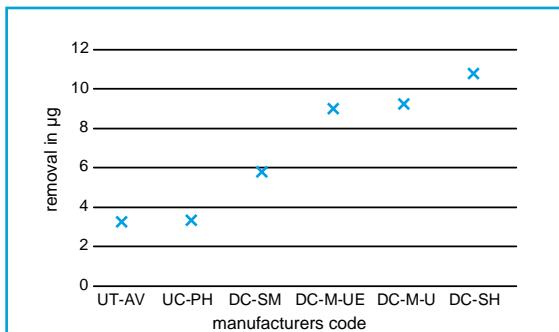


Fig. 29 Diagram: The removal of contamination from a quartz plate. (6 cleaning wipers from three manufacturers.)

C&C-Particle Transfer Test (fig. 25)

In this C&C-test method, which is currently in its trial phase, for example, a Transfer-plate of high surface cleanliness and low roughness with a defined contact pressure of 0.35 bar/cm² is applied by means of a pneumatic press for e.g. 10 seconds to the cloth, film or paper sample that are to be tested. As a result, particles and fibre fragments located on the material surface are transferred to the indicator plate and find a new resting place there. The particle coating thus obtained on the indicator plate can be evaluated microscopically by means of suitable software for particle analysis [6].

The main objective of the development of this test concept was to circumvent the effects of constantly changing adhesive forces by electrical charge phenomena like relative ambient humidity and temperature. A similar but more severe test has already been described by Sovinsky (NASA) in 2009 [29]. Cleanroom wipers: piezoelectric scale test

C&C-Mass Transfer Test - Experimental

We would have liked to determine the mass transferred to an object surface caused by the use of a cleanroom wiper. For this purpose, we wiped with selected wipers over the pure surface of a quartz balance. The mass change can be calculated on the basis of the frequency change caused thereby. However, it was found in the experiments that the mass transferred from the cloth to the crystal was too low with < 50 ng to produce consistent data. The mass transferred lay in the lowest measuring range of the quartz balance, and the variation coefficients of the measuring series fluctuated between 50 and 150%.

In the end, we depended on the proven Transfer-plate for these experiments. In this way, we did not obtain the numerical data we had hoped for, but a good visualisation of the transferred film-contamination from the wiper to the indicator plate as can be seen in figures 30, 31 and 32.

A further experiment in connection with the piezoelectric micro-balancing technique should tell us the mass which can be removed from a surface by the use of different cleanroom wipers by means of wiping over oil-coated surface of the balance. For the trials, we had selected 12 pcs. of cleaning

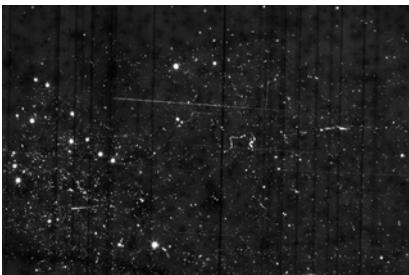


Fig. 30 Cleanroom wiper DC-MU-EC

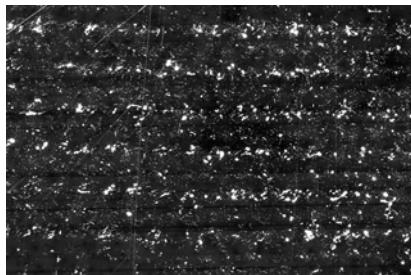


Fig. 31 Cleanroom wiper UT-V

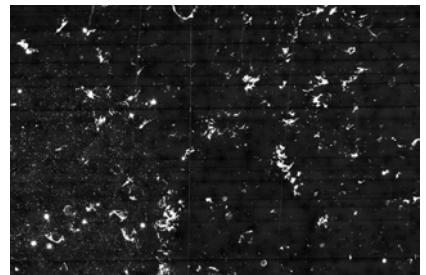


Fig. 32 Cleanroom wiper DC-SM

wipers, each of six different types from three well-known manufacturers. For the statistics the lowest and the highest mass-values were ignored. Finally the results as expressed in figure 29 were obtained.

These results show once again that the cleaning performance of the internationally available cleanroom wipers vary in a ratio of 1:3. We had already obtained similar results in laboratory tests with the cleaning efficiency test according to Labuda. Testing the particle release of cleanroom clothing

Testing the particle release of cleanroom clothing

When testing clean-room garments for particle release, the quantity of particles released from the clothing into the environment in the wearing state is to be determined. The following release mechanisms are relevant:

- Release by the handling-deformation of the textile material
- Particle emission caused by the pump effect and vented from cuffs, trouser leg openings and collar closures.
- Particle abrasion by contact with objects.

Apart from particle-shedding the transfer of filmlike contamination from the textile structure of the garment to objects may be of importance.

The above-mentioned release mechanisms cannot be simulated within the frame of a single test method. The following tests for particle release have become popular in the past:

- 1 - Method ASTM F51-00 (Suction Method)
- 2 - Helmke drum test according to IEST-RP-CC003.4
- 3 - Containment test according to IEST-RP-CC003.4

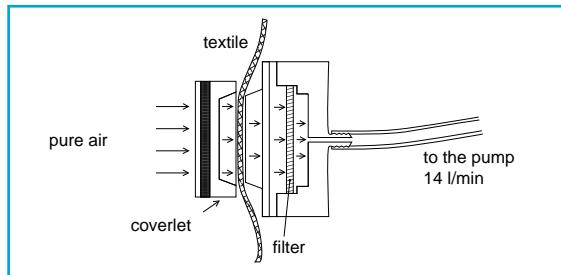


Fig. 33 Test scheme for cleanroom clothing according to method ASTM F51-68

Clothing: ASTM test

Test Method ASTM F51-68 (Suction Method) (fig. 33)

This easy-to-use test method is based on the suction of particle-free air through the pores of a cleanroom. As a result, part of the particles located in the through-flow area of the pores are removed from their resting places. The freed particles are collected on a filter or automatically fed to an electronic counting process. The other part, on the other hand, is not included in this method. For physical reasons, especially

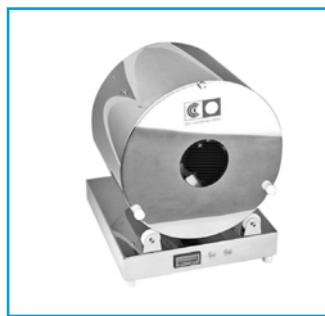


Fig. 34 Test device: Helmke drum, determination of the particle covering of clean room clothing, (CCI-von Kahlden GmbH)

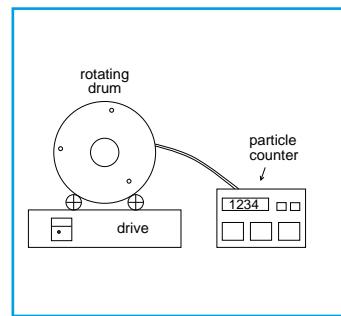


Fig. 35 Test scheme for clean room garments using method IEST-RP-CC003.4 (Helmke Drum Test)

the larger particles are more easily detached from the yarn filament surface. However, the motion-induced particle release is not simulated by this method. This however is the real cause of the particle release in the wearing state of the garment-surfaces. Nevertheless, the method has become widely known and is in permanent use.

Clothing: Helmke drum test

Helmke drum test method according to IEST-RP-CC003.4 (fig. 34, 35)

In the Helmke drum test according to IEST-RP-CC003.4, the garment is placed in a mobile drum similar to a clothes dryer. The drum is rotated for the purpose of generating particles. The generated number of particles is being determined by means of an air particle counter. However, it can be assumed that the drum circulation not only results in the release of the particles resting on the surface of the garment but also in the generation of particles by abrasion. This kind of particle release is also not significant in terms of the simulation of the

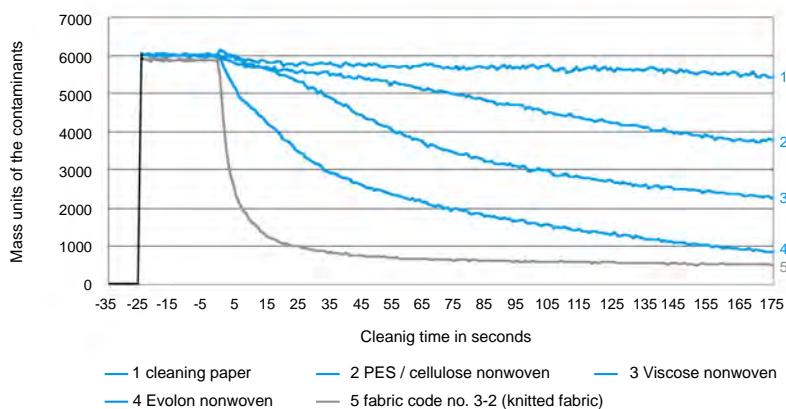


Fig. 36 Diagram: Cleaning performance of various nonwoven wipers compared to a knitted wiper, measured with the Labuda rotary wiping simulator Mk III (fig. 37). The cleaning performance of the knitted wiper (red) is significantly higher than that of the four nonwoven wipers.

Clothing: Containment method test

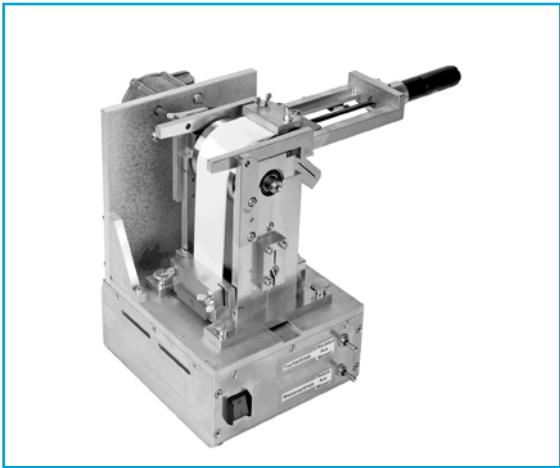


Fig. 37 Labuda rotary wiping simulator MK III in operating position. The clamping lever S is brought into the operating position while an oil coated roller rotates. The oil layer is slowly removed by the cloth and the mass-reduction of the oil is measured by laser-fluorescence.

wear-induced particle-release, since it cannot be ruled out that some of the released particles are attracted by electrostatically charged surface domains of differentiated electrical charge polarities and find new resting places in the same clothing without being counted. Nevertheless, this test method is in use worldwide, mainly because hardly any plausible alternatives are known so far.

Containment test method according to IEST-RP-CC003.4

This method is the most plausible of all test methods concerning the particle release of humans clothed in cleanroom garments: This is because all possible particle release mechanisms are integrated in the measurement result. In the method description IEST-RP-CC 003.2 [10], it is mentioned as „BodyBox Test“. The Body Box was recreated by Thomas von Kahlden and Carsten Moschner, subsequently it was used by Moschner for general investigations of the particle release of humans and clothing, the results of which are available as a publication [8, 9]. The device is a hermetically sealed chamber with a perforated bottom of 1.48 m^2 . Clean air flows through the air outlet from the filter ceiling to the floor with an inflow speed of up to $0.5 \text{ m/s} = 1605 \text{ m}^3$ of clean air per hour. In the chamber is a test person dressed with a selected cleanroom garment completing a particular movement program. The particles emitted by the test person itself as well as by her clothing are counted at the various sampling points of the BodyBox (not specified in the IEST recommendation) with particle counters and subsequently they are classified according to Feret diameter. Unfortunately, this also relates to the individually very much differing particle delivery of the respective test person so that the result is hardly usable for the evaluation of the garment alone.

In a different context, however, the containment method is of particular interest: The BodyBox enables to count and classify the quantity of particles released by the clothed person per unit of time to be known and thus related to the total amount of particles in the cleanroom. Thus, the percentage of particles released by the operator and his clothing system in the cleanroom atmosphere can now be determined more precisely than ever before. This is of great advantage for the cleanroom technology in general. But it also goes for the determination of the consumables induced particles.

Part III - Discussion

Particle release of consumables vs total no of particles in a large cleanroom

The question is: What is the particle release of individual cleanroom consumables as a percentage of the total particle burden in a cleanroom?

For an ISO class 4 cleanroom (Fed-Std class 10) of 5000 m² floor area and 3.5 m ceiling height, the volume is 17,500 m³. The maximum permissible particle count for an ISO class 4 = 352 particles > 0.5 µm/m³. However, we are assuming that only 20% of the max. permitted particles are actually present there. This corresponds to 70.4 Part > 0.5 µm per m³. At 300 air changes per hour, a clean room of 17,500 m³ within 24 hours thus generates 8.8 GPart (17,500 x 70.4 x 24 x 300 = 8.87 x 10⁹).

The total particle release in the clean room thus corresponds to 8.8 GPart/day. Let us then compare the above mentioned particle generation with the particle generation of popular consumable materials.

People and clothing

According to the mentioned BodyBox tests [8, 9] the particle release of people and clothing together averaged between the movement modes „go“ and „stand“ 67.6 kPart. > 0.5 µm/min. This applies, however, only to persons wearing a cotton jogging suit, a cleanroom overall, a full protection hood and knee-high pull-on boots.

The calculation: shows 67 x 1440 min/day = 96.5 MPart per person x 50 employees. This would be: 4.82 GPart > 0.5 µm/24h which are released by humans and clothing together. The amount corresponds to 54.8% of the total particle quantity of 8.8 GPart, which flow through the clean room within 24h.

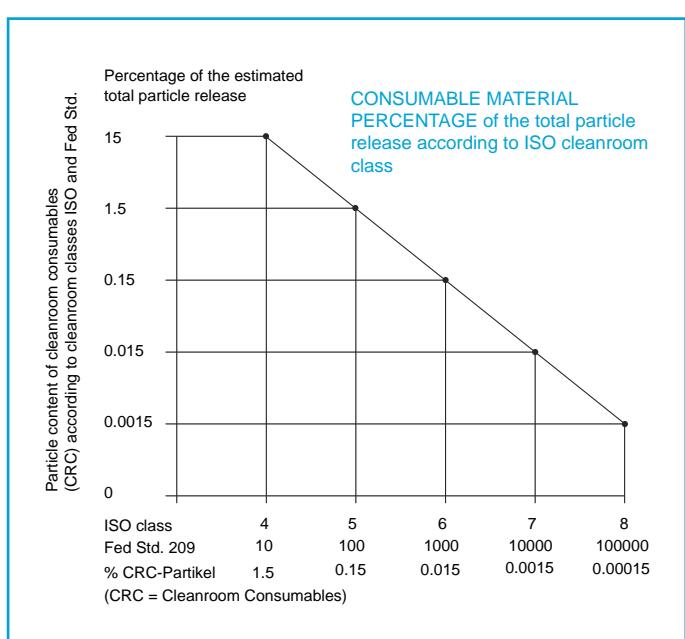
Protective gloves

One fist-stretching movement with both hands in the gloved state releases 156 Part > 0.5 µm from the gloves. Assuming 50 employees do this fist-stretching movement every 5 seconds with both gloved hands, 156 x 12 x 60 x 24 x 50 particles = 134.8 MPart would be released in 24 hours. This would result in: 0.135 GPart > 0.5 µm/24h which would be released from the gloves. The amount corresponds to 1.5% of the 8.8 GPart > 0.5 µm/24h, which pass through the cleanroom as a whole. However, since the assumed test scenario is deliberately exaggerated, a percentage clearly below 1% can safely be expected as the particle contribution by gloves as a consumable group.

Cleaning wipers

Cleaning wipers are often removed from the packaging in the dry state, folded twice, then saturated with a solvent and used in this condition. Particle release takes place almost entirely in the dry state. We measure a maximum of 100 Part > 0.5 µm during the package removal and the quarter-folding procedure. For example, a cleanroom with 50 employees uses 120,000

Fig. 38 Percentage of particles released by selected cleanroom consumables material based on the total particle release, graded according to cleanroom classes.



cleaning wipers per year. This is 330 wipers per day. Of these, a total of 33,000 particles are released. This corresponds to: $0.033 \text{ MPart} > 0.5 \mu\text{m}/24\text{h}$ corresponding to 0.36% of the total particle quantity of 8.8 GPart, which passes through the cleanroom within 24h.

If we add the percentages of human and clothing items, cleanroom gloves and cleaning wipers to the total particle volume that passes through the cleanroom, we conclude that human beings and clothing contribute 54% of the particle volume in the cleanroom. However, the consumables gloves and wipers taken together contributed only 1.9% to the total particle burden.

Conclusion



Fig. 39 DRE mapping ellipsometer (Dr. Riß)

Almost 55% of the particles released in an ISO 4 cleanroom are released by the people working there and their clothing. The particles released of the cleanroom consumables, gloves and cleaning wipers is negligibly small amounting to a total of < 2%. All this is expected on the assumption that the underlying cleanroom is operated only with a partial load of 20% of the maximum permitted particle load limit.

The cleanrooms of the semiconductor industry are among those with the highest air purity of all industries. It is therefore justified to assume that in most cleanrooms of other industries, the particle load of the cleanroom ambient air is higher than that in the above example. This means that the percentage of the particle load through the use of cleanroom consumables decreases further with each increasing ISO-cleanroom class by the power of ten.

Specification and certification suitability

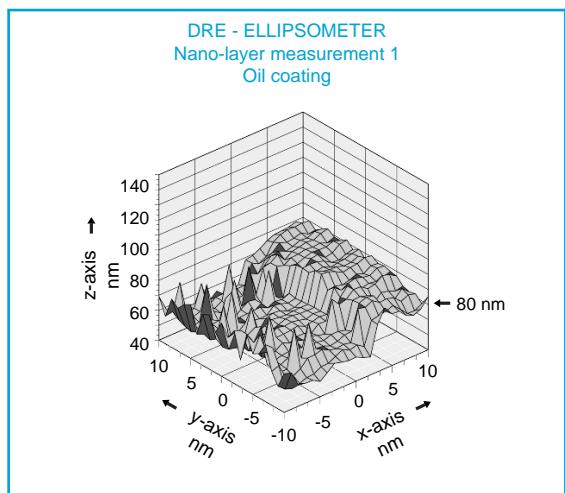


Fig. 40 Substrate: coated silicate glass - roller coating of an oil layer

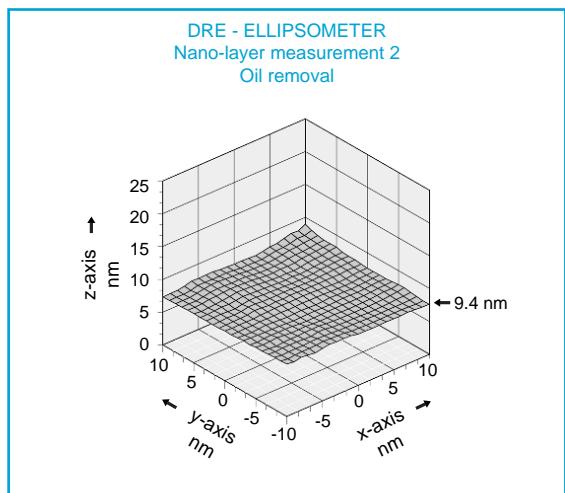


Fig. 41 Substrate: coated silicate glass - cleaning by dry wiper

Cleanroom consumable manufacturers are mainly so called „converters“ (another expression for consumable manufacturers). These are companies that „convert“ a product of large-scale production such as fabric, nonwoven, knitware or paper from large rolls into smaller, hand-held units such as wipers, sheets or small rolls. In the framework of clean manufacturing technologies that involves a four-step process like formatting, decontamination, testing and packaging. In Table 3, the production flow of some cleanroom consumables from the basic material through the raw material production up to the converter operation is cross-sectorial. It becomes clear that certain chemical and particle content substances from the production stages I and II are already in the material when these are supplied to the converter. For such product groups, a specification / certification is, as a matter of principle, not necessary as, for example, in the case of packaging films, or even not possible as in the case of nonwoven fabric wipers.

The manufacturers of roll goods are, for example, not able to guarantee to the converter the clean technology-parameters particle release and ionic content. Neither do they have the measuring equipment or the necessary experience, nor do they have the possibility of quality monitoring this particular range of products. In addition, the quantity of material required by the clean-technology sector is comparatively low for the roll-goods manufacturers. A large spunlace production produces about 400 m² of nonwoven fabric per minute. This corresponds to the material quantity of 430,000 cleaning wipers per hour - the annual requirement for wipers of a medium-sized semiconductor manufacturer.

Roll goods, however, also include knitted fabrics from which the converter produces fine and precision cleanroom wipers. These knitted fabrics still contain chemical residue from the original yarn production. No knitting company is able to carry out the necessary chemical analytical tests in order to determine the amount of chemical residue remaining in the raw materials supplied. And even if this was possible, the perpetual compliance with specified data could not be guaranteed. The knitting companies would have to complain about an excess of chemical content, or deviation from the previous delivery, at the yarn factories. The contaminants partly result from the production of yarns. However, these production sites are usually found in China, India or Malaysia. The converter is therefore in many cases dependent on decades of experience with selected manufacturers of yarns and knitted fabrics.

A general problem is the specification and certification of cleanroom consumables manufactured areas under foreign jurisdiction. In Germany, quality certificates issued for foreign products can lose their relevance after weeks of testing and be practically worthless in the absence of continuous quality monitoring of the foreign production lines by regular on-site

Production flow - Cleanroom Consumable Material

Products ▼	Basic Material Manufacturers	Raw Material Manufacturers	Converter (Finished Material Manufacturer)			
	Material	Type	Convert	Decontaminate	Particle Count	Packaging
Manufacturing Stage ►	I	II	III	IV	V	VI
Immersion Gloves	Granules, Plates	Glove Manufacturer	Immersion, Stripping	Bleaching Bath, Washing	Stat. Q-Contr.	Manually
Film Gloves	Granules, PE / PU	Extruder	Punching	No	Possible	Manually
Nonwoven Wipers	PET Fibres, Wood Pulp	Nonwoven Manu- facturer	Mech. Cutting, Folding	No	Roller Attachment	Manually, Automatic
Knitted Wipers	Granules, PET, Spinning	Knitter, Weaver Equipment provider	Laser Beam, Ultrasound	Drum Washing	Stat. Q-Contr.	Machine Manually
Paper, Notebooks	Cellulose Manufacturer	Paper Factory	Mechanical	Decontamination of Edges, Latex Coating	Stat. Q-Contr.	Machine Manually
Garments, Disposable	Granules, PP	Extruder	Punching, Sewing, Welding	On Request	According to Specification	Manually, CR
Garments, Reusable	PET Yarn	Weaver	Punching, Sewing	Regular	After Wash	Manually, CR
Packaging Films	Granules, PE	Extruding in the Cleanroom	Punching, Welding, Bagging, etc.	Process-depen- dent: No	Stat. Q-Contr.	Machine Manually, CR

 Decontaminated
 Not decontaminated or Not decontaminable

Table 3 Production flow for cleanroom consumable material production
(For immersion gloves: manufacturing steps II - VI in the same company)

auditing. Such certificates, however, may have a five-year validity period. It is therefore not excluded that cleanroom consumables importers provide their indigenous customers with a certificate for 5 years duration, which does not even guarantee that the foreign manufacturer of the certified product is still in existence after this time. This is not just a question of the „suitability for certification“ of products, product groups and production processes. This raises the question of the certification capability of the certifiers and their control by a higher-level technical body or authority. Thus, before thinking about the certification of cleanroom consumables, it should first be ascertained whether the materials as well as the trade routes are at all suitable for certification. Considering this aspect one may already reach the limits of certifiability for many products.

In the following, some pro and contra arguments describe the development and implementation of new and changed test methods for cleanroom consumables:

The Pros and cons of improved specifications for cleanroom consumables

Pro

- 1- The conceptual errors of the American test specifications ASTM and IEST could be corrected. Plausible test methods would probably have a higher user acceptance in non-American countries.
- 2- The risk hypothesis concerning consumable materials in a clean production-process would finally be rejected or confirmed. This would result in more clarity and planning security for both, the users and the converters.
- 3- Cleanroom consumables would be perceived as a vital product group more strongly than before.
- 4- The producers of consumables in the emerging markets would be more motivated to manufacture according to European specifications. However, the prices would increase.

Contra

- 5- Until now, cases of damage caused by cleanroom consumables have not been documented. The discussion about this is thus artificially brought about and in the author's opinion, is based on an assertion to serve the purposes of special interest groups.
- 6- A correlation between the parameter particle release due to the use of the cleanroom consumable materials and the process yield in clean production processes has so far not been described in the reference literature. Only if this had been secured, would a certification of the cleanroom consumable material come into question at all. So far, however, no attempt has been made to relate a process parameter such as the process yield to any cleanroom-consumable-performance.

- 7- Particle release occurs permanently in every clean production process. However, this is part of the process, and the process objective is not affected except in case of catastrophic failures.
- 8- In the semiconductor and pharmaceutical industries, production yields of up to 99% are considered normal. In general, this speaks for an adequate cleanroom but also an excellent consumable material quality. Hence, only a very small group of users see a need for change.
- 9- In the event of problems with particle release in the production environment, the user is free to choose a higher-quality consumable offered by technically leading consumable manufacturers with a well-equipped application laboratory (Clear & Clean, Texwipe).
- 10- Part of the cleanroom consumables is in principle not specifiable in terms of the clean technologies. First, the ability to specify this is limited by the unambiguous application diversity of some consumables such as cleaning wipers, cleaning sticks and gloves. Second, the restriction is due to the basic contamination of various raw materials which is unavoidable during production and which cannot be eliminated in the downstream production steps. The best example is the spunlace production of polyester/cellulose nonwoven-fabrics for the manufacture of wipers. Their ion content and specific particle release cannot really be influenced by the converter plants by the way of material-selection or post-processing (Table 3).
- 11- International specifications introduced decades ago cannot be changed in the short term, despite the plausibility problem existing and described in this article.

Summary

Neither the resting places nor the propagation paths of particulate matter or film contamination in cleanroom production environments can be regularly predicted or are comprehensible. Any contamination effect on the process yield is therefore to be considered „process-specific“ and not general.

A causal relationship between consumable-induced contamination and process yield is not apparent nor described in the literature. A general stipulation of product-specific contamination limits for cleanroom consumable material is therefore not possible.

The determination of application-related test methods and contamination limits for cleanroom consumable materials is however possible but limited to methods of comparative quality assessment.

The term Process-specific Contamination Barrier (PSCB) identifies the effective inhibition of all forces contributing to the distribution of yield-relevant contamination [2].



Fig. 42 Labuda Rotary Wipe Stimulator Mark II for testing particle abrasion

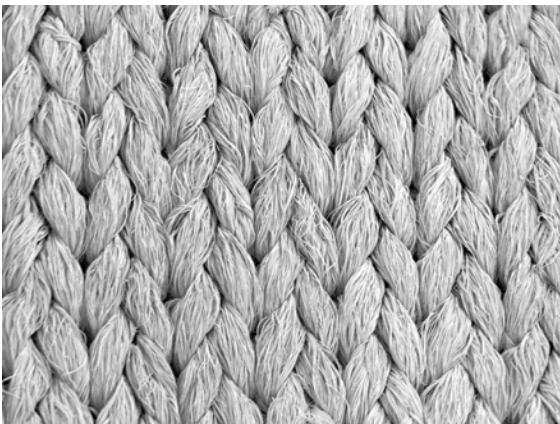


Fig. 43 Surface of cleanroom knitted wiper type Sonit™ MD-H, SEM 30x

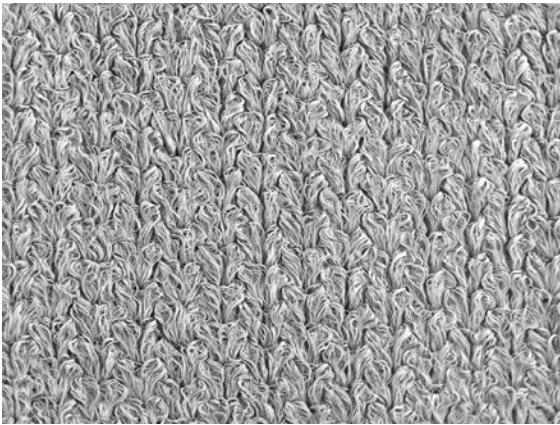


Abb. 44 Surface of precision cleanroom knitted wiper type Microweb™ UD-G, SEM 30x

These include [18] the hermetic isolation of the process (SMIF), the laminar airflow, the handling by trained operators, the number and duration of rinsing and etching processes (e.g. during a chip production), regular cleanroom cleaning, contamination reduction by the linear or spherical contamination propagation and the spatial distance between the manufacturing environment and the core area.

In the cybernetically conceived process system, a potential process-relevant contaminant maximum corresponds to each consumable material. This is, however, reduced by process engineering measures to such an extent that at least the regular contamination by consumables is not process-relevant but system-immanent.

We realize there is a clear need for increased knowledge in connection with the use of cleanroom consumables, which is not met by the existing simulation and measurement methods. Part II of this paper deals with the deficits of the known test methods. Three new test methods are being presented. The real application-induced particle release of the cleanroom consumable material is determined both by the mechanical work leading to a surface deformation (in joules) as well as by the environmental conditions which influence the forces of particle adhesion. If generally comparable test results are produced, it seems necessary to agree on a defined simulation system, in which the detection of all liability-relevant influencing variables is ensured.

The maximum application-induced particle release is a parameter of the second order as long as it cannot be brought into relation with a possible reduction of the process yield (yield loss). Therefore, the selection of cleanroom consumables is only process-specific and possible by means of heuristic methods, as is also the state of technology in clean work environment techniques. The selection of cleanroom consumables for certain manufacturing processes is usually carried out by means of comparative test methods or so-called „practice tests“, in the absence of reference to the process yield.

We show the fundamental differences between particle release in a liquid ambient relative to air, as far as they play a role in the simulation of particle release of cleanroom gloves and wipers. In doing so, we point out the numerous intermediate states which decisively influence the final results in the case of partially saturated cleaning wipers.

We would like to point out that the particle release of cleanroom consumables must always be seen in connection with the film contamination of surfaces. It is an almost never observed physical state that in an air ambient a surface is completely free of film contamination. This also has a significant influence on the particle adhesion and its release. For the consumable

products like cleanroom gloves, wipers and garments, a total of six known test methods are explained in Part II of this article. In addition, three relatively new test methods developed by the Clear & Clean Research Laboratory are presented.

Finally, reference is made to C. Moschner's investigations [8, 9, 10] with the BodyBox (by von Kahlden and Moschner). Moschner's measurement data are used in Part III as the basis for a calculation of the total particle emission of a working person and his/her clothing in the cleanroom. These data are set in relation to the particle release of cleanroom gloves and wipers.

We are seeking to find an answer to the question of the amount of particle release of cleanroom consumables (including those of the worker) on the total particle volume in an ISO class 4 cleanroom. Our calculations show that just about 50% of the particle release in an ISO class 4 cleanroom is released by the worker and his clothing. The particle release through use of the cleanroom consumables gloves and cleaning wipers is negligibly small according to our calculation.

The higher the cleanroom class, the lower the percentage of cleanroom consumables contributing to the quantity of particles present in the cleanroom. Cleanroom class ISO 4 (according to ISO 14644-1) about corresponds to the former cleanroom class 10 according to Fed. Std. 209. In the following classes 5 to 8, the class limit of the particle load increases by one power of ten respectively. As a result, the percentage of the application-induced particle release of gloves and cleaning wipers in a cleanroom class 5 is still only 0.15% of the total particle volume.

Not all cleanroom consumables are suitable for certification and/or specification. We show in Table 3 those consumable materials which already have an unspecified and also non-decontaminable level of impurity, even before they are supplied to the converter.

We address the problem of certification for products manufactured outside the country and jurisdiction of the place of use. In this context, we advocate certification monitoring to ensure certain audit frequencies at the manufacturers of certified foreign products.

In a list of pro and contra arguments, we summarise the development and publication of new test methods and their submission for ISO certification.

This essay contains an extensive bibliography.

A list of all known ASTM and IEST resp. MIL test methods for cleanroom consumables in German and English is also attached.

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Acknowledgements and author's note for Part I



Win Labuda (80) has been active in cleanroom technology since 1973. He is the author and co-author of 40 expert articles and 10 patents on surface cleanliness and cleanroom consumables. He was one of the first authors in 1988 to devote himself to this specialised field. In 1979 Labuda was a founding partner of the company Clear & Clean Werk for Reintechnik GmbH in Lübeck, a German manufacturer of cleanroom consumables. In 1990 he founded the Clear & Clean Research Laboratory, which designs and carries out tests of surface cleanliness and by wiping cleaning procedures.

- Some of the titles of the above essays have been translated to English language. The translation is unauthorized.

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This essay is dedicated to the Dutch physicist Lodevicus Hermans - in gratitude for lifelong friendship and excellent professional advice.

Appendix

US-Spezifikation - Commercial item description (CID)

A-A-59232A - 24 March 2005, Superseding: A-A-59323 Type 1 - 30 June 1999	CLOTHS, CLEANING, LOW-LINT (for all federal agencies like US-Army, US-Navy)
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Appendix

**ASTM-American Society for Testing and Material
Summary of ASTM methods for cleanroom consumables (x)
and other clean room-relevant ASTM test methods (o) (extract)**

		English (original title)	German (unauthorised translation)
x	E1549	Specification for ESD Controlled Garments Required in Clean-rooms and Controlled Environments for Spacecraft for Non-Hazardous and Hazardous Operations	Spezifikation für (ESD) Entladungs-reduzierte Bekleidung zum Einsatz in Reinräumen und reinen Arbeitsbereichen der Herstellung von Raumflugkörpern für Tätigkeiten von normalem und erhöhtem Gefährdungsgrad.
x	E1560	Test Method for Gravimetric Determination of Nonvolatile Residue from Cleanroom Wipers	Prüfmethode für die gravimetrische Bestimmung nicht flüchtiger Rückstände in Reinraum-Reinigungs-Tüchern.
x	E1731	Test Method for Gravimetric Determination of Nonvolatile Residue from Cleanroom Gloves	Prüfmethode für die gravimetrische Bestimmung nicht flüchtiger Rückstände in Reinraum-Handschuhen.
x	E2090	Test Method for Size-Differentiated Counting of Particles and Fibers Released from Cleanroom Wipers Using Optical and Scanning Electron Microscopy	Prüfmethode für die Größen-differenzierte Zählung von Partikeln und Faserfragmenten aus Reinraum-Reinigungsstüchern mittels optischer und elektronenmikroskopischer Instrumente.
x	F51	Test Method for Sizing and Counting Particulate Contaminant In and On Clean Room Garments	Prüfmethode für die Größen-differenzierte quantitative Bestimmung partikulärer Kontamination in und auf Reinraum-Bekleidungs-Produkten.
x	F739	Test Method for Permeation of Liquids and Gases through Protective Clothing Materials under Conditions of Continuous Contact	Prüfmethode für die Durchdringung von Schutzbekleidungs-Materialien durch Flüssigkeiten und Gase unter der Bedingung dauerhaften Kontakts.
o	E595	Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment	Prüfmethode für den Gesamt-Masseverlust eines Prüflings durch Ausgasen seiner flüchtigen, kondensierbaren Stoffe in eine Vakuum-Umgebung hinein.
o	E1216	Practice for Sampling for Particulate Contamination by Tape Lift	Praxis der Probenahme partikulärer Kontamination durch Klebefilm-Entnahme (tape lift).
o	E1234	Practice for Handling, Transporting, and Installing Nonvolatile Residue (NVR) Sample Plates Used in Environmentally Controlled Areas for Spacecraft	Praxis der Handhabung des Transports und der Installation von Prüfplatten für nicht flüchtige Rückstände in kontrollierten Umgebungsgebieten von Raumfahrzeugen.
o	E1235	Test Method for Gravimetric Determination of Nonvolatile Residue (NVR) in Environmentally Controlled Areas for Spacecraft	Prüfmethode für gravimetrische Bestimmung nicht flüchtiger Rückstände in kontrollierten Umgebungsgebieten von Raumfahrzeugen.
o	E1559	Test Method for Contamination Outgassing Characteristics of Spacecraft Materials	Prüfmethode für die Ausgasungs-Charakteristika der Kontamination von Materialien der Raumfahrt.
o	F25	Test Method for Sizing and Counting Airborne Particulate Contamination in Cleanrooms and Other Dust-Controlled Areas	Prüfmethode für die Größenbestimmung und Zählung luftgetragener, partikulärer Kontamination in Reinräumen und anderen Staub-kontrollierten Bereichen.

Appendix

Cleanroom consumables specifications
Summary of IEST methods for cleanroom consumables (x)
and other clean room-relevant IEST test methods (o) (extract)

		English (original title)	German (unauthorised translation)
x	CC 003	Garment System Considerations for Cleanrooms and Other Controlled Environments	Empfehlungen für Bekleidungs-Systeme in Reinräumen und anderen Reinheits-überwachten Bereichen
x	CC 004	Evaluating Wiping Materials Used in Cleanrooms and Other Controlled Environments	Die Bewertung von Wischmitteln für den Gebrauch in Reinräumen und anderen Reinheits-überwachten Bereichen
x	CC 005	Gloves and Finger Cots Used in Cleanrooms and Other Controlled Environments	Handschuhe und Fingerlinge für den Gebrauch in Reinräumen und anderen Reinheits-überwachten Bereichen
x	CC 020	Substrates and Forms for Documentation in Cleanrooms	Substrate und Formulare für Dokumentationszwecke im Reinraum (Reinraum-Papier)
x	CC 025	Evaluation of Swabs Used in Cleanrooms	Die Bewertung von Reinigungs-Stäbchen für den Gebrauch in Reinräumen
x	CC 032	Flexible Packaging Materials for Use in Cleanrooms and Other Controlled Environments	Flexible Verpackungs-Materialien für den Gebrauch in Reinräumen und anderen Reinheits-überwachten Bereichen
o	CC 009	Compendium of Standards, Practices, Methods, and Similar Documents Relating to Contamination Control	Kompendium der Richtlinien, Praktiken, Methoden und ähnlichen Schriften in Bezug zur Reinheits-Überwachung
o	CC 022	Electrostatic Charge in Cleanrooms and Other Controlled Environments	Elektrostatische Ladungen in Reinräumen und anderen Reinheits-überwachten Bereichen
o	CC 023	Microorganisms in Cleanrooms	Mikro-Organismen in Reinräumen
o	CC 031	Method for Characterizing Outgassed Organic Compounds from Cleanroom Materials and Components	Methoden der Charakterisierung ausgegaster organischer Stoffe von Reinraum-Materialien und Komponenten
o	CC 040	Cleaning of Equipment Surfaces in the Cleanroom and Controlled Environments	Reinigung von Geräte- und Maschinen-Oberflächen in Reinräumen und anderen Reinheits-überwachten Bereichen

