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Cleanroom Consumable Products

Part 1 - Wipers and Paper

The Influence of the Cleanroom Consumables Quality on the Process Yield • Quality Optimizing • Quality Testing

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Introduction

The category *cleanroom consumables* includes wipers, paper, gloves and cleanroom clothing. However, this first part of the essay will deal exclusively with *cleanroom wipers* and *cleanroom paper.*

Cleaning by wiping has been a fundamental part of human civilization for thousands of years. Today it accounts for a considerable portion of people‘s working time. Worldwide about 4 thousand millions of square meter of nonwoven materials are annually being converted into wipers, which have a value on the market of over 3.7 thousand million US $. Therefore, it seems somewhat astonishing that neither the physical, nor the chemical, nor the industrial sciences have ever considered the process of *cleaning by wiping* important enough to invest in fundamental research activities, to gain more knowledge about the mechanics of this kind of cleaning.

Even in our HiTech day and age, in several special areas, methods of cleaning by wiping have become established on the highest technical level. This is true in particular for *cleanroom-wipers.*

Recording information which accompanies a physical or technical process is as old as paper itself. Think of Gallilei's notes about the processes of the mechanics of the planets. For years it has been said that the computer would soon replace paper. Until now, however, the demand for cleanroom paper has risen each year. Thus, for this material one has need for deeper physical and chemical knowledge, if one wants to avoid mistakes in its HiTech-application or assessment.

Cleanrooms are to be found for the most part in the semiconductor, computer, pharmaceutical, or optics-industries. The materials, as well as the production and testing methods which are used in these industries, differ considerably from those in the fibre-material-based industries of textiles and paper. Therefore, there are often misunderstandings with respect to appropriate product use and with respect to the application of user tests, meaningful for *cleanroom wipers* and *cleanroom paper.*

This essay intends to show the user technical relationships and practical solutions for choosing cleanroom consumables. At the same time it will point out safe, practice-oriented methods for simulating performance tests.

The Cleanroom Consumable Products

which are referred to in this essay are listed more precisely as follows:

Cleanroom wipers

- *Standard wipers*
  Absorption of liquids, removal of particles, grease, pastes and paints, cleaning of work surfaces, glass surfaces and tools

- *Equipment wipers*
  Cleaning of instruments, apparatus, and the interiors of machines (Equipment)

- *Optical wipers*
  Cleaning of optical glass surfaces, mirrors and polished devices

Sources of Particles in the Cleanroom

- *particles imported*

  air in the external cleanroom
  air in the internal cleanrooms
  deposits on clothing
  inert gas and etching gas particles
  particles in the process media

- *particles generated*

  human breathing
  material attrition of the consumables
  migration through clothing
  reactive products of the process
  attrition caused by the conditions of the process
  growth of fine material substance

Table 1 Source of particles in the cleanroom

- *Floor-cleaning wipers*
  Removing and absorbing the contamination from cleanroom floors which often have a sharp-edged, perforated structure

Cleanroom Papers

- *as running protocols*
  which accompany the manufactured product in a multistage production as forms, usually DIN-A5 sized sheets which are bound together as logbooks. There the technical data of the various production lots are recorded

- *as information carriers*
  inside the cleanroom, as e.g. operation manuals of machines and installations

- *as interleaving*
  to separate stackable, flat products and protect the surfaces

- *as notebooks*
  with back-binding to hold and look up notes and memos

The Function of the Cleanroom

The cleanroom fulfills the task of keeping airborne and creeping particles away from the product during the production process. Industrial production processes take place in cleanrooms, because with a normal production environment the process-yield would be considerably less. Such processes are e.g. the production of optical components, integrated semiconductor circuits, data storage devices (hard-disks), hybrid circuits, micromechanical components, Liquid Crystal Displays and data carriers (i.e. compact disks).

Particles in the air are not the only contaminants which can diminish the process yield. In semiconductor production, for example, there are also particles of inert gases, etching gases, process agents such as deionized water, acids and lyes, as well as reactive products which are generated during production, for example etching residue and polymers for lacquer removal. Last not least there are cleanroom consumables and people who breathe and wear clothing. The „cleanroom" is, in reality, two or more interconnected clean volumes. (Fig. 1)

In the „external" cleanroom in which people move about, there are machines, apparatus and devices which maintain a high degree of cleanness in their interiors. They constitute a multitude of *internal* cleanrooms. Even cleanrooms are only *relatively* clean. A certain amount of remaining contamination is unavoidable even there. The contamination of the external cleanroom penetrates in part into the free volume of the internal cleanrooms (equipment). How much of it enters depends on how the internal cleanroom is protected against the contaminants coming from the external one. This *sluice factor* has been significantly improved in recent years by the equipment manufacturers.

The contamination of the cleanroom can be divided into two categories:

- *suspended particles* in the air of the cleanroom
- *particle residue* on the surfaces of the cleanroom

The *suspended particles* are held to a reduced level which is permanently monitored by a filtering-system (filtered incoming air > contaminated outgoing air).
The *surface-contamination* cannot be measured quantitatively. However, its amount is much greater than that of the suspended particles. Both *contaminants* - suspended particles and surface-contamination - are not distributed in the framework of a comprehensible mathematical function. Through variable bonding or anchoring conditions the particles are continually released from their resting place on a surface and then borne into the air. At the same time air-borne particles are sedimented in order to find a resting place on a surface again. Also, particles and other contaminants are transferred by the contact of people and their clothing with the cleanroom surfaces. The *cleanroom consumables* are especially involved in this kind of contact-particle transfer and abrasion.

The Risk of a Lower Process Yield

Because of the higher standards of cleanness in a cleanroom, the consumables used there differ significantly from those which are used in *non-clean* manufacturing-processes. The contamination which is being generated by using cleanroom consumables is, in essence, *fibre and particle attrition*, which - as part of the particle circulation immanent to the cleanroom - in the worst scenario can get onto the surface of the product and ruin it. In other cases, especially by using wipers which are not optimal, the waiting periods until expensive equipment can operate again after service-cleaning can be prolonged considerably and cause the down-times to rise. That is why cleanroom-wipers should be made in such a way that the release of particles, fibres, fibre fragments, chemicals and surface residue

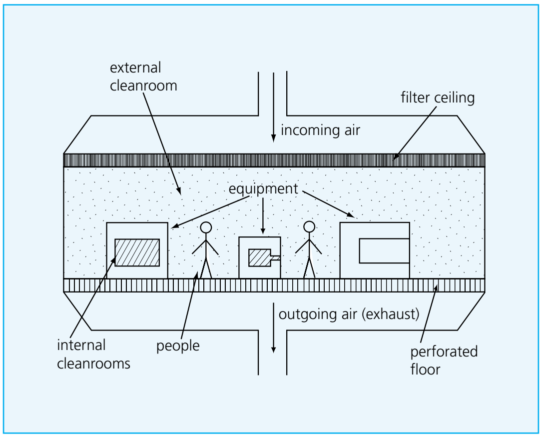

Fig. 1 Contamination in the cleanroom (schematic representation)

can be avoided. Even if this is not completely attainable, it is an important part of a diversely contrived *strategy of avoidance* with the aim of keeping the process-yield as high as possible. If and up to which quality level of the consumables this *strategy of avoidance* is justified has not been investigated to the knowledge of the author.

In the reference literature no information could be found which would prove a definite dependence between, for example, wiper construction and process result (see fig. 2).

However, cleanroom engineers agree, based on their experience, that e.g. decontaminated knit-type wipers made from polyester-yarns (equipment wipers) release fewer particles upon use than, for example, polyester-cellulose-nonwoven wipers (standard wipers) and for this reason they are to be preferred for critical cleaning processes.

The constructive and qualitative composition of cleanroom wipers can be divided into two categories with respect to their detrimental effects on process costs:

- *Process group I* - Processes with a definite dependence between the quality of the wipers and the process costs
- *Process group II* - Processes with a hypothetical dependence between the quality of the wipers and the process costs

Both process groups will be discussed in greater detail as follows:

Process Group 1 - Processes with a *definite* dependence between the quality of the wipers and the process costs:

One example for the *definite* dependence of the process costs on the quality of the wipers is the preventive maintenance of plasma-etching machines. While running, these machines can get very soiled. For this reason they undergo preventive maintenance in rotation. For that, they are disassembled and then cleaned in an etching process and rinsed. The parts which cannot be disassembled are cleaned with the aid of cleanroom equipment wipers. After reassembling them, the devices are cleaned again with wipers. Afterwards the devices are conditioned by pumping them down to a high vaccuum level and venting them. Then a test wafer is inserted into the device, and its contamination is measured after venting. By using insufficient wipers fibre fragments from it on the surface of the test wafer can be observed. This process is repeated until the quantity of particles and fibres is so small that the equipment can be allowed back into operation. If wipers are used in this process which do not have a sufficiently high degree of cleanness or which are not abrasion resistant, the number of pump and vent cycles increases considerably and so does the downtime of the plasma-etching machine. Such machines cost about 1.2 million US $ and the downtime costs per hour are correspondingly high.

In this example *wiper costs* play hardly any role if the equipment can be back in operation somewhat earlier because of a *higher-quality-wiper.*

Another example for process group I is cleaning printing screens for printing hybrid cicuits in the electronics industry. In this process electrically conductive pastes are printed onto a ceramic substrate by a screen-printing process and subsequently they are thermally hardened.

In the screen-printing process it happens that the pastes dry out on the screen, and partic-

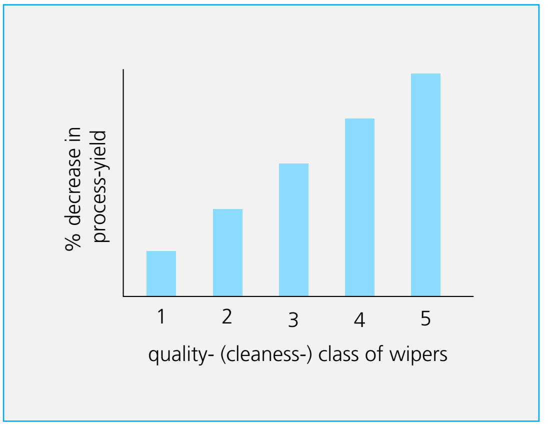

Fig. 2 Example of a hypothetical function of relating the wiper-quality to the process-yield (1 - ultra-fine knit, washed, sealed; 2 - knit, washed, sealed; 3 - knit, washed, unsealed; 4 - nonwoven, sealed; 5 - nonwoven, unsealed)

les on the screen prevent the precision of the printed picture. In both cases the paste must be removed from the screen by cleaning it, often with the aid of wipers. If these wipers tend to abrade fibre fragments or meso-particles, a decrease in process-yield is immediately noticeable. In this way a large German manufacturer of hybrid circuits could increase the process-yield by 35 % just by using more appropriate wipers. Here also, the price of the wiper does not play any role if the savings are many times that of the increased wiper costs.

Further examples could be mentioned for cleaning laser mirrors, and for optical glass in the processes of manufacturing flat screens. The same is true for the manufacturing processes of assembling storage disks. *Cleaning swabs* are often used here, and what is true for wipers is essentially true for them. There are many processes in which the use of improved (and thus more expensive) wipers can lead to considerable savings in the area of reducing scrap.

Process Group II - Processes with *hypothetical* dependence between the quality of the consumables and the process costs:

In general, all processes belong to this group which can be damaged by air-borne particles or particle migration on the surfaces, but by which a definite relation of the *process costs : quality of the consumables* cannot be established. The cleanroom consumables described in this essay consist essentially of fibrous materials (textiles, paper). By nature, these have a soft, porous composition and tend to fibre- and particle-abrasion upon use or upon contact with other surfaces. Thus, they are amongst the contaminants of the cleanroom. How many particles and materials with a chemical content may be released for a decrease in the process-yield really to occur? That is the *central question for optimizing materials and costs* for this group of products. What would be ideal is a possibility of directly relating the quality of the cleanroom consumables to the variation in the process-yield (Fig. 2).

Cleanroom consumables, however, are only *one of several* sources of contamination in clean industrial processes. A relation of defects in the manufactured products to different groups of the defect particle source is therefore difficult and mostly impossible. The defect-density-engineer can rarely be sure - and if, only with very large particles - if a defect particle, which has the form factor of a fibre fragment, comes, for example, from a wiper, from cleanroom underwear, from a cleanroom garment, or from cleanroom-alien products.

The second law of thermodynamics states that the *entropy* (disorder) of an isolated system will continually increase unless work is performed to maintain order. If one looks at the cleanroom as an isolated system, it follows that to maintain cleanness (order), it is necessary to put in work.

In this sense, two systems exist which considerably reduce the particulate but also liquid and pasty contaminants (disorder) in the cleanroom on the way from their origin to the place where they can harm the product.

- Laminar airflow

The transfer of undesirable material from cleanroom consumables into the cleanroom occurs almost continually, but the cleanroom itself must be seen as a cross-flow filter with a large separation capacity (see Fig. 1). This is because a considerable portion of the air-borne, particulate contamination present in the cleanroom is led off by the laminar airflow into the area of the floor and taken up by the exhaust airstream underneath the floor. The cleaning factor therewith amounts to circa a class leap i.e. 10 particles > 0,5 µm per cubic foot near the filter ceiling and 100 particles measured in the area of the floor to be lead off. The cleaning efficiency of the laminar airflow amounts to about 90 %.

- Cleaning by wiping in rotation

For the surfaces in the cleanroom a cleaning-by-wiping operation is usually planned in rotation, whereby the cumulative contamination is reduced time after time. By this method an infinite increase in surface contamination is prevented. A portion of the cleanroom wipers used are for this purpose.

The origin, source, ways, whereabouts and removal of contaminant particles in the cleanroom are in physical terms too unclear to be comprehensible for each individual contaminant group. Thus, many of the assumptions regarding the causes of particle-bound defects of manufactured products are hypothetical and have to be considered.

The compulsion to such a hypothesis of a physical occurrence always shows a deficiency of knowledge, but the fact of the physical occurrence and its effects on the process remain nevertheless.

The risk to clean production processes by particulate and surface contamination has been mentioned in the reference literature many times. In recent years the risk of such contamination has been significantly reduced by improving construction of the equipment. At least in semiconductor production the product has been shielded more and more from a natural production environment during the critical process steps. With SMIF technology, for example, the product hardly ever comes into contact with the normal atmosphere during the process.

User Attitudes

In the semiconductor industry, the reduction of risks through expenditures on equipment on the one hand and the pressure to reduce costs on the other hand have resulted in a discussion about *using cleanroom consumables of reduced price (and quality).*

Cleanroom engineers can be generally divided into four groups of opinion regarding their view about the minimum limits for the acceptable quality of cleanroom consumables

Attitude 1 -

The *absolute avoidance strategy*: With the insignificantly small portion of the costs of cleanroom consumables of < 1 thousandth relative to the total production costs of a wafer FAB and yet the high exposition time of this material to the operators, it is sensible to use the best and purest material available (by wipers e.g. the exclusive use of high-quality, washed knits in the entire production). The constant intensive discussion about the use of cleanroom consumables of lesser quality is more expensive than the possible resulting benefits.

Attitude 2 -

The *statistically based middle course*: As long as a direct ratio between the *degree of cleanness* of the consumables and the process-yield cannot be calculated with a justifiable expenditure of time and money, cleanroom consumables of a medium to good quality should be used, which have proved their value over the long periods of time. Consumables of a lower quality or assumed quality are rejected because of a possibly increased risk to the process-yield. The basic idea is not the actual damage which occurs but the increase in the *statistically based risk*. The experience expressed here is that even small supply problems result in costs which quickly exceed the savings made by purchasing material of even the lowest quality.

Attitude 3 -

The *course of co-ordinating proportions*: This group believes it is nonsense to use consumables of high cleanness if e.g. the operators wear clothing which does not have the same level of cleanness. Or, for example, that it makes no sense to use low-ion paper in a production where no gloves are worn. The co-ordination of the quality of cleanroom consumables, they believe, should be oriented on the existing surface cleanness of the production environment. The component with the *least* surface cleanness is made the standard on which the quality of the cleanroom consumables should be based on.

Attitude 4 -

SMIF - The separate unity of product and environment: Wherever the product does not come into contact with the natural environment, but is produced in closed mini-environments, there is actually hardly any risk. Inexpensive consumables could balance out a portion of the increased costs for the cost-intensive production environment.

World-wide there is no agreement among users on which of the four attitudes listed above is the right one. Because no one can bring any counterevidence to the controversial opinions mentioned, it is finally a matter of faith which kind of consumables are actually chosen. This general lack of orientation has certain disadvantages: one of them is that the users feedback to the manufacturer does not take place, which normally would happen in advance of an innovation for improved products.

Common Ground

Several fundamental principles can be put forth which all four of the above user attitudes would accept:

- A certain measure of yield-relevant contamination by the consumables exists. It is not known at this time, however, in which magnitude.
- The material should be as good as necessary - as inexpensive as possible.
- If the price is the same, the better material should be used.
- If the price is the same, the more comfortable material should be used.
- If there is a risk to health, the better material has to be used.

From experience in the development and application of cleanroom consumables, the author would first like to list the possibilities (see Table 5) and then state appropriate limits in the framework of four theses.

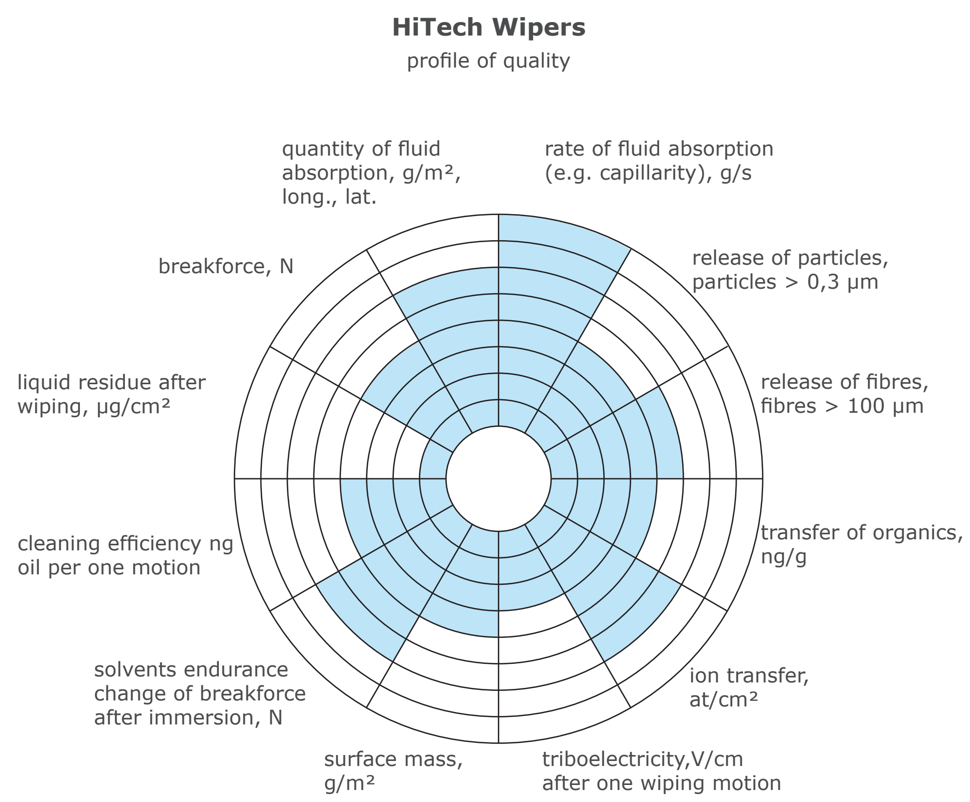

Fig. 3 The circle profile allows a quick comparative survey of the qualities of various HiTech-wipers.

Cost-Saving Methods

A study on the topic wipers from the recent past shows alternative possibilities of cost-saving for *cleanroom wipers*. It shows the way from exclusively focussing on the material price to a more superordinate way of looking at the whole block of costs for *cleaning by wiping*. There the author stated that in the framework of *cleanroom maintenance, availability near the workplace, optimization of cleaning time, the secure extraction of individual wipers, the optimization of the degree of wiper-dampness, and the disposal* of wipers far greater cost-saving potential exists than would ever be possible through material price reductions.

Here conflicts of interest often exist between the production and the purchasing departments of FAB-companies. An acute saving in purchasing - *even if it is very small* - is always more transparent and at hand than a saving in the production area - *no matter how great it is*. This is because the production department of the companies - aside from occasional suggestions for improvement by the staff - normally does not have any form of presenting cost-savings in the framework of technical facts. Many mistakes are made in this area in all kind of industries. In the study already mentioned, the author proves that with workplace costs of 1.30 US $ per minute in the German semiconductor industry, a cleaning operation with a wiper costs on the average 1.04 US $ including material costs, whereby the average material costs for a wiper are below 0.10 US $.

Before the material-bound cost block is being reduced from 0.10 US $ to 0,08 US $ - with a possible increase in the risk of added contamination, it would certainly make much more sense to reduce the production-bound cost block from:

- cost for one wiping operation	1.04 US $
- cost for materia	0.10 US $
- working cost	0.94 US $

to say 0.75 US $ for example, because this area has a much greater potential.
That would be:

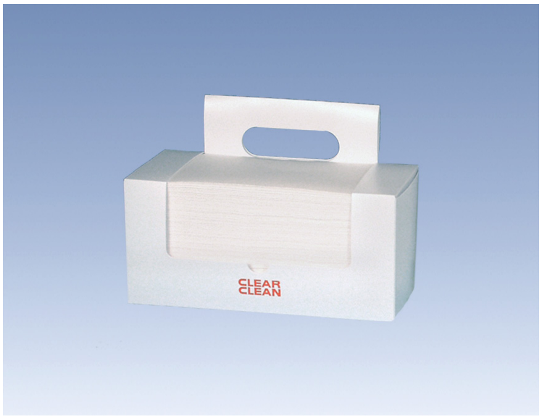

Fig. 4 A handy box-construction containing cleanroom wipers can be transported easily to any place in the FAB where cleaning is necessary.

- *Reduction of taking two or more wipers by using the appropriate dispenser*
- *Reduction of the time taken to fetch the materials by setting up more dispensers closer to the workplace*
- *Reduction of the time needed to look for the materials by setting up more dispensers closer to the workplace*
- *Reduction of the moistening time by using pre-moistened wipers*
- *Improvement of the dampness-homogeneousness by using damp cleanroom wipers or spray bottles with a droplet diameter above the aerosol limit*
- *Increase in cleaning efficiency by using wipers with a high dry-wipe capability*
- *Increase in cleaning efficiency by appropriate operator training*
- *Reduction of the disposal time by increasing the number of disposal places*

Manual cleaning is amongst the most time- and cost-consuming jobs in all areas of industry. That must be taken more into consideration. The technical possibilities of cost-saving are not sufficiently used, because it is perhaps connected at first even with an increase in material costs; and the cleanroom technician often does not have the courage or experience to support such a measure and not the time to present it to the management.

Possible Material Choices

Which alternative materials are available on the market for the user to choose from?

Standard wipers: For the standard tasks of surface cleaning and spill-control in the semiconductor-cleanroom, hydro-entangled spunlace nonwovens made out of a cellulose-polyester mix have gained acceptance nearly everywhere. It is possible to use them without reducing the process-yield even in class 10 cleanrooms. Ten years of experience with this material by many large semiconductor manufacturers support this assessment.

An experiment with wipers consisting of 100% cellulose, which ran over a year in a large German semiconductor plant, was not successful because of the insufficient strength of the material *cellulose* during cleaning, which led to the mechanical destruction of the wiper before the cleaning operation was finished. Thus, a downgrading of these materials motivated by price possibly has its limit not in the area of clean requirements but in the area of mechanical stability.

Some cleanroom operators put viscose in their standard wipers for ecological reasons, or in Japan cupramonium-nonwovens; others prefer spunbonded fabrics from propylene. There have not been any yield-related problems with the millions of wipers made out of hydro-entangled cellulose delivered to a German semiconductor factory. In the future, the differences in standard cleanroom wipers will not be based as much on the construction of the wipers but on *the way they are dispensed and disposed* of. The pioneer of this development was the Bosch company in Reutlingen, which put individual wiper-dispensers in the cleanroom many years ago.

The construction of the lowest quality is at this time a nonwoven wiper with circa 50 % cellulose, the remainder is polymer fibre. The criteria for choosing are:

Standard wipers

- Delivery condition
  - dry
  - moist
- Dispensing form
  - folded flat
  - interfold in a mobile dispenser
  - interfold as refill-pack
  - quarterfold

*Equipment wipers: T*here are about 20 different cleanroom knits available on the global market. These are preferably used for cleaning critical equipment-interior in semiconductor FABs and also by storage disk manufacturers. They vary according to the following selection criteria.

- Washing condition
  - washed
  - unwashed
- Edge cut
  - thermal
  - mechanical
- Delivery form
  - folded
  - as bulk goods
- Delivery condition
  - dry
  - moist

Essential differences exist among the individual products, however, in the parameters particle release, cleaning efficiency, water absorption per time unit, liquid residue on the cleaned surface and triboelectricity.

Even today there are still a few suppliers of unwashed knits and wipers without thermo-fixed edges.

Reusable Wipers

In the framework of necessary cost-saving, the topic of *reusable wipers* has come up time and again for many years. While the topic is not of interest to the semiconductor manufacturers because of the different contaminants which are still present as residue (cations, varnish wastes, etc.) even in recleaned wipers, the manufacturers of storage disks have a certain inclination to the reusable product. The hope of saving speaks *for* the reusable wiper; the subsequent costly handling speaks *against* it. These costs must be included in the calculation of the cost-levels of European cleanroom companies, and this makes the reusable wiper more expensive than disposable wipers.

- Collection of the wipers
- Sorting out „injured" wipers
- Wrapping in a transportable package
- Transport to the laundry and washing
- Drying under cleanroom conditions
- Wrapping in a dispensable package
- Transport back to the place of use
- Testing the cleanness
- Testing the cleaning efficiency

In addition, the collector in charge must be capable of deciding if a wiper has been washed many times before and should be disposed of or if it is still new and hardly used.

Cleanroom Paper

Cleanroom paper (loosely stacked sheets): Cleanroom paper is usually needed as a recording medium for production data. In the semiconductor production the sheets are often near the wafers as process recording data. Cleanroom-paper must be printable in printers and photocopiers. World-wide, there are five well-known suppliers of cleanroom-paper based on cellulose which vary a great deal in quality.

The selection criteria are:

- general criteria
  - toner bonding
  - tear resistance
  - writeability
  - machine operability
- clean-technical criteria
  - particle release - edges
  - particle release - surfaces
  - release of ionic matter
  - triboelectricity (ESD)

It is not advisable to use cleanroom- paper without previous quality testing. The differences in quality of the products of the individual manufacturers are quite significant.

Cleanroom notebooks: General criteria for choosing these products are:

- clean plastic cover
- spiral binding made of plastic
- cleanroom paper inside
- delivery in plastic foil

Downgrading the Quality of Cleanroom Consumables

Whenever facts cannot be gathered in the marginal areas of technical *processes, expert based assumption* comes the closest to the truth. The results of an expert based assumption, while taking a margin of error into account in order to avoid damage to the process, are to be seen as binding until more knowledge is available. This indirect level of knowledge has gained acceptance world-wide in choosing cleanroom consumables. However, this method is only as good as the competence of the people using it. The consumables in current use worldwide best reflect this.
The following arguments are for engineers who sympathize with attitude 3 (the course of reduced means). Differences in the degree of surface cleanness in single process steps or components do not justify the assumption that the whole process can be reduced to the

Wiper (coded)	Fibre diameter in the thread (µm)	Total particles after immersion method (K-Part/m²)	Total particles after bowl method (k-Part/cm²)
CLHDSG	7.6	26.5	1.28
CLHDMG	8.1	21.6	3.12
TEAWPU	11.2	15	8.15
CLMDMG	12.1	11.6	5.95
BSU30U	13.9	2.3	12.01
TEALTU	14.7	3.3	13.58

Table 2 Particle release of different kind of cleanroom wipers (coded)

degree of cleanness of the components with the least surface cleanness. All contamination accumulates, and under the assumption of reduced cleanness in the whole process, damage to the goal of the process *cannot be ruled out*. That means in practice: even if the operator's overall does not correspond to the requirements of surface cleanness, the cleanroom paper, wipers, and all other materials may for that reason not be downgraded to a lesser class of cleanness.

By critically approaching the risk hypothesis, the idea of reducing the material quality to the lowest conceivable limit leads to an instructive imaginary experiment. Reduction to the mini-

Product group	A - high-quality well-known Material	B - next-lower Quality Level	Comments on Downgrading
standard wipers	cellulose-PES-nonwoven in single-sheet dispenser as standard-wiper	woodpulp-PES-nonwoven, flat-layed in packs, wrapped in PE-bag	Multiple extraction increases the wiper costs considerably or prolonged fumbling increases the time costs, but some savings in cost of material
		100% cellulosic wiper	Strength problem with dry use; moist use not possible - deterioration of the wiper caused by friction on corners and edges
			high degree of ionic contamination
equipment wipers	knit, DI-water washed,soft-edge sealing, folded, high thread density	knit, DIW-washed, no edge sealing	loose fragmented mesh increase cleaning time
		knit, DIW-washed, soft-edge sealing, bulk-packed (unfolded)	If enough special dispensers are provided in production, savings are possible.
		knit, DIW-washed, hard-edge sealing, bulk-packed	Possible damage to sensitive surfaces by hard sealed edge; savings possible by bulk-packing instead of flat packing
		knit, DIW-washed, edge-sealing, lower thread density	Increased residue after moist wiping results in more contaminant residue and significantly longer wiping times. Grease layers not completely removed.
		thermobonded nonwovens, washed, soft-edge sealing, folded	Savings possible as compared to knits, but lower strength of material limits application.
floor wipers	wipers made of thermo-bonded nonwoven fitted to a floor-cleaning device	floor-cleaning wipers of cellulose-PES-nonwoven	strong wear even after brief use; completely unsuitable for perforated floors with sharp edges of the holes
		reusable, woven floor wipers	possibly even after brief use much fibre attrition and therefore drastically increasing quantity of particle-remains
cleanroom paper	decontaminated low-ion and low-particle paper; high tear resistance and light marking dye	non-decontaminated, low-ion and low-particle paper; high tear-resistance, light marking dye	less expensive, but edge contains more particles and fibre fragments; for running protocols doubtful; in SMIF-environments possible
		non-decontaminated paper, high tear resistance with high content of ions and particles	hardly less expensive than A; no real savings; In the cost-benefit analysis probably not profitable.

Table 3 The Effects of Downgrading the Quality of Cleanroom Consumables

mum limit would mean:

- Tissue-paper instead of a polyester-cellulose wiper
- recycling paper instead of cleanroom paper
- never using gloves in production
- never wearing cleanroom clothing
- wearing street shoes

If one went one step further, one could also imagine:

- working in unfiltered air

Assuming that all of these steps are theoretically feasible without any bad effects, the fact still remains: *concrete knowledge* about the effects on the process-yield would only be available *after* the experiment had been running for a long time.

A cleanroom manager is hardly imaginable who would be willing to operate a wafer factory, with construction costs of a thousand million DM, under the minimum conditions mentioned above for two years- and then *possibly* to find out, that he had saved some money in consumables, but the wafer factory has to be closed for four months for *general cleaning*.

As an alternative to the imagined possibility of operating a factory with minimum-quality consumables, one can also imagine the possibility of reducing the quality of the consumables slowly over a longer period of time until acute risk cases occur. Thereafter the quality of consumables could subsequently be slightly raised again.

The execution of this idea founders on fundamental, physical facts: the contamination of a cleanroom is in principle an infinite, progressive, additive process. This progress is hindered by removing the contaminants, that is by carrying out the periodical cleaning. Reducing the amount of contaminants takes place in intervals, so that their accumulation to the point of being potentially damaging can be prevented. If the condition of acute risk through the slow accumulation of particulate contamination would have been reached, the elimination of this condition would only be possible over a longer period of time and the result would probably be a 5 month closure for a gerneral cleaning . Here a fundamental rule of cleanroom technology can be put forward: *The work needed to bring about particulate contamination on surfaces is always many times less than the work needed for its elimination.*

Three Theses of the Author

- Thesis 1: *If complete insight into a technical process cannot be expected for a long period of time, then one has to act according to the least risk of potential damage shown by anticipation. That means in particular: As long as proof of the opposite cannot be brought, one has to assume that cleanroom consumables present some risk to the process yield and act accordingly.*

- Thesis 2: *Because of the possible accumulation of negative influences on the process, the cleanness of consumables cannot be oriented on the process component with the least surface cleanness.*

- Thesis 3: *The costs of cleanroom consumables can be looked at under two aspects:*
  - *Under the aspect of risks to the process (yield costs) and*
  - *under the aspect of handling (time costs).*

Today, the possibilities to reduce process costs are considerably greater in the area of reduced time costs than in the area of reduced material costs.

Quality Testing by the User

New or improved cleanroom consumables meet with varied acceptance by cleanroom engineers and cleanroom managers. The time period between presenting an innovation and introducing it into practice is often unnecessarily long. The user always justifies this with the reason that the new or improved product must first undergo *technical user testing* before it can be approved for use or not. But other hurdles as well, such as little interest in product change, pretended high testing costs and the blunt demand for price reductions which derive from them, or even the assertion problems of cleanroom engineers with the purchasing department or with the staff are reasons why technical innovations in the field of cleanroom consumables have only slowly found their place in the companies.

This essay describes the real facts of a possible user testing with the example *cleanroom wipers* and shows perspectives for a rapid and transparent evaluation of the product for the benefit of all the participants. The technical features of cleanroom wipers can be divided into three groups with regard to their ability to be tested (Table 4). They are:

- features which are easy for the user to test
- features which are more difficult for the user to test
- features which cannot be tested by the user

A semiconductor manufacturer, for example, usually has neither the equipment nor the trained examiners to test the fundamental technical features of the textile product *wiper (breaking load, ultimate elongation, liquid absorption as a whole, absorption rate, liquid residue after wiping)*. He has e.g. the equipment to count the particles for the features *particle release* and *fibre release*, but he does not have the equipment for *particle collecting.* For the range of meso-particles above 100 µm, he usually has no equipment available at all which could give reproducible results. For the rare tests which the user would make in the field of cleanroom consumables, the acquisition of equipment or specialist staff is not justifiable, if only because of the costs. Thus, he cannot run most of the product tests in his own location and must make a choice, which is shown in Table 5. This table shows which tests are feasible for the user and which are not.

But even with *simple function tests* in the production environment, experience shows that great problems arise with a meaningful, neutral - and therewith useful - evaluation of

	technical features of cleanroom consumables	**testing in the laboratory at the user's location**		
		possible	hardly possible	impossible
1	area mass	Δ		
2	thickness			Δ
3	breaking load, machine and cross-direction			Δ
4	elongation break, machine and cross-direction			Δ
5	total water absorption	Δ		
6	capillary water absorption			Δ
7	half-time of water absorption			Δ
8	liquid residue after wiping			Δ
9	particle residue after wiping		Δ	
10	triboelectricity, charging level			Δ
11	triboelectricity, discharge time			Δ
12	cationic transfer		Δ	
13	anionic transfer		Δ	
14	cleaning efficiency (for particles)			Δ
15	cleaning efficiency (for pasty layers)			Δ
	possible visual function testing in a production environment			
18	solvent distribution in double-folded wiper after wetting	Δ		
19	liquid residue on the surface after wiping	Δ		
20	absorption of a given quantity of liquid in double-folded condition (number of wiping motions)	Δ		
21	removal of a grease layer from a mirror	Δ		

Table 4

the product. The testing level of the user is usually not up to the technical standard of the product. Several reasons for that are listed below:

User testing of the quality of cleanroom consumables is not based on measurements, but on human observations, experience, and feelings. If one wanted to reach a relatively meaningful result on this basis, about 160 tests by different persons would be necessary to be convincing inside normal tolerance limits, according to the opinion of the anthropological institute of the University of Kiel (Dr. Helbing).

Textiles are by nature somewhat non-homogeneous materials. In many tests of textiles, variation coefficients of around 30% are looked upon as normal. That means that one must make at least 5 individual tests in order to have a test result inside a tolerance of about 20 %. The required number of individual tests would thus increase once more. Many cleanroom-engineers do not have the time for that, and, of course, not the experience in textile-testing methods.

Measuring means *comparing to a certain reference datum*. In practice, the reference datum in *user tests* is a combination of experience and wishful thinking. The product is „good" if it corresponds to the good experiences the examiner has made with that particular or similar products. If the examiner has little or no experience with such products, wishful thinking and imagination often replace experience.

The „measuring instruments" in such testing are the human senses. The most important technical parameters of cleanroom wipers, however, cannot be perceived with the assistance of the human senses.

The results of testing in the production environment cannot easily be expressed in numbers. In practice, *dot scales* (from 1 to 5) are often used for that reason in order to translate an evaluation made by observation, experience and feeling onto a linear-structured scale. This form of presentation is supposed to raise the value of the results from being unmeasured or unmeasurable to the level of digital information of supposedly higher credence. But the assignment of the recorded phenomena to the various groups of the scale occurs on a *subjective* basis.

The author has experienced that the user tests of a certain cleanroom material in a semiconductor factory showed as a result that it was an exemplary product with reference character. In another factory of the same company exactly the same product was evaluated as the worst on the market and was rejected for purchase.

Faulty Testing Methods

Especially in the area of *testing the particle and fibre release* of wipers, a great deal of uncertainty exists among the quality-examiners. This has its cause in the astonishingly faulty perception of the cleaning-by-wiping process by an American private institute (Institute of Environmental Science), which gives recommendations for testing cleanroom wipers and is sponsored by individual companies of the U.S. industry. Here is the idea on which the test published there (IES-RP-CC-004-87T and RP-CC-004.2) is based:

If a cleanroom wiper is immersed in distilled water and the number of particles thereby transferred into the water are counted, then one gets a reference for the „particle-release-quality" of this wiper.

This idea is physically completely erroneous, because in the wiping process two surfaces come into frictional contact: *the surface of the wiper and the surface to be cleaned*. In the course of this, material abrasion takes place.

There can be no material abrasion while immersing a wiper into water, but there is, rather, a washing out of the particles into the surrounding liquid. That is a completely different physical occurrence. The results are therefore also very different, even contradictory (Fig. 5).

In 1990, Laban, Arrelano et al. stated that after a dry wiping process on surfaces of the least roughness (wafer-surfaces), all wipers, regardless of their construction and their washed-out condition, left the same quantity of particles on the surface [Lit. 1].

Possibilities	positive	negative
accept the technical statements of the product manufacturer	little work	uncertainty concerning the truth of the statements
contract a scientific institute to run comparative tests	neutral comparative results	expensive, quite a lot of preliminary work to define the task for the institute
run the tests in the consumables manufacturer's laboratory with your own, (prior-coded) samples	inexpensive, trained personnel, routine testing methods	if the samples are not well-coded, the manufacturer (laboratory owner) finds out the test results of the competition's products

Table 5

In 1993, the author expanded the Laban experiment in that he carried out the wiping processes on various rough surfaces and set the released particles in relation to the strength of the textile material which was used in manufacturing the wiper (Fig. 6).

Although Laban's and Labuda's work was known to our American friends, they did not want to stop this obscure IES immersion method. The IES (Institute for Environmental Science) has not reacted until now (1999) in any case.

According to our experience, the mechanisms of cleaning by wiping can be seen as follows:

In the *dry wiping process* an interaction between the relevant surfaces takes place first:

1. The active surface (wiper) comes into contact with the particles present on the passive surface. A portion of these are bonded by means of the Van der Waals forces to the fibres of the wiper. Another portion is mechanically bonded.
2. At the same time, the dry wiping process generates triboelectricity through friction, and electrical fields are built up which are dependent in their strength on the fibre material. They are also dependent on the chemicals which are normally present on all thermoplastic wipers for hydrophilization.
3. *Particulate abrasion occurs* depending on the strength of the material, the chemical composition of the wiper fibre, and the roughness of the passive surface. At first the particles of the chemical surfactant of the textile are abraded and then, with increased rubbing, parts of the fibres themselves.
4. A large portion of the abraded particles and fibre fragments, however, are bonded again to the wiper surface in the same wiping process. This recapturing effect, as described by the author, essentially determines the quantity of particles left on the passive surface.

In the *moist wiping process*

1. The Van der Waals forces do not appear.
2. No electrical fields are built up.
3. However, with only partially moistened wipers, electrical fields are built up depending on the extent of the dry area [Lit. 2].
4. Overly moist wipers have by far less cleaning efficiency than dry wipers.
5. Moist wipers show greater material attrition on rough surfaces than the same wipers in a dry condition.

Subliminal Influences on the Test Results

If a test engineer expresses his or her opinion about the sample product to a second person, the formation of the second person's opinion about the product is dependent to some extent on the opinion of the first person. It can be approval, disapproval, or at best neutrality - according to the personal relationship and degree of dependence between persons 1 and 2. The inner presence of this relationship toward each other or against each other often completely covers over the inner presence of the testing task.

By people in general, wipers are found to be „good", the softer and more „natural" they feel to the touch. This is true as long as no material content is visibly released. Experience shows that these components go into the judgement of a wiper more than any other considerations. However, it is a fact that soft materials in particular show the greatest invisible particle and fibre attrition.

If the manufacturer of a product is known to the examiner or examiners, a positive image of the manufacturer has a considerable influence on the quality the examiner decides on. However, the image of the manufacturer is dependent on the fulfillment of the user's expectations. Often, these are not exclusively related to the product quality and effectiveness in practical use. Technical dissidents - even if they are evidently much closer to the truth - occasionally have a negative image. Yes-men frequently have a positive manufacturing image, even with little product efficiency.

The user cannot be expected to constantly concern himself with tests of new materials or with known products developed by manufacturers new on the market, testing takes time and binds the staff to this task. They might be more productive somewhere else.

On the other hand, it would be foolish not to monitor the developments on the market, turning away from all innovation going on, just so that one would not have to test anything anymore. There is a good way of establishing whether a manufacturer's new product should be tested:

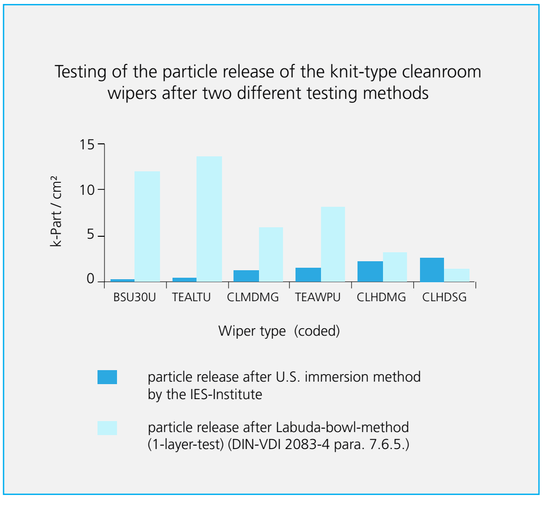

Fig. 5 Results of measuring the parameter particle release of several known cleanroom wipers after two different testing methods

That is a questionnaire in which the manufacturer is asked to compare his innovation to the standard technology and to point out the additional benefits. If this questionnaire indicates that the innovation could be promising, then one should test immediately.

Most manufacturers' offers to the user, however, do not request testing for innovative reasons but rather in order to make themselves known, or because of a supposedly better price. Here the cleanroom engineer must be able to distinguish which products testing would be meaningful.

In the field of cleanroom consumables there are world-wide only two manufacturers who do intensive research. Three other manufacturers do not pursue systematic research, but they are capable of recording a large portion of the technical data of their products. Of the five mentioned manufacturers, only one is in Europe, and the remainder are in the U.S.A. In addition, there are a multitude of companies world-wide, which declare their products as cleanroom consumables, but neither have quality controls for clean production processes nor an experimental laboratory for clean textile materials. Concerned users do of course not purchase the products of these manufacturers.

Summary I
(concerning choice of materials)

- The existing cleanroom consumables have established themselves in price and in their cleaning efficiency over a long period of time. From the established manufacturers a significant reduction in price could only be expected with a corresponding downgrading of the technical standards of the material.

- Occasional price reductions could be expected from manufacturers who do not have any mentionable R & D capacity and/or advanced manufacturing and quality control technology. Of course, such companies lack the inventiveness, the expertise, and most often the capital to invest in the more interesting cost reductions in the handling sector of cleanroom consumables.

- These are improvements in the dry-wipe capability, homogeneously moistened wipers in quick access containers, increased cleaning efficiency for equipment wipers, screen-cleaning wipers with significantly lessened screen-cleaning time in the field of circuit printing and hybrid technology.

- Many possibilities exist to deduce the costs of consumables, which are based on changes in their *construction, delivery condition* and *availability in the production environment*. Almost 90 % of the possibilities for a reduction of costs lie in this area and not in the cost of material.

Anybody who buys a motor-car wants to know e.g. its maximum speed, fuel-consumption, accelleration etc.

It is remakable that in hundreds of discussions with the users of cleanroom wipers the only question has been for price and not for performance. And this despite the fact that a large user needs in excess of one million wipers a year. That means one million times a year a person uses extremly valuable time for cleaning-operation.

Summary II (concerning user testing)

- User testing of cleanroom consumables without proper test-equipment and specification or without a statistically sufficient number of samples is worthless, even dangerous for the wrong conclusion it might lead to.

- The test engineer of the user should never know who the manufacturer of the sample-product is (coded samples).

- A qualified and renowned manufacturer usually knows more about the individual aspects of the quality of his products than an examiner of the user. Therefore, it is sensible and time-saving to include the manufacturer of the product in the product-testing before it begins.

- If the requirement of *coded samples* is strictly fulfilled, no objection need be made against a test at a consumables manufacturer‘s laboratory. It makes much more sense to test it there with the testing equipment available, than implementing own user tests without the appropriate equipment or experienced personnel.

- The comments of the user‘s production staff who use the products to be tested daily often contain valuable advice on the *practice-oriented* features of a product. The user‘s staff should not, however, be employed as *examiners*, because they are usually not specialists *in this field.*

- The decision about which consumables should be used in a cleanroom should be made only by a qualified and respon-

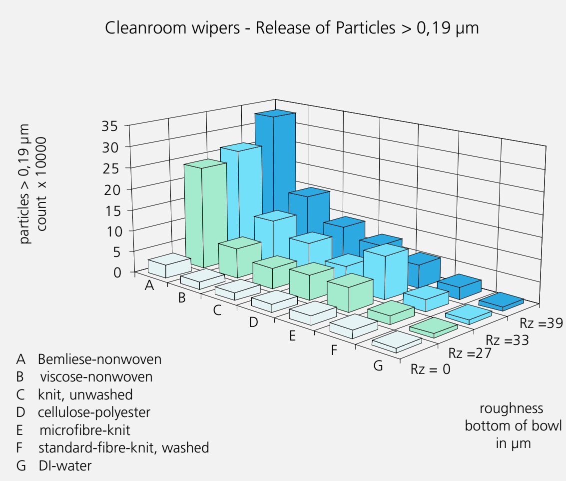

Fig. 6 Release of particles >0,19 µm depending on the textile material used and the roughness of the wiped surface

sible *cleanroom-engineer*. With products in which comfort criteria have a role in the choice, cleanroom material-managers should also have a say. Integrating all other possible members of the staff with an opinion in order to win support for the decision should be avoided.

- The results of a test should *definitely* be discussed with the manufacturers of the tested products. Keeping test results secret from the manufacturer is a relic from the past. It is in the interest of the examining user to get a critical feedback of his testing modalities and results. The examiner should therefore be obligated to cooperative action.

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