
Fig. 1 Stretchbond gloves

The term protective glove is normally associated with protecting the human epidermis from outside influences. But in the high-technology manufacturing environment it can be just the other way round: the product must be protected from skin contaminants during the manufacturing process. Skin abrasion, greasy scum, bacteria or virus can endanger the required surface cleanliness of the manufacturing environment or even the product. For these reasons, wearing protective gloves is considered to be indispensable in most high-tech factories.

Protective Gloves in Clean Technology

Elastic Barrier between Person and Product

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Manufacturing Methods and Basic Materials

In manufacturing protective gloves for clean technology, various manufacturing methods and basic materials are utilized, which the product descriptions of such products denote:

- *Film gloves manufactured in a form-dipping process:*

In this process, a number of ceramic forms modelled after the human hand go through a bath of the liquid basic material e.g. a latex-suspension. After the hand forms are covered with the liquid material, they pass a vulcanisation tunnel and then become an elastic film on the hand form. There they are stripped off manually and collected in large containers. After that, the whole batch of gloves is washed with DI water in a suitable machine and then dried and packed.

- *Latex gloves:*

Very elastic gloves made of natural or synthetic rubber. Standard glove type of HiTech-industries. Contain proteins, however, which can possibly cause allergic reactions.

- *Nitrile gloves:*

Elastic gloves made of nitrile-butadiene-rubber. Normally contain fewer proteins than latex gloves. Are somewhat more expensive. Also may cause allergic reactions.

- *Vinyl gloves:*

Less elastic gloves made of polyvinyl chloride. They contain plasticizers which can in time be perspired out. By contact with surfaces one can observe the forming of streaks. They are often very thin in the fingertip area. Vinyl gloves fit less well on the hand than latex and nitrile gloves.

- *Film gloves manufactured by the cutting-welding process:*

In this manufacturing process the gloves are made of two films or nonwovens superimposed. The basic hand-forms are stamped out of the sheets with heated contour-milled tools and at the same time they weld together at the form edges. Such gloves are easy to package because they are flat.

- *PE gloves:*

Non-elastic film gloves very well-tolerated by the skin. Such gloves are not ideally adapted to the curvature of the hand. They are worn in the cleanroom for short lengths of time (see paragraph: gloveless manufacturing). They are rather inexpensive.

- *PU gloves:*

Elastic nonwoven (Polyurethane) gloves, very well-tolerated by the skin. Through the pores of this elastic polyurethane nonwoven material, the moisture of the skin evaporates naturally and no sweaty feeling is generated. These gloves are relatively expensive, but they can be worn longer and they can be washed several times. Ideal for employees with problems of the skin.

Special cleanroom gloves

This group includes sewn cotton and polyester gloves, high temperature and cold resistant gloves as well as solvent-, acid- and lye-resistant gloves. Apart from the sewn polyester gloves, the clean technical requirements for these special gloves are seldom very high. Particularly with the chemical-resistant types, however, barrier resistance is of special significance. In Asian countries, sewn polyester gloves are utilized in many cases. They consist of closely-meshed knits or wovens and have the advantage that they may be washed several times. Besides that, they are very comfortable because of their porosity and the low degree of vapour blockage which goes with that. A Japanese company has developed a machine which can manufacture a closely-meshed, seamless knit glove on whose inside hand a coat of polyurethane is applied.

Latex-Glove	**Mio Part > 0,5 µm**
1	0.185
2	0.391
3	0.481
Bare Hand	
1	2.223
2	1.58
3	1.15

Fig. 2 Particle Generation in Comparison Latex Gloves / Bare Hands. Test method: Dipping the hand / glove 3 times into a DI water bath Following that, microscopic particle evaluation of the filtrate

Quality testing of cleanroom gloves

A certain problem for the cleanroom user is the clean-technical quality assessment of the gloves received. A large part of the world supply market is concentrated in Asia, with Malaysia as the largest supplier. Even well-known non-Asian brands, some of them with their own manufacturing plants, buy rather large amounts as a supplement when required. When an order from such countries of manufacture is not delivered according to specification, a substitute in a matter of days is usually not possible. The investigation of a complaint can take several months in Asia. Moreover, a clean-technical problem arises in the context of glove manufacture: in manufacturing latex, nitrile or vinyl gloves, the ceramic glove forms are normally powdered with cornstarch to reduce the adhesion of the gloves to the ceramic form and to enable the vulcanised gloves to be more easily stripped off. This is the reason for the general contamination of the manufacturing environment with cornstarch powder

in many factories. To be sure, factories which chiefly manufacture gloves for medical examinations and cleanroom gloves utilize the corresponding decontamination processes (washing the cleanroom gloves several times). But because the proportion of cleanroom gloves is often less than 5 percent of the total amount produced, the problem of cornstarch powder is not easily solved by the manufacturer. The as-received quality of cleanroom gloves thus varies greatly (see Fig.2).
Because of this, it is understandable that users wish to conduct their own tests to build up a long-term quality profile for the product of their choice. Most often, however, the user lacks the equipment and the experience in technical testing. Large quantities of highly contaminated gloves get into the HiTech manufacturing environment. For reasons of safety, a solution here could be to contract a special laboratory with the corresponding equipment and specific experience. On a regular rotation basis, the laboratory could test the gloves delivered and check if they were cleanroom quality. (Ref. 1)
The REM photos by Yuko Labuda (Fig. 3 - 7) clearly show the cleanroom critical structures of the surfaces of different types of cleanroom gloves.

There are at present three important criteria for testing cleanroom gloves. The gloves should be:

- nonallergenic
- made of strong material
- cleanroom compatible

The classification nonallergenic is based on medically known, empirically established figures for various raw materials such as latex, polyvinyl chloride, polyethylene or polyurethane used in glove manufacture. They cannot be technically tested by normal means. Only statistically relevant test series are meaningful. Several dermatological clinics in Germany have access to the relevant statistics.

The strength of the material can be determined using known test methods.
But in order to test protective gloves for their clean-technical suitability, well-conceived methods and special equipment are needed. As in the area of HiTech wipers, it is not enough to analyse the number of particles on the surface of the product and to conclude its cleanroom compatibility from that result. Quite a number of features of material strength are not insignificant in determining how suitable the gloves are for the cleanroom:

For example, the number of so-called pinholes and their diameter is important for a clean-technical material test. This is because after a certain wear time, hand perspiration collects on the inside of the glove and can get to the outside through the pinholes. Hand perspiration contains a lot of sodium ions that in e.g. semiconductor production are undesirable. Perforations of the glove material due to mechanical strain during work also occur. Roger Welker (Ref. 2, 3, 4) reports about two tests of barrier strength (unfortunately without statistical details). In the first one, after two hours 70% of the gloves had a leak and in the second test 57 %.

The same is true for the cutting strength of the glove material. Especially the fingertip area of the thin-walled gloves is critical, be-

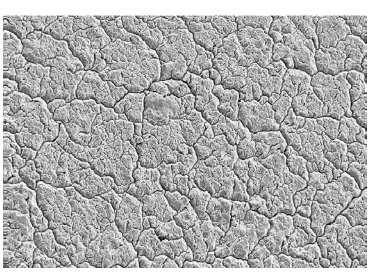

Fig. 3 Structure of a latex glove, surface magnified 400 times, REM photo: Yuko Labuda

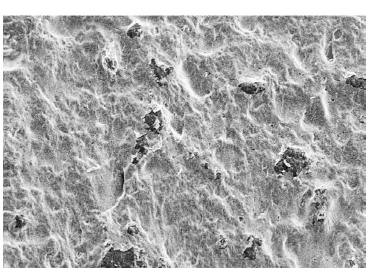

Fig. 4 Structure of a vinyl glove, surface magnified 400 times, REM photo: Yuko Labuda

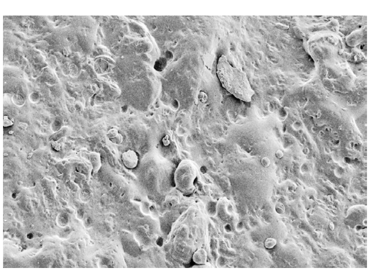

Fig. 5 Structure of a nitrile glove, surface magnified 400 times, REM photo: Yuko Labuda

cause here sharp-edged fingernails often have an effect like knives when pressing or pulling at surfaces through the glove. The gloves thin-walled material between 25 and 50 µm thick can be destroyed very quickly. On the other hand, just this range of thickness is required to retain the sense of touch.

The glove material's resistance to chemicals is of clean-technical significance, too. Even brief contact with some solvents, acids or lyes alters the surface structure of the glove in the sense that it softens. When the material and the surfaces come in contact after that, a greasy smearing effect can result.
A meaningful test for clean-technical quality in protective gloves must be oriented on the maximum strains which occur in practice in the context of important parameters.
These practical maximum strains have to be identified to work them into a meaningful testing method. In the framework of test procedure they may not be exceeded by more than 25 %.

The IES (Institute of Environmental Sciences), USA has developed a method to test gloves (IES-RP-CC-005-87-T) which describes the testing of a multitude of features. According to this method, the glove being clean-technically tested for its particulate contamination is dipped into DI water and then shaken there for ten minutes. The particles released from the surface of the glove into the water are counted. In principle, this is a well-known testing method in clean technology. Whether it is really useful for protective gloves must be shown in a special study of the correlation between the washed off particles and the number of particles transferred to the surface by contact. When measuring the contamination of the glove surfaces by dipping the test sample into DI water, it is important to consider that the *washed off glove surface* is appreciably larger than the *actual surface* involved in contact transfer. Contact transfer only takes place in the area of the inside flat of the hands, and there in particular in the area of the fingertips and the balls of the hands. This results approximately in the anatomically determined position of the hand when cleaning by wiping (Ref. 2).

A meaningful test method must therefore include the following parameters:

- the actual contact transfer of particles > 0.5µm in the context of normally practised activities
- the contact transfer of organic matter from the glove material in the context of normally practised activities

These tests should also be conducted after contact of the glove surface with such media that, experience shows, alter the surface structure of the polymer. The continued use of the glove would possibly lead to altered particle transfers or to grease smears from organic matter.

In his interesting series of three essays on cleanroom gloves in the American journal Micro Magazine, Roger Welker describes various approaches for test methods. In his essays he mentions residue density oriented test methods, but he also describes transfer oriented methods. He is the only author who has objectively analysed the problem of contamination, decontamination and recontamination during the wear time of the cleanroom gloves. Due to his contributions we learn many interesting details about the product cleanroom gloves that we did not know prior to that.

In the context of assessing the surface cleanliness of

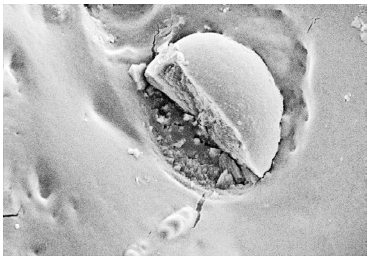

Fig. 6 Surface of a nitrile glove, magnified 3,800 times, particle formation in the vulcanising process, REM photo: Yuko Labuda

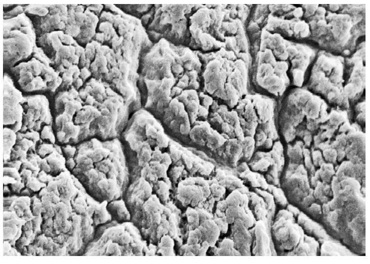

Fig. 7 Surface of a latex glove, magnified 3,800 times, distinct groove formation, REM photo: Yuko Labuda

gloves, one thinks first of the ultrasonic-supported washing off of particles in DI water. This, however, does not work in testing natural latex gloves, because the latex is rapidly damaged by ultrasonic waves. For counting the particles, liquid particle counters (LPC) seems at first to be most suitable because these work fastest. In the experiment in which the particles were counted by the LPC, however, there were gross errors, probably because of air bubbles in the test chamber. This was the case even when a vacuum- or ultrasonic degassing had taken place. Moreover, such counters generally do not work together with liquids containing surfactants.

In several series of experiments, we discovered that dipping the glove three times in 18.2 M-Ohm DI water plus 0.03 wt % surfactant yields repeatable particle releases. It must be noted however, that particles released into DI water must be extracted through a micropore filter.
The filter evaluation can be done microscopically-visually or using electronic image analysis.

Welker also reports about a test of the release of ions from protective gloves. In that experiment, a glove was filled with 18 M-Ohm DI water and sealed at the opening where the glove is pulled on. After that it is exposed to a temperature of 60°...80°C for one hour. After cooling, the DI water is investigated using ion chromatography for anionic residue. In the results chlorides and sulfates dominated. In addition, particle concentrations of > 8,000 particles/cm² with a particle size of >0.8 µm Feret-diameter were counted. It seems to the author that such extraction methods demonstrate an excessive degree of simulation because in practice no glove would be used at these temperatures and at the same time in a liquid environment with extraction character.

An interesting test method for the ionic barrier function of cleanroom gloves was suggested to the author in a conversation in 1986 by Mr. Wolfgang Kraft, at that time at Intermetall in Freiburg. After a cleanroom glove has been worn for one minute, it is dipped into a bath of 18.2 M-Ohm DI water. Following that, the water is analysed using conductometry, ion chromatography or with AAS for metal ions. The same test is conducted after the glove is worn for 30 minutes. Significant differences indicate a strong ion migration. This inevitably affects the contact transfer of ionic contamination.

Collecting and recording relevant data about organic microlayers cannot be mastered qualitatively with standard measuring methods. Quantitatively, however, it is possible, using the Anaplate-System invented by the author (Ref. 6), to make contact transfers visible down to the magnitude of a few nm layer thickness. This seems sufficient to be able to make practice-relevant statements.

Cleanroom gloves and electrostatics

As the author already described in detail for the product cleanroom-wipers, protective gloves also number among the supplies used in the cleanroom that are ESD-critical because they consist of synthetic materials and constantly come into contact with other surfaces. In addition, gloves are often the contact point over which the electrical charge equalization of a person takes place. The HiTech-products that are endangered in the manufacturing process by charges of protective gloves include wafers, magnetic heads, solid state lasers, etc.

As of the time of publication of this paper (June, 2000), only triboelectric charging in kV (e.g. produced in a drop slide after Ehrler) and discharge time can be used as meaningful parameters, according to our experience. A detailed description of the method is found in the references (Ref. 7). We did not recognize the parameter surface resistance as reliable. It therefore is excluded from our appraisal of the ESD-qualification of cleanroom products. It seems to be essential that all tests made in connection with ESD take place in a temperature/relative humidity chamber (TRH) cham-

	Particles
As received	175
After washing	3
After 5 minutes cleanroom-use	50
After 20 minutes cleanroom-use	90
After rewashing	3

Fig. 8 Cleaning Gloves while worn (after Welker / particles > 5 µm diameter per cm²)

ber and that they are conducted for example, at 40% relH and +20° Celsius or at 25% relH and +20° Celsius. In the context of cleanroom gloves and ESD behaviour, Hartkopf, Heymann, Lehmann, Newberg and Welker have made an interesting contribution, also citing the discharge time as the essential test feature (Ref. 5).

Studies examining the discharge times of nitrile, latex and PVC gloves were made under varying wearing conditions. The wearing of glove liners was also taken into account. The results are summarised below:

- Discharge times increased considerably when the test subject did not wear any grounded wrist strap. No subject without a wrist strap was able to attain the discharge times required by the HiTech-industry.

- Discharge times decrease when nitrile gloves are chlorinated according to manufacturing guidelines

- Discharge times for PVC gloves did not change in relation to the ambient air (12%: 50% relH). For the nitrile gloves, the change in the discharge times was more pronounced. The difference was greatest for unchlorinated gloves and the least noticeable for the gloves that were chlorinated inside and out. All four tested glove types exhibited discharge times of < 500 ms for a voltage drop from 1000 to <10 V.

- Wearing glove liners generally lengthens the discharge time. Even with them, however, this stays within the bounds of < 500ms for a decrease from 1000 to <10 V.

- Discharge times decrease when glove liners are worn and stabilize after a wearing time of about five minutes.

- Gloves that are already contaminated exhibit considerably higher discharge times than gloves in as-received condition.

- Gloves washed in DI water have slightly better (lower) discharge times than unwashed gloves

Cleaning gloves while worn

In his paper, Welker reports about the possibility of cleaning the protective gloves sporadically during work, thus reducing particle contamination of the surface considerably. By simply rubbing the hands under a stream of DI water the count of transferred particles was reduced. Using a Hamamatsu wafer inspection system, this reduction was recorded - from 175 particles per cm² to 3 particles per cm² for particles with a diameter > 5 µm. To collect data about the recontamination of washed gloves, after 20 minutes of cleanroom work the surface cleanliness was measured again. It turned out that the particle contamination count had returned to approximately half of that of the as-received condition even after this short time. This is shown in Fig. 8.

Attempts to persuade cleanroom operators in the United States to plan a glove-washing procedure at certain intervals in the work process came to nothing, because the operators were very reluctant to organize the work in this way. Three kinds of glove washing were tried:

- occasional washing

- occasional touching of a sticky mat with the glove (particle reduction of about 40%)

- cleaning the gloves with a HiTech-wiper

While the second option failed because of some opposition amongst the operators, for the third option it was not possible to find low-cost, premoistened, disposable wipers on the market that could ensure the desired cleaning effect.

Hypoallergenic protective glove

Such gloves differ from latex, nitrile, or vinyl or polyetylene gloves in the following ways:

- They allow the skin to continue to „breathe“; perspiration occurs to a far lesser degree and the notorious build-up of heat when wearing the gloves is greatly reduced.

- They are very elastic and fit the hand-form well.

- They are hypoallergenic, i.e. extremely seldom do they cause allergies.

- They can be washed repeatedly. Due to the pore structure of the nonwoven material, the inside of the glove is also automatically washed in the washing procedure.

Because of their porosity, these gloves let liquids permeate through. They are therefore not suitable for work in wet- or chemical-process areas. The disadvantage of a high price seen at first is balanced almost completely by the fact that the gloves generally last longer and can be washed several times. When the significantly higher wearing comfort of the PU glove for the employee is taken into consideration as well, the advantages outweigh the disadvantages.

These gloves are also available made of a 25µm thick film on the inside of the hand, combined with a PU nonwoven on the back of the hand. This combination is better suited for working with moist workpieces and/or with cleaning-wipers, for example.

In the future, a statistically based study should provide information about whether or not this kind of gloves transfers comparatively larger amounts of particles and/or ions and organic contaminants to the surfaces of the environment during work. Moreover, it must first be known to what extent transfer occurs with the other kinds of gloves.

Wearing comfort versus glove costs

There is a natural conflict of interest between the desire of the cleanroom owner to limit costs and the staff‘s desire for more wearing comfort of the protective clothing in general. Only the person who has once worked for seven hours wearing tight-fitting overalls or protective gloves made of PVC or latex can judge which adverse effects that has on working comfort. In this context it is interesting to note that to date, the factory personnel committees have not yet addressed this explosive issue. The topic is often a matter dealt with by the company‘s physicians, thus putting it in the category of anomaly or illness. If it does not come under the competence of the physicians in the company‘s internal organisation, then it often comes under the competence of the safety engineers. But even this group is not committed to the non-numerical factors of wearing comfort and contentment. In general, this perception that it is an anomaly or safety issue impedes product development directed toward protective clothing with a higher level of working comfort. Strictly speaking, this subject should be delegated to a factory committee consisting mainly of staff members who have to work the whole day while wearing this kind of protective clothing.

Meanwhile, however, there are quite a number of large cleanroom companies for which protective gloves are a central issue and which utilize PU-nonwoven gloves throughout their entire production. In Germany that includes a large, southern German high-technology company and a chip manufacturer, who utilizes such gloves in backend operations. In England, a well-known manufacturer has been utilizing PU nonwoven gloves throughout their entire production for a long time.

The concept of „gloveless“ manufacturing in semiconductor cleanrooms

At Infineon AG (formerly Siemens AG) „gloveless“ manufacturing has been in operation since 1992. In principle, in the cleanroom production of semiconductor wafers it is essential to keep the wafer surface away from contaminants from the human hand. That usually occurs by wearing gloves. But one can also choose another option. For example, when transporting the wafer carrier, the operator can hold the wafer carrier by using a carrier handle at a sufficient distance away from the body.

„Gloveless“ manufacturing does not mean that not a single glove is utilized in this manufacturing. In procedures where carrier handles are not used, the operator puts on a low-priced polyethylene glove which he or she wears only for the duration of performing the task, pulling off the glove and disposing of it afterwards. These skin-friendly, non-irritating polyethelene gloves cost only about one-fourth of the price of nitrile gloves. It is possible that from this employee-friendly work model, a basis for an industry-wide abandonment of wearing protective gloves could result with regard to many work procedures in cleanroom technology. This seems especially feasible where semiconductor-cleanrooms are equipped with a SMIF system. Besides, the demand for gloves is reduced by about half in cash value, which is also interesting from the aspect of overhead expenses.

In the past, it was often doubted whether the Infineon concept was a genuine alternative to the glove concept, without reducing again the benefit of the defect-density increase accompanying it. A test conducted by the Fraunhofer Institute for Integrated Circuits in Erlangen has confirmed Infineon's (Siemens') years of experience. For information on this topic see (Ref. 8).

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