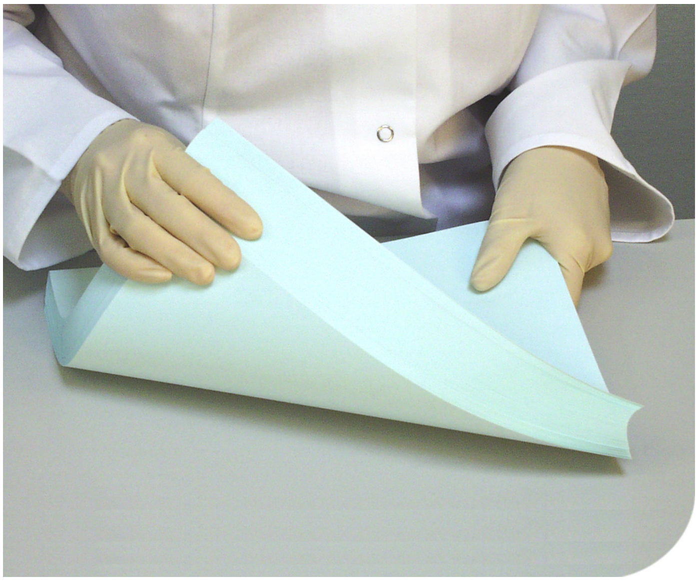

In cleanroom operations, as in all HiTech manufacturing, a busy exchange of information takes place. This can be staff-information, equipment manuals, machine performance data, installation data, consultation notes, drawings or sketches and frequently also lot-accompanying protocols for the manufactured products. All of this information is stored and distributed inside and outside of the cleanroom on the most mobile data carrier in the world - paper.
An additional application of clean paper is the separation of specific clean-technical products which are not allowed to be stacked flat on top of each other either before, during or following production, for example, silicon wafers. Here cleanroom paper sheets often serve as separating leaves to protect critical product surfaces from scratching.

Cleanroom Paper

Mobile Data Carrier in cleanroom operations

Win Labuda
Clear & Clean - Research Laboratory

There are two kinds of cleanroom paper. The first kind consists of cellulose and has a distinct paper character. The other kind consists of plastic and is, strictly speaking, not paper. For economic and environmental reasons, it was not able to gain acceptance on the market. Moreover, it cannot be used with the high-temperature fusing rollers in laser printers. This essay therefore deals exclusively with cellulose paper.

Cleanroom paper used for documentation comes in two forms, as stapled loose sheets (Fig. 1) for the printer or photocopier or bound as cleanroom notebooks (Fig. 2). Such notebooks must have cleanroom-compatible qualities. Opening the cover or turning the pages must allow as few particles as possible to be released. For these reasons such notebooks have a spiral binding made out of plastic wire. The covers consist of plastic suitable for the cleanroom and are made with rounded corners. The inside pages are cleanroom paper sheets printed as a grid. Such notebooks come in various sizes from DIN (German Industrial Standard) A4 to A7. They are for making handwritten notes or rough sketches in the cleanroom. Both a requirement profile and a performance profile can be drawn up for cleanroom paper.

The requirement profile results from the necessity for cleanliness in the processes of clean manufacturing. The performance profile, on the other hand, is based on the technical possibilities of the five-step paper manufacturing process. These are:

- pulp processing (grinding, colouring)
- sheet making and smoothing the surfaces
- treatment with a latex coating
- formatting
- decontaminating

Essentially, the top cleanroom papers on the market today (October 2000) have almost identical requirement and performance profiles. Papers of this class leave hardly anything to be desired. Some of the papers on the world market are not quite top-notch, however. Thus, quality-conscious engineers are challenged to make the right choice for their manufacturing purposes.

Of course, paper used in a clean work environment must have a clean composition. Not only should it have a high level of surface cleanliness in its as-delivered condition, but it should also release only small amounts of particles or fibre fragments into the environment whilst being used in the cleanroom. Moreover, it should have additional quality features that are not required of standard paper.

The essential features are summarised as follows:

- high surface cleanliness
- high edge cleanliness
- low triboelectric chargeability
- low amount of ions
- satisfactory tensile strength and
- low tendency to split

Cleanroom papermaking

Prior to the manufacture of cleanroom paper, a decision has to be made on the kind of fibres to be used and the degree to which these fibres are to be ground. Production aids in normal papermaking, like china clay additives used as fillers, have to be ruled out for this manufacture. As far as possible, this is also true for ionogenic bleaching processes and additives which have ionogenic characteristics.

Cleanroom paper is produced in rolls of about 4 meters width and 2.5 meters diameter. For

Fig. 1 cleanroom paper (loose sheets) in shrink foil packing

Fig. 2 cleanroom notebooks with spiral binding

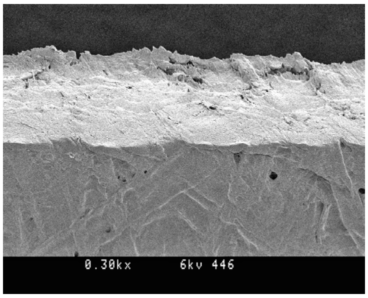

Fig. 3 edge of paper by manufacturer 1, (300 x)

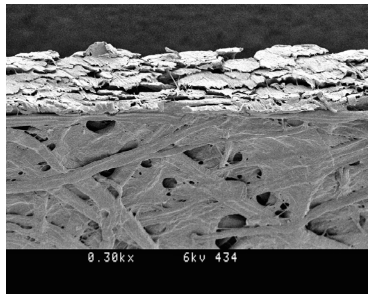

Fig. 4 edge of paper by manufacturer 2, (300 x)

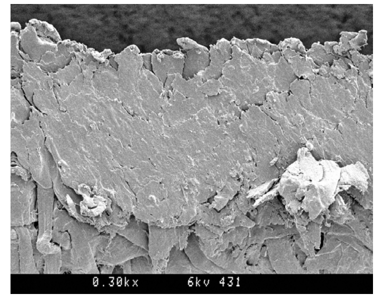

Fig. 5 edge of paper by manufacturer 3, (300 x)

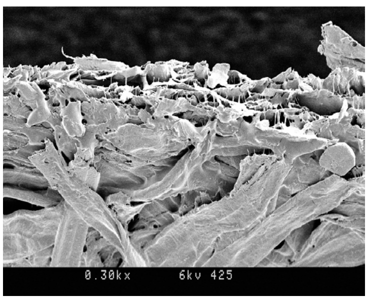

Fig. 6 edge of paper by manufacturer 4, (300 x)

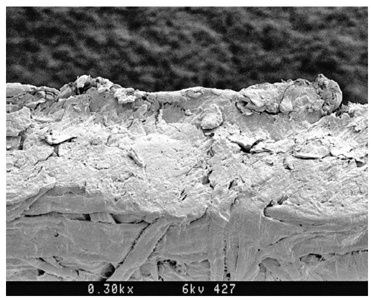

Fig. 7 edge of paper by manufacturer 5, (300 x)

better handling, these rolls are then divided into three smaller rolls, for example. Thus, about 80 to 100 tons of raw cleanroom paper with constructive characteristics for later use as cleanroom paper are produced in one single batch. In a subsequent operational step, the paper on the roll is coated with a specially made coating low in ions. Manufacturers of cleanroom papers use elastomers for that, coating the cleanroom paper on both sides. These are usually carefully chosen latex compounds, customized for this special application. The coating is carried out with the purpose of securely binding the particles naturally found on the surface. As a result, a large portion of the pores of the paper are closed. But although the latex treatment promotes the cleanliness of the paper with regard to its further use, it creates other problems along with that by automatically increasing the triboelectric chargeability of the paper

After the batch of cleanroom paper is dried, it is converted from the roll to flat stacks. In a subsequent conversion procedure - the most critical - the stacks are cut to a DIN-A4 or DIN-A5 format. This step essentially determines the degree of surface cleanliness of the edges of the formatted paper. With top-quality cleanroom papers, special techniques of format cutting are used to keep the amount of particles and fibre fragments on the cutting edges of the stacked paper at a low level. The ready-to-sell stacks of paper with 500 sheets of 100 g paper have a height of about 6 cm. With a DIN-A4 format size, that corresponds to a critical, highly particle-contaminated surface of about 600 cm². The amount of the remaining contamination in the vicinity of the edges varies with the method of cutting that was used. Depending on the method, the particle count on these surface edges differs in a ratio of 1:5 between high quality and lower quality cleanroom papers. From the viewpoint of a paper manufacturer, there is a very small world-market for cleanroom paper and therefore there are only five known manufacturers worldwide. The surfaces and edges of their papers were photographed with an electron microscope. The results are shown below (Fig. 3-12, SEM photos: Yuko Labuda).

Clean-technical test methods

Cleanroom paper is one of the large-surfaced products that permanently pass the cleanroom area - exactly like overalls or wipers. Therefore the cleanroom engineer should give this product due consideration in his *clean-concept*. That also means knowing the quality features of the utilised papers.

One of the essential requirements of cleanroom paper is its low particle release during use. Three possibilities of how cleanroom paper can be a source of particles are:

- because of the condition of the surface
- because of the condition of the edges
- through the release of toner particles after printing in the photocopier/printer

As a consequence, it is necessary to measure and record the surface cleanliness of the paper. In this context, an older American test method for cleanroom wipers (IES-RP-CC004) is occasionally referred to that is also often used for the clean-technical qualification of cleanroom wipers. The test sample is immersed in a bath of deionized water and shaken (biaxial shake test). As an alternative, the method allows carefully pouring DI water over the sample and subsequently recording the amount of particles in the DI water. The particles that were released during the pouring of the DI water are filtered off, and the filter is evaluated microscopically. In our laboratory experiments up to 1995, we had immersed the samples three times and then let them drain. But in doing that, variation coefficients beyond the 40% mark resulted. After we had reduced the number of immersions from three to one, the variation coefficients fluctuated between 5.6% and 31.3%. In the measurements we took in our laboratory according to this method, we had to follow the immersion and drain time schedules very strictly. Otherwise unacceptable inaccuracy was the consequence. Fig. 13 shows the results for five cleanroom papers of different manufacturers in comparison to standard office paper.

The cleanroom user is rarely able to test the clean-technical quality of cleanroom paper in as-delivered condition by himself. In most cases, the special equipment needed for that is lacking, as well as staff trained along those lines and a data base for a comparative assessment. For this reason, it is better for the user to cooperate with a manufacturer of cleanroom paper who, on the basis of his *in-house analytic laboratory*, is able and willing to furnish proof of quality and to constantly improve the product.

The test method mentioned above, which is only conditionally reliable, shows the number of particles released after briefly immersing the cleanroom paper into DI-water as a result. Unfortunately, this is not exactly what the user wants to know. The basis of the quality assessment should

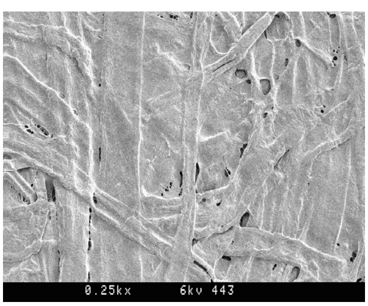

Fig. 8 surface of paper by manufacturer 1, (250 x)

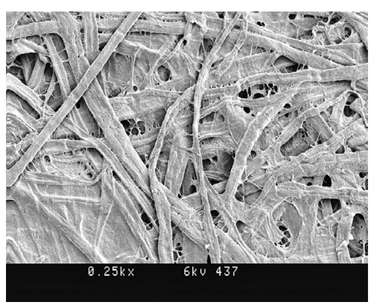

Fig. 9 surface of paper by manufacturer 2, (250 x)

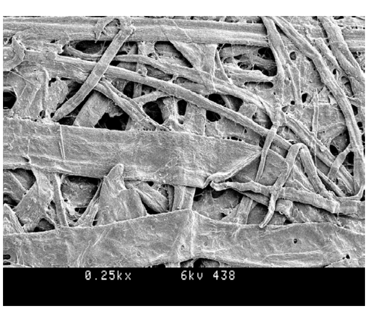

Fig. 10 surface of paper by manufacturer3, (250 x)

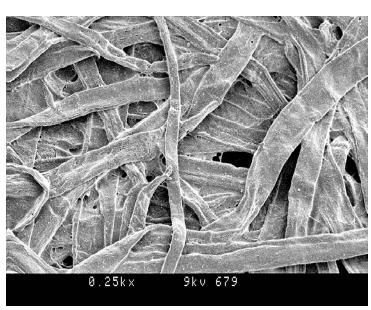

Fig. 11 surface of paper by manufacturer 4, (250 x)

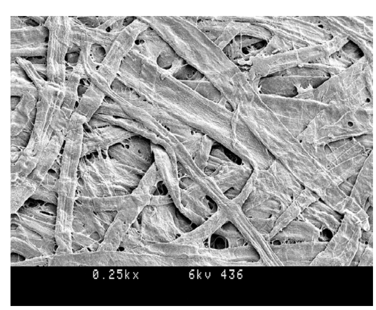

Fig. 12 surface of paper by manufacturer 5, (250 x)

instead be the amount of particles released at the papers regular handling and their size and distribution. But at present there is no such test method that satisfactorily simulates the handling of the paper as actually used in the cleanroom. The reason for that is in that the transfer of particles from the paper to other cleanroom surfaces occurs in two ways:

- *first, as contact transfer from the paper surface to any other cleanroom surfaces*
- *and second, as particle detachment from the paper. These particles simultaneously become airborne and are then sedimenting.*

To date, no test results regarding the distribution in percentage of the two means of contamination are known to the author. Moreover, the essential argument against the immersion method remains that the nature of the sample is changed during immersion into DI water whereas the product in practical use never comes into contact with water.

A semiconductor-manufacturer in Japan reports about an in-house test method by which an ultra-clean wafer is pressed against a sheet of cleanroom paper with a defined amount of pressure for a certain defined period of time. Before and after the test, the number of particles on the wafer are counted and the difference is calculated. At first this test seems to offer a very plausible simulation of the transfer of particles from the cleanroom paper to other surfaces. Upon close inspection, however, the contact transfer seems to depend on many parameters: the electric charges of the paper as well as those of the wafer surface, the roughness of the paper surface, and even the humidity of the paper. Provided that all of these parameters could be controlled, one could investigate if there would be a low-enough variation-coefficient to justify. If that was the case, the Japanese method could be an interesting possibility of recording contact transfer.

Particles are located on all of the surfaces of a stack of paper, yet they are most frequent along the cutting edges. To our knowlege, there was no safe method for testing the surface cleanliness of the cutting edges of stacks of paper. Therefore, we had to develop our own method. The result was a collecting device for particles on surfaces (PART-LIFT™ particle collector) [4]. This can be described as a lift-limited spring punch designed furnished with an adhesive front plate. When this device is pressed onto the sides of a paper-stack, the loose particles bind to the adhesive front plate of the collector. The front plate is darkly coloured and can now be examined and evaluated under a microscope. The pictures in Figures 14 and 15 show microscope photos of particle layers which were taken up with the Part-Lift™ collector from the cutting edges of a stack of paper, before and after decontaminating the edges.

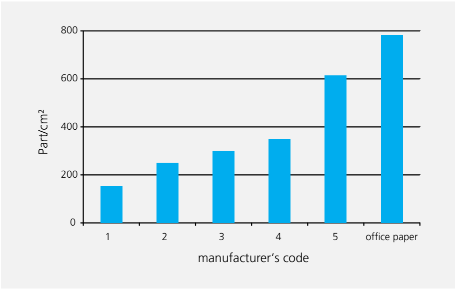

Fig. 13 comparison of particle release of cleanroom paper and standard office paper
(5 various manufacturers plus standard office paper), immersion method

Particles released from cleanroom paper into a cleanroom cannot necessarily be equated to e.g. polymer particles in their effect on the process taking place. Because of the way it is manufactured, paper as a material always contains a relatively high proportion of sodium ions, thus representing a potential risk for semiconductor and wafer production processes. In this sense, released paper particles are also released ions. The better the cleanroom paper, the fewer ions it contains. Measuring the kind of ions contained in cleanroom paper can be done without any previous preparation by means of electron dispersive x-ray analysis (EDX). Figures 16 and 17 show corresponding diagrams.

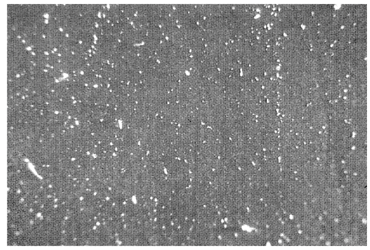

Fig. 14 microscopic photo of the cutting edge of a stack of paper before decontamination

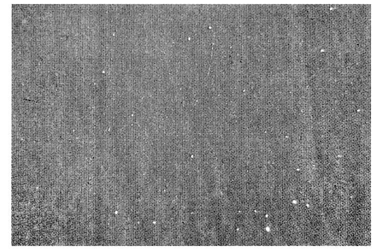

Fig. 15 microscopic photo of the cutting edge of a stack of paper after decontamination

Cleanroom paper in the printer and the photocopier

Cleanroom paper is often used for printing in office printers or photocopiers. These are usually constructed in such a way that the paper transport from the stack of paper into the printer or photocopier is implemented by a rubberized feed gear, whereby the top sheet of paper is transported against the second sheet. During this process a lot of friction develops between the moving sheet and the paper stack. The triboelectricity that is produced increases the slide inhibition between the individual sheets of paper and a jamming of the paper feed occasionally occurs. In such cases, it is usually assumed that cleanroom paper is the sole cause of the problems which have arisen.

In principle, the reason for the faulty paper feed is that the slide inhibition is too high between the sheets of paper lying on top of one another. However, there are several possible causes of that:

Experience shows that the main reason is storing the paper open for a long time in heated rooms with relatively low humidity and the drying out of the paper associated with that. Dry paper is much more rapidly triboelectrically chargeable as damp paper. There are modestly-priced paper dampness gauges for large-scale users of cleanroom papers to ensure interference-free copying operations during the winter months. Additional causes of jamming are:

- the adjustment of the pressure setting of the paper carriage of the printer or photocopier is too high
- the surface friction between the sheets of paper is too high
- too little discharge of the Corona charge buildup of the paper inside the printer

The triboelectric behaviour of the paper is thus only one of many factors influencing the parameter *slide inhibition*. In analysing the causes of too high levels of slide inhibition it is not sufficient to solve the problem by comparing the *electric surface resistance* of the paper. Usually, the problems that lead to jamming in the paper feed are storage-bound and device-specific in nature.

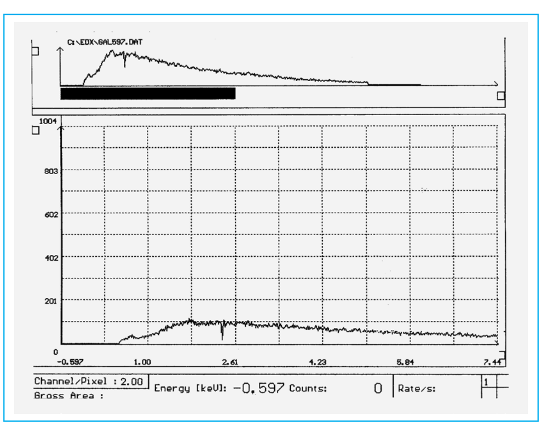

Fig. 16 EDX- diagram of the ion-content of paper by manufacturer no. 1

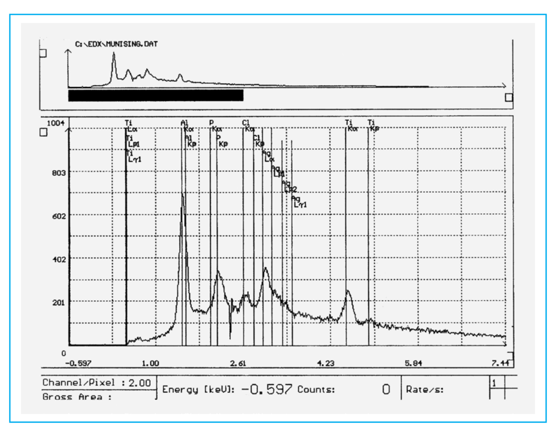

Fig. 17 EDX-diagram of the ion-content of paper by manufacturer no. 4

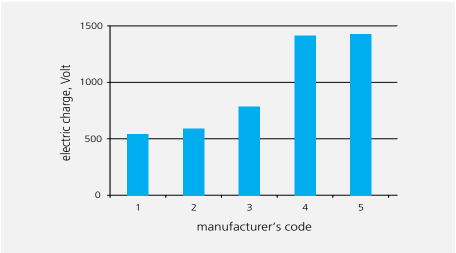

Fig. 18 Test results for the triboelectric charge of various cleanroom papers (measured by a Drop Slide after Ehrler)

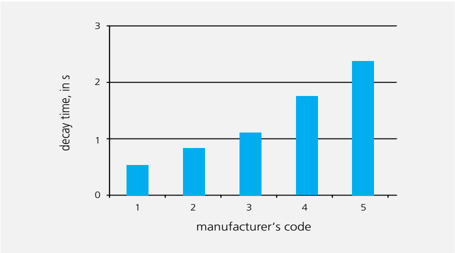

Fig. 19 Test result for the decay time of the electric charge on various cleanroom papers (manufacturer's codes corresponding to Fig. 18)

To a great extent, the amount of triboelectricity generated is modifiable by the manufacturer's choice of the paper-coating. In the test, very different charge and discharge diagrams are shown for the most important cleanroom papers offered internationally, as can be seen from figures 18 and 19 [2].

However, in order to also measure the dynamic triboelectricity, an electric field meter was attached to the paper intake system of a laser printer in our laboratory. The charge-impulse-diagrams arising in the paper feed were serially recorded. Figure 20 shows the impulse series of two differently coated cleanroom papers in comparison to standard office paper.

Surface smoothness

One can generally assume that smoother paper surfaces release fewer particles during use than rougher ones. This is especially true for paper used in copying operations where surface friction is a general working condition. Therefore, the surfaces of cleanroom paper should have a low amount of surface roughness. Even for a homogeneous printing job, a paper surface of high smoothness is very beneficial. Polymer toner particles are applied onto the paper in the form of letters during the printing process, fused into it and thereby thermally fixed. But the fusing process can only function faultlessly if the temperature of the fusing roller of the printer is adjusted high enough and if sufficient pressure from the fusing roller onto the paper is ensured. Otherwise free toner particles remain on the paper-surface which get into the cleanroom sooner or later and contribute to contamination there. For this reason it is advisable to check the fusing roller temperatures of the copying devices. With problems concerning *too little toner bonding* on the paper, one should at first search for the error in this area. Figure 21 shows the roughness of the surfaces of the five internationally known cleanroom papers.

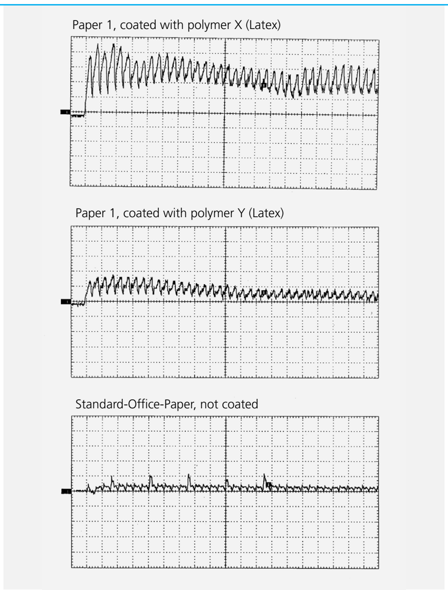

Fig. 20 triboelectric charge diagrams of cleanroom paper furnished with diffferent latex-suspensions and of standard office paper without coating

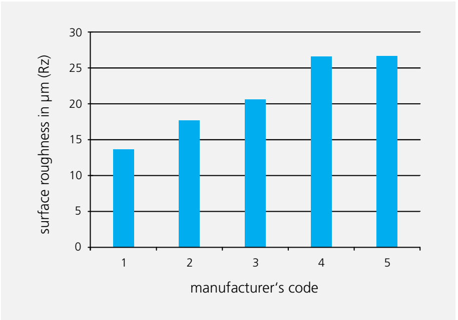

Fig. 21 roughness of different cleanroom papers

Batch differences

To a certain extent, paper is a living material and different production batches can thus turn out differently. Whereas the typical parameters of paper such as thickness, tensile strength and tear resistance can be constantly controlled with modern manufacturing technology, one cannot assume that all cleantechnical parameters show the same values with each production batch. Thus, when the paper sheets are coated with a latex coating, the surface roughness can still be subject to certain fluctuations. Also, the curling tendency of the paper changes when the two sides are coated consecutively with a one-sided coating. Even the ionogenic content is subject to certain fluctuation. The fact that no filling materials to facilitate smoothness may be added by the manufacturer to cleanroom paper naturally predisposes fibre-dependent differences in surface roughness, too.

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Note: No essays by other authors on the topic of cleanroom paper were found in the reference databases searched.

Translation: Carol Oberschmidt