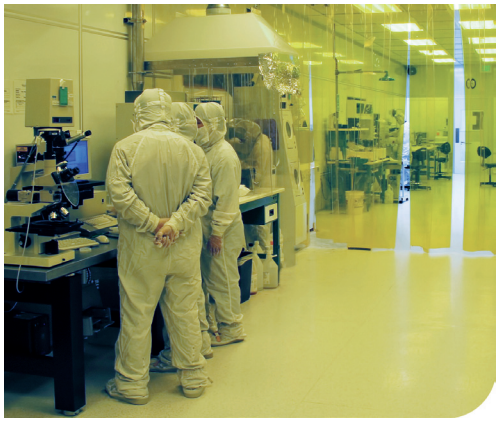


Win Labuda

On the History of Clean Working

from a German point of view

Clear & Clean - Research Laboratory
Luebeck/Germany, 2nd ed. 1-2020

With increasing industrialisation in the first half of the 19th century – probably initially in the small series production of optical parts – there was a need to pay more attention to the phenomenon of „technical cleanliness". This was necessary especially after the invention of achromatically corrected lens systems by Josef von Fraunhofer in 1830 and the establishment of a precision mechanics workshop by Carl Friedrich Zeiss in 1846. Hence, due to the production of high-quality telescopes and microscopes, increased demands were placed on the surface cleanliness of glass and metal surfaces with regard to particulate matter. In the same period, there was a growing awareness in medicine that a lack of cleanliness could have unforeseen consequences for patients' lives and health. The realisation emerged that doctors with unwashed hands transferred germs from corpses or sick people to healthy people, who then died from infection or sepsis. A certain awareness of the possible effects of invisible particles on the one hand and microbes on the other hand gradually entered people's consciuosness. But with a somewhat more intensive study of Roman-Latin literature, this could have been known earlier: The Roman scholar Marcus Terentius Varro (116 - 27 BC) already wrote in his book „Rerum Rusticarum, vol.1, chapter 12 on infectious diseases about the suspected bacteria and viruses:"animals that are so small that our eyes cannot see them and that enter the body through the air – through the mouth and nose – and cause various diseases."

Already in ancient China a very special type of contamination control [8] was in use. To keep their surfaces dust-free while painting, the Chinese painters went on their junks out to sea, where the air was almost dust-free. Several thousand years later, it was medicine that recognised the need for specific purity conditions. In St. Elisabeth Hospital in Kiel separate surgical rooms were set up for septic and aseptic operations, thus creating what could be considered the first cleanroom for medical purposes.

In the nascent sector of precision engineering in the 1930s, apart from the optical industry further manufacturing processes developed in which there was a risk that the yield could be reduced by ambient air particulate matter, thus imperiling the production of watches and clocks but also precision ball bearings for gyro compasses. Hence, there was a historical juxtaposition between technology and medical purposes, albeit with different objectives. While medical doctors were motivated by humanitarian and hygienic reasons, the engineers' reasons for using the techniques of clean working lay first in the military and only later in the industrial sector. At the beginning of the 1940s, the first attempts of the Manhattan project to build the atomic bomb posed the problem of obtaining suitable fine filters with which the ambient air could be highly purified

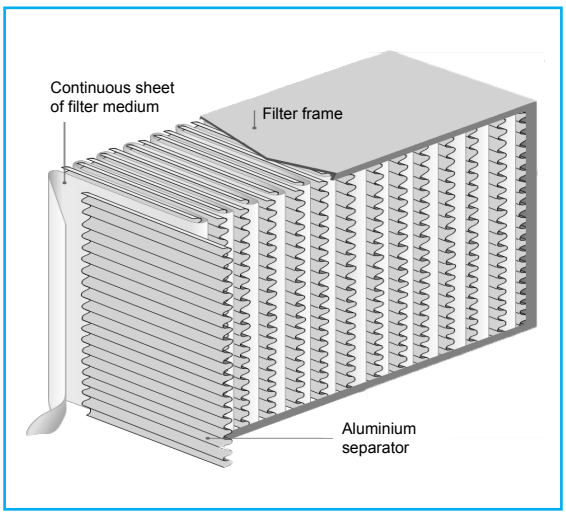


Fig. 2 modern HEPA filter, sectional drawing - the most important element in the construction of cleanrooms. (Scheme: Wikimedia Commons)

of radioactive particulate matter. Thus, the HEPA filter was created due to this necessity.

The terms cleanliness and cleanroom

Cleanroom technology cleaning technology or simply clean technology?

First and foremost, the term cleanroom technology stands for a certain combination of building and ventilation technology. It is one of the prerequisites for carrying out certain manufacturing processes in dust-reduced air. Cleanroom technology is therefore a subordinate term of the „techniques of clean working". The semantics of the term in the usual sense, however, also includes the particulate cleanliness of the volume designated as „cleanroom", the measurement methods related to air and surface cleanliness, cleanroom clothing, cleaning aids used in cleanrooms, and cleanroom consumables.

"Cleanliness" is not an absolute parameter. Thus, the term cleanroom actually refers to a „cleaner" room in relation to the „less clean" room. A „cleanroom" is neither absolutely clean nor is a „standard production room", e.g. for the manufacture of women's shoes, absolutely unclean. In addition, the cleanliness specification for cleanrooms only refers to the number of airborne particles per unit volume present there, but not to the total number of particles contained therein. While we generally associate the term cleanroom with the idea of a room structure with reduced albeit homogeneous particle distribution, on closer study we have to realise that this assumption does not entirely correspond to reality. Rather, in the operating state of cleanrooms, so-called hotspots are created by different flow conditions – these are local volumes with increased or reduced particle density.

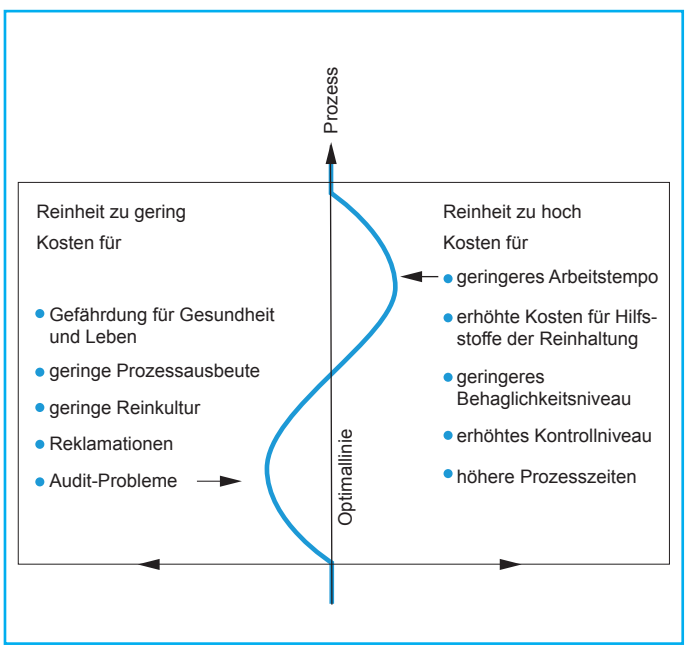


Fig. 3 In every process dependent on specific purity criteria there is an optimal level of purity. Devinitions from this always increase the production costs. The table shows the various types of costs that arise due to a too high or too low level of purity. (Scheme: Win Labuda)

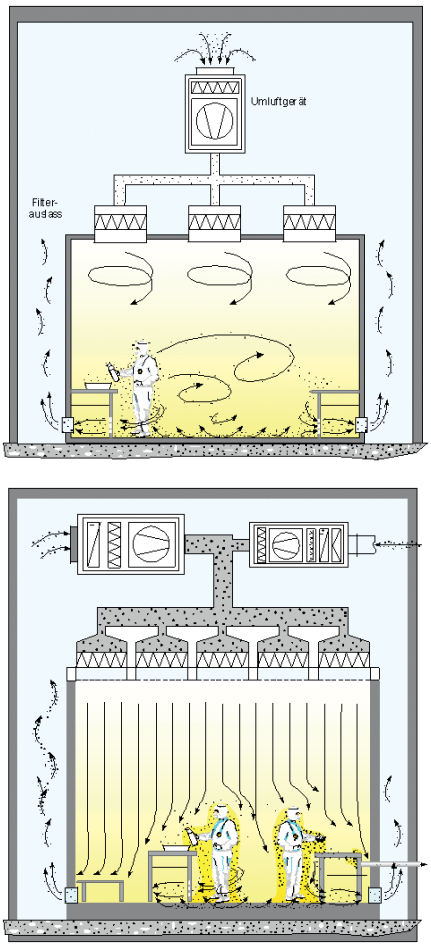


Fig. 4 Air flow pattern, left „turbulent clean room", right „Laminar flow clean room" (Schemes: Rudolf Simon - Wikimedia Commons)

Fig. 5 SMIF-pod for 6" wafer (Photo: 邱銘乾 - Wikimedia Commons))

Moreover, in many cases the number of particles present on cleanroom walls and object surfaces exceeds the number of airborne particles quite significantly. If all this is taken as given, cleanroom appears to be an insufficiently defined generic term. Such imprecisely defined generic terms, however, are often the basis for equally weak subordinate concepts. We find these, for example, in the terms cleanroom suitability, cleanroom glove or cleanroom packaging. Users frequently ask whether cleanroom wipers may only be used for cleaning purposes or „otherwise". As a result of such semantic shortcomings, countless suppliers of consumables define the terms cleanroom wiper, glove or paper as they so choose, according to their own liking. Worse still, they frankly recommend in which ISO air purity classes the material they sell or even certify can be used without hesitation. All this only contributes to the confusion of the user, who is overwhelmed by the many conceptual uncertainties.

If the term „cleanroom technology" lacks precise semantics, it may be time to think about a more appropriate generic term. We are putting „clean technology" up for discussion as a generic term that is currently gaining ground. This term could be diversified by a number of meaningful subordinate concepts. Occasionally, the term „cleaning technology" has been used, but it lacks a phonetic distinction from the term „heating technology" and also has a trivial aura.

According to specifications, only the ambient air in a cleanroom is subject to continuous cleanliness monitoring. This used to be standardised by the US Federal Standard 209 and has been internationally standardised according to ISO 14644-1 since 2001. Classification elements of the standard are nine air purity classes and six particle diameters. However, the continuous maintenance of a certain air purity in cleanrooms is rarely carried out on its own but mostly with the aim of ensuring a process-optimised surface cleanliness. In the production of semiconductor chips, for example, it is the wafer surface that must be kept clean in order to keep the defect frequency as low as possible. Ultimately, therefore, the yield-relevant parameter is always the surface cleanliness.

Surface cleanliness is not as easy to achieve as air purity, nor can it be measured without problems. While the air, with the particles present in it, is to a broad extent homogeneously distributed in a certain volume of space, the particulate cleanliness of the spatial surfaces varies quite significantly in a domain-like distribution. Carefully trained employees of the cleanroom service providers must therefore restore the process-compatible surface cleanliness in the cleanroom at regular intervals by means of manually performed cleaning procedures [4]. Workers in such rooms also wear special clothing to keep the air and surface contamination of the working environment caused by people within process-compa-

tible limits. This gives rise to other industry branches and services such as cleanroom laundries, manufacturers of cleaning wipers, overalls or cleaning service providers. However, all cleanroom technology measures ultimately have one goal: to maintain or improve the cleanliness of functional surfaces. There are three determining factors to achieve this: effective protective clothing, effective work equipment and efficient training of personnel.

The pioneers of clean working

The application of the techniques of clean working goes back to far before our time. As was often the case in the history of medicine and technology, a growing social or technical need was solved by innovative researchers. A number of outstanding inventors and two technical working groups have become known as pioneers of clean working techniques:

- In 1847 Ignaz Semmelweis, (1818-1886), was the first in medicine to introduce hand washing with chlorinated lime solutions at the General Hospital in Vienna, thereby reducing the post-partum maternal mortality rate from 12.3% to below 2%. Semmelweis is the founder of hygiene.
- In 1884 Gustav Adolf Neuber, (1850-1932), introduced a separation of surgical rooms for septic and aseptic operations at St. Elisabeth Hospital in Kiel and thus made a significant contribution to modern surgery.
- In 1961 Willis Whitfield (1919-2012) of Sandia National Laboratories USA published his ideas regarding low-turbulence displacement ventilation as a fundamental principle of cleanroom technology. Modern microelectronics would be inconceivable without his invention.
- Also in 1961, Hugh Howorth (1909-2004) developed a zone of laminar airflow inside a small operating room in England

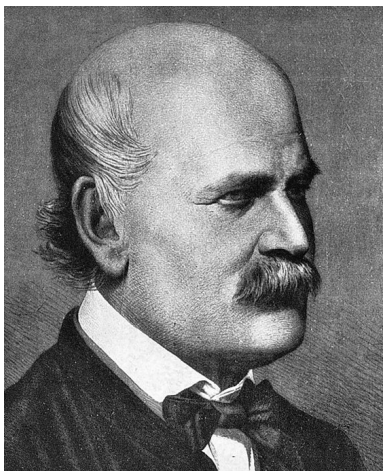


Fig. 6 Ignaz Semmelweis, founder of asepsis (engraving by Jenő Doby, image: Wikimedia Commons)

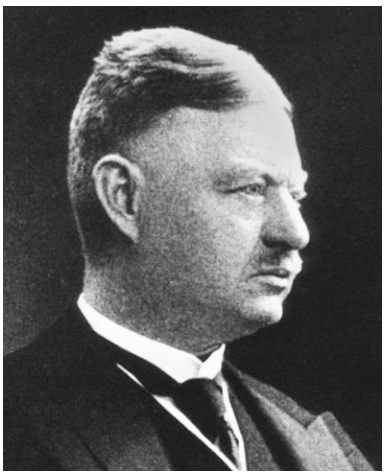


Fig. 7 Gustav Adolf Neuber built the first hospital in Kiel (1886) according to aseptic principles (Photo: Wikimedia Commons)

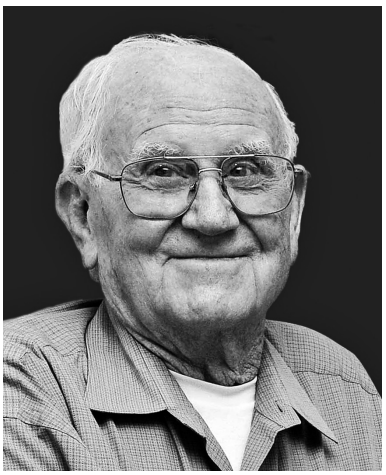


Fig. 8 Willis Whitfield, inventor of the modern laminar-flow clean room (May 14, 1962) US Pat. 3,158,457 (Photo: Sandia)

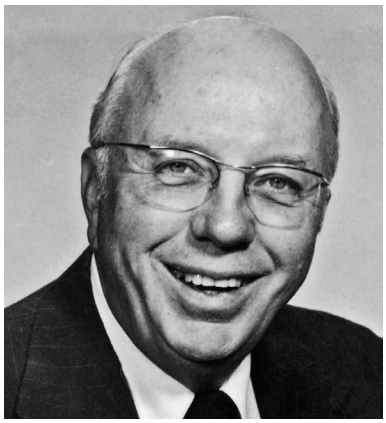


Fig. 9 Wallace H. Coulter, inventor of the Coulter particle counting principle

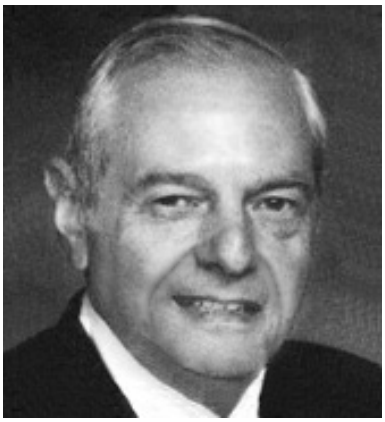


Fig. 10 Alvin Lieberman, „Father" of the particle Counter

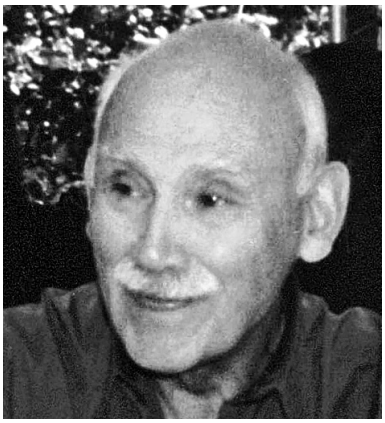


Fig. 11 Edward Paley, Texwipe made the first „cleanroom wipers"

in order to reduce the postoperative complication rate of hip surgery performed by orthopedic surgeon Sir John Charnley, an endeavour which was ultimately successful.

- In 1953 Wallace Coulter (1913-1998) invented an electronic counter for particles in liquids. Thus, particles became both quantifiable and classifiable according to their Feret diameter.
- The Manhattan Project group developed the HEPA filter (high efficiency particulate air filter) in the 1940s. At that time, the task was to filter out the radioactive particles from the ambient air that were generated during the first attempts to produce a nuclear bomb.
- In the 1980s, the technologists Ulrich Kaempf, Mihir Park, Dave Trasher and Barclay Tullis developed a standardised, modular manufacturing platform for the production of semiconductor wafers at the American technology corporation Hewlett-Packard. The inventors called the technology SMIF for „Standard Mechanical Interface". This is a manufacturing technique in which all manufacturing steps from the insertion of the silicon wafers to the finished wafer are isolated from a normal manufacturing environment.

But there were also memorable personalities in the league of lesser-known inventors and entrepreneurs: One of them was the American physicist Alvin Lieberman. Along with Wallace Coulter, he was one of the fathers of electronic particle measurement. Without this technique it would not have been possible to provide the physical-mathematical framework for technologies such as the techniques of clean working. Lieberman was also one of those who had eloquently contributed to the U.S. Federal Standard 209. He also wrote several books and a myriad of essays. A technology prize of the IEST Institute of Environmental Science and Technology in the USA bears his name. Another American inventor/entrepreneur in

the field of contamination control was Edward Paley (1924-2012). In the 1960s he had a visionary idea with regard to the increasingly clean requirements of future high-tech industies: Paley hypothesised that the structures of the emerging microelectronics sector would become smaller and smaller over time, while the contaminants – particulate matter and grease – would retain their original size. He envisioned important industries arising out of the increasing difference in structures. In 1964 he founded Texwipe Inc. and began to develop special products for cleaning by wiping, which at that time had an innovative character. When Paley sold the company for $100 million in 2001, 400 people worked there. It is said that Paley‘s generous wife Florence distributed one million dollars to the Texwipe employees after the sale.

The early years

At the end of the 1950s, cleanroom technology in the industrialised countries, but particularly in the U.S., experienced its initial upswing phase. First, however, a binding standard had to be created, and in 1963 the U.S. Federal Standard 209 "Cleanroom and Workstation Requirements, Controlled Environment" was published. Standard 209 was adapted five times to the state of technology until 1992 and replaced by an ISO standard in 2001 (ISO 14644-1). As always, when a technology is in its early stages, a lot of experimentation was necessary because there were no homogeneous standards for cleanrooms and cleanroom practices. Above all, however, even at the beginning of the 1980s there was still no growing awareness of cleanliness and hygiene among the employees working in the cleanroom. In a large cleanroom in southwestern Germany, for example, the American employer had to enforce the wearing of the prescribed mouthguards by threatening employees' dismissal. In a cleanroom in Essonne, France – so it is said – one also initially encountered one or the other operator with a burning cigarette. In Germany, starting in the mid-fifties, cleanroom technology developed slowly at first. In the sixties, it was boosted by the increasing germanium transistor fabrication, which at that time took place in clean rooms rather than in cleanrooms. However, this was followed relatively quickly – i.e. from 1962 onwards – by silicon technology, which came to us from the U.S. Now the production environments also had to become increasingly clean. In the early years of clean working – around 1960 – it was mainly white lab coats with cuffs that kept some of the particles away from the finished product during work, later – in the early 1970s – hoods were increasingly worn and the all-day wearing of gloves became established.

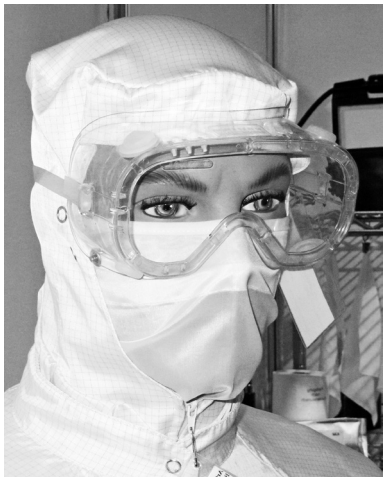


Fig. 12 cleanroom head garment (Photo: Rudolf Simon - Wikimedia Commons)

The production environments also had to become purer because at the beginning about 12 different transistor types were obtained from one diffusion using germanium technology – manually. But of course, despite higher purity, these were still not controlled production processes in today‘s sense. Only after the broadcasting industry decided to use transistors to

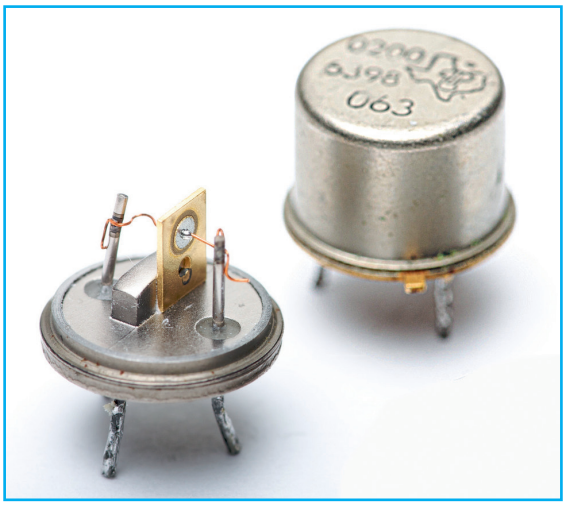


Fig. 13 Transistor (Photo: Marcin Wichary, Source: https://www.flickr.com/photos/mwichary/3949281947/in/album-72157622284092113/ - the photo was digitally reworked)

Fig. 14 Portable transistor radio „Transita" by Nordmende from the 1960s (Photo: Wikimedia Commons)

replace the outdated radio tube, the relatively low production yield for transistors had to increase so that their prices could reach market-conform levels, and now the cleanliness issue became serious.

The appearance of the first transistors in the electronics market was a challenge for all of us. The author recalls that in 1956 a Siemens trainer called together all his apprentices, holding up a cylindrical structure about 10 mm in diameter with three wires emerging from it. Then he said in a solemn voice: „This part will change your future more than the Second World War changed us." This was an absolutely incomprehensible prophecy for us at the time and gave rise to countless ironic imitations of the strangest objects in the training workshop, but in the end it proved valid with regard to microchip technology to an extent that we ourselves would not have thought possible at the turn of the millennium.

Only thirty years later – in 1986 – the first large cleanroom of Siemens AG for the production of memory chips was built in Regensburg. There was already a well-functioning production of semiconductor circuits of lower storage capacity at the Siemens site in Villach, Austria. At about the same time there were also cleanrooms for semiconductor production at IBM- Sindelfingen, Texas Instruments in Freising, Intermetall (later Micronas) in Freiburg, Bosch in Reutlingen, Philips-Valvo (since 2003 NXP) in Hamburg and the Dresden semiconductor plant. Of all these, however, apart from Siemens-Regensburg, only IBM-Sindelfingen had the capacity to produce 1 megabyte chips in large series at that time. The production start of the 1MB chip at IBM in Sindelfingen was even carried out in the presence of then German Chancellor Helmut Kohl.
The Siemens cleanroom in Regensburg was an „open ballroom" type cleanroom accessible via air sluices. With this project, Siemens sent a clear signal. The company was not willing to leave the European markets to American and (at that time still Japanese) competitors. Siemens had acquired a licence from the Japanese company Toshiba for the manufacturing process. Nevertheless: over the period of one year, the Regensburg technologists were unable to achieve a sufficiently high process yield. The source of the error was difficult to identify and could not be attributed to a single process step. Only after 12 months of intensive searching was the error found: A process chemical with a slightly too high degree of purity turned out to be the culprit.

Siemens made a loss of almost DM 1 million per calendar day in Regensburg in the first year. At that time it became clear to all of us that production systems at the forefront of technology were associated with previously unimaginable risks. Even for a large corporation, a tiny, unnoticed detail could generate an economic disaster amounting to billions of euros. The Regensburg cleanroom still exists today, albeit it has been expanded

Fig. 14 Infineon location Regensburg (Photo: Infineon)

several times. Today, chip housings are developed there as well as chip cards and sensor chips.

Over the past half century, the capacity of memory chips has increased from 64 kilobytes to several hundred gigabytes. This is a 16 million-fold increase, probably the largest increase that any purity-dependent technology has ever seen. After the mid-1980s, when cleanroom class 10 according to the U.S. Federal Standard had become standard, cleanroom technology did not need to be further developed with regard to the improvement of air purity to the same extent as lithography or other structurally relevant manufacturing processes. Rather, it has always met the requirements of production engineers, and today, seen from the perspective of clean technology, production environments are supported in which 256 G-byte chips are manufactured. That speaks for itself. The cleanroom has proven itself to the highest degree as a technological manufacturing architecture in many industries. In Germany, cleanroom builders such as Meissner & Wurst and Zander dominated the scene during the initial years of cleanroom technology for major projects.

However, we must not forget that a cleanroom is first and foremost a structure of reduced contamination. This does not necessarily have to be an architectural structure in the sense of a building. Rather, it can also be understood as a pure process chamber within a machine or apparatus. If we look at this aspect in terms of technical progress, for example, then the development is evident. It can be assumed that in the future more and more machines will be constructed in which there are inherent cleanrooms in the sense of chambers. These are machines with built-in self-cleaning mechanisms, so that an external cleanroom architecture is no longer required to the same extent as before. This development will also influence the demand and type of cleanroom consumables and cleanroom interior services.

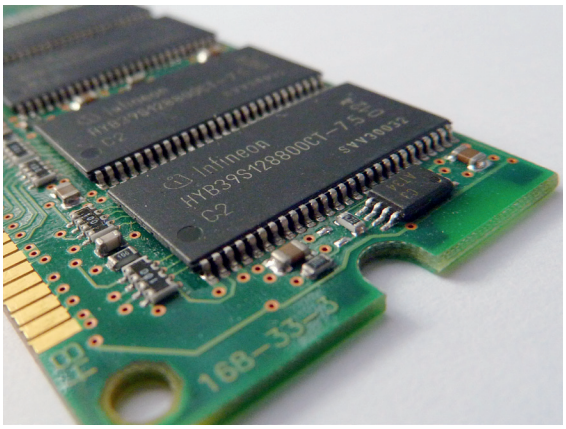
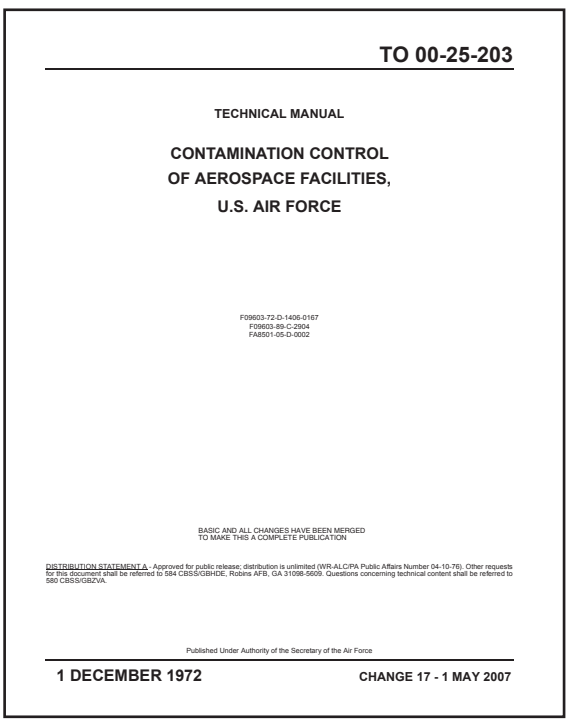


Fig. 15 Random access memory in the form of an IC on an SDRAM module (Photo: Laserlicht - Wikimedia Commons)

Gerhard Rauter, then Technical Director of Infineon AG Dresden, said in his highly respected symposium lecture in Lübeck on the future of the cleanroom industry in 2002: *„In our SMIF cleanrooms we would already be able to work with simple gowns, but we are not exactly sure of this.*"

Computer technology has greatly influenced the development of memory chips and, subsequently, the techniques of clean working. Today, computer chips have conductor widths of 10 or, experimentally, 6 nanometers; 20 years ago this development was not thought possible. Large equipment manufacturers in semiconductor manufacturing such as ASML, Applied Materials, Varian, Canon, Süss or Lam Research are very innovative and successful. On the other hand, we must reckon with the fact that, bearing in mind the more complex structures of the final products, even more complex structured contaminants can now be detrimental to the manufacturing process even in the smallest quantities. This is evident, for example, in ionic and molecular contamination (AMC). Nanoparticle applications and the associated measurement technology are experiencing a considerable increase in importance and are bringing countless new applications with them.

Standardisation in Cleanroom Technology



TO 00-25-203

TECHNICAL MANUAL

CONTAMINATION CONTROL
OF AEROSPACE FACILITIES,
U.S. AIR FORCE

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F09603-89-C-2904
FA8501-05-D-0002

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Fig. 16 The „US Air Force TO 00-25-203" was the first standard published in the history of clean working in 1961.

Standardisation in cleanroom technology can be divided into several sections, such as:

- Standards for industrial cleanrooms
- Standards for medical and pharmaceutical cleanrooms
- Standards for military use
- Standards for cleanroom consumables

The first known standard in the history of clean working was the U.S. Air Force Technical Order 00-25-203 in 1961, which was followed in April 1963 by a meeting of about two hundred representatives of the U.S. authorities dealing with clean engineering tasks as well as representatives from science and industry at the Sandia Laboratories in Albuquerque, NM, USA. A working group was set up there, consisting of a representative of each of the American branches of the military, authorities such as the Atomic Energy Agency, the Aerospace Agency and a number of cleanroom experts from industry. They were given the task of formulating a national U.S. standard for the operation of rooms with increased air purity. It is surprising that this national standard – the Federal Standard 209 – Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones – could be presented in the same year. It was not until 2001 that the U.S. Federal Standard was replaced by the ISO 14644-1 standard, which has now become internationally valid, so that the standardisation of cleanroom technology has found a globally accepted basis.

The U.S. IEST – Institute of Environmental Sciences and Technology in Schaumburg, Illinois, USA has also established a

total of 39 working groups in the years since it was founded in 1952 and 1997, which have addressed the various aspects of cleanroom technology and developed so-called „Recommended Practices". The IEST working groups consist of representatives of cleanroom-related industries, technical authorities, branches of the military and university institutes. In this respect, the IEST working groups are comparable to those of the German VDI. IEST Recommended Practices are not state standards like ASTM in the USA or DIN standards in Germany, but they are a proven solution for many standardisation tasks, although it should not be forgotten that some Recommended Practices urgently require a new version, a project that is currently being tackled by the ISO TC 209 working group on an international basis.

For several decades now, the Association of German Engineers has published the guideline VDI 2083, which deals with the special concerns of clean technology (cleanroom technology) with regard to the various requirements in the best possible way.

Standardisation is certainly indispensable for the broad, regulated use of mass products, but only to the extent that it actually meets the needs of a wide range of users. If this condition is not met, standardisation becomes a burdensome, cost-intensive bureaucratic duty. Moreover, it cannot be ruled out that it has become a questionable source of income for those who want to profit from gullible product users by issuing completely superfluous quality certificates or by refusing to issue these in order to hinder the free movement of goods for their own benefit. There have been more than enough attempts in this direction over the past centuries.

Medicine and pharmaceutical industry

If this essay has mostly dealt with cleanrooms in semiconductor production rather than pharmaceutical cleanrooms, the main reason for this is that cleanroom technology has undoubtedly received the greatest impetus from the semiconductor industry. The main difference between the three types of cleanrooms is that products manufactured in pharmaceutical cleanrooms often come into contact with humans – their blood or tissue – during their later use. They are therefore always a potential health hazard.

Whereas in semiconductor cleanrooms the contamination of the product surface by particles and ions determines the avoidance strategy, in pharmaceutical cleanrooms bacteria, viruses, other microbes and endotoxins could come into contact with people or patients via the product as intermediate carrier. Because the particle problem is eliminated to a certain extent, the focus is essentially on disinfecting the cleanroom surfaces and avoiding the transfer of germs and endotoxins from the worker to the finished product.

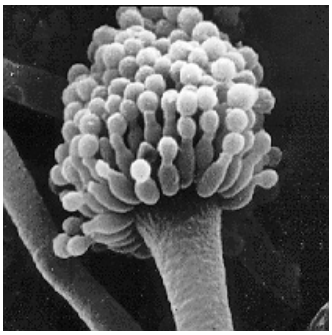

Fig. 17 Aspergillus fumigatus, fungus, electron microscope (Photo: Wikimedia Commons)

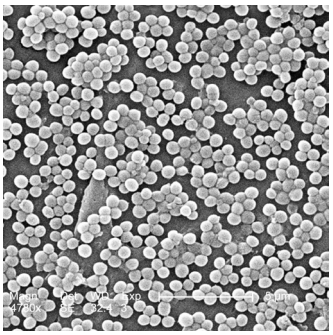

Fig. 18 Part of a MRSA colony, electron microscope - 4780x (Photo:Wikimedia Commons)

The greatest challenge is especially in the area of hospital hygiene. For example, we still are very concerned about too many deaths from nosocomial bacteria. Here it is absolutely essential to disinfect the critical surfaces in the patients' hospital rooms, the intensive care units but also in operating rooms. This also affects hand hygiene. Many scientists and doctors are constantly working on this task, and first successes have been achieved.

Honours and awards

Especially in the U.S., the protagonists of clean technology are honoured in that awards for advances in research have been named after them. The IEST in Schaumburg, Illinois has issued a series of awards related to the work of leading cleanroom technologists. Just to name a few: the Willis J Whitfield Award, the James R Mildon Award, the Robert L Mielke Award and not least the Al Lieberman Mentoring Award. The latter in particular provides an insight into the humane mentality of the award's patron. The award is accompanied by the words: „For significant contributions to the success of others through counsel and teaching as well as the willingness to share knowledge."

In Europe, too, outstanding achievements are occasionally honoured with prizes and awards. Well-known personalities in European cleanroom technology were awarded the „Hall of Fame Award" of the American magazine „Cleanrooms" years ago. These included, for example, William Whyte in the United Kingdom and Hans Schicht in Switzerland. In Germany, the well known aerosol researcher Heinz Fissan was awarded the VDI Medal of Honour in gold 2003. Lothar Gail received in 1999 and Horst Weißsieker in 2010 the VDI badge of Honour – both for their excellent representation and standardisation work. A similar badge (2014) from the same was also given to Udo Gommel by the VDI Association of German Engineers. Frank Duvernell from profi-con GmbH and the Fraunhofer Institute IPA have recently become prominent donors. Both sponsored an annual award to promote innovation in cleanroom technology.

Fig. 19 Heinz Fissan, VDI Medal of Honor in Gold 2003

Thoughts on Industry 4.0

Fig. 20 In his book „Now. Next. Future", Frank Duvernell discusses Vision *Industrie 4.0* in 2017.

The discussion about the future – also in the German clean technology industry – is currently entirely determined by the possible changes in work processes within the framework of a vision of the future known as Industry 4.0. It is also occasionally called the 4th Industrial Revolution. The term was coined by the German Federal Government in order to mark the 4th stage of the overall industrial development to date in the historical context. Industry 4.0 stands for the interlocking of industrial production with modern information and communication technology. In the book „Now Next Future", the authors Frank Duvernell and Gernot Dittel take a knowledgeable approach to this development and describe some of the hoped-for synergies from the combination of production and IT in a very committed and colourful manner. So far, the author of this essay has not been able to reach a final judgment regarding Industry 4.0 and therefore has taken on the role of a discussion partner who poses counter arguments:

We do not see any revolutionary change impacting our industries because the technological transitions from the electron tube to the transistor, from the mechanical calculator to the electronic pocket calculator and from the first 16 kilobyte PC to the 200 GB SD card have already taken place without any noticeable change in our economic structure, nor have these led to social tensions. Moreover, Industry 4.0 also lacks the inventive feat that triggered the known social upheavals in the past with the introduction of the steam engine.

There are several arguments against the introduction of higher-density and more complex mechanisation and networking systems:

- the unclear cost situation
- serious safety concerns
- the lack of suitable interfaces
- a foreseeable lack of specialised staff
- the large number of small and medium-sized enterprises (550,000)
- the concerns of the trade unions
- the "why" question: What is this all about?

That is why it is not entirely unlikely that Industry 4.0 will turn out to be a seamless consequence of Industry 3.0 (IT, Internet, networking) rather than a „revolution" in the sense of a sublimation. The whole Industry 4.0 hype with the rather academic demarcations between the four periods of industrial development is more reminiscent of a journalistically revived Kondratiev theory from 1932. The trade unions' demands for a „fair" share of the expected increase in value creation are certainly understandable and the assumed interface problems with the automation systems already in operation will not be resolved within a short time. Above all, however, it is the large number of 550,000, mostly small and medium-sized German

companies in the manufacturing industry which must have a retarding effect on progress to such an extent that rapid, let alone revolutionary changes in our economic structure are hardly to be expected as a result of the planned boost in networking and automation. It is also a new experience that a term similar to Industry 4.0 does not seem to exist in the U.S., although such developments usually originate there. And in the end some people will certainly ask thoughtfully: What good is that going to do us? Will the army of the unemployed that such an industry would „automatically" produce be able to generate the purchasing power it would need to finance such a drastic paradigm shift?

Outlook

If we broaden our focus on clean working and direct our attention to the issue of purity in the environment and nature, it is not difficult to foresee that the importance of microbial contamination, especially of soil and water, will be the dominant topic in the coming decades. So far, policymakers in government and the political arena have not been able to convince the professions of the necessary measures that are crucial for our lives and our health. For example, this means avoiding the use of antibiotics and reducing the use of pesticides in agriculture and of microparticles in the oceans. It may be that this lack of the persuasive power of science and the inadequate assertiveness or ignorance of policymakers will ultimately cause irreparable damage if – in the interest of all of us – we are unable to reduce and prevent the progressive contamination of our agricultural soils and waters to a tolerable level.

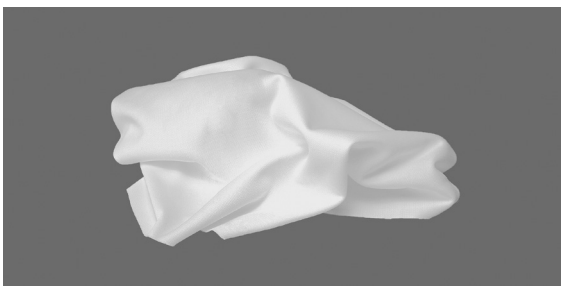

Fig. 20 HiTech Wiper Microweb™ UDG for precision cleaning (Photo: Clear & Clean)

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