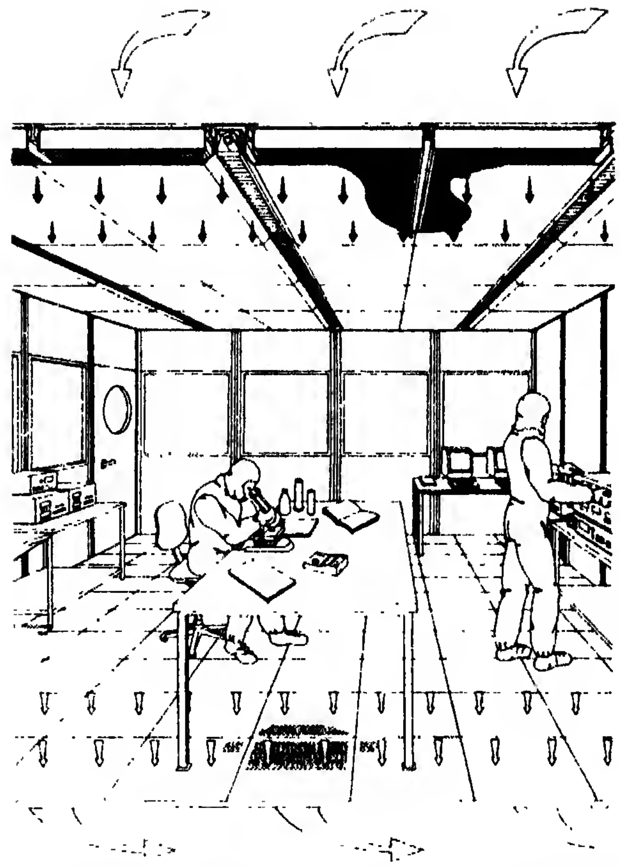
# CLEAN ROOMS



Clean rooms, once thought to be a luxury, have become the precision tool of sophisticated technology today. The electronics industry, right from the wafer fabrication to the final assembly of the printed circuits, has a common concern for quality control of the manufacturing process.

The airborne dust particles have disastrous effects on the final product in terms of yield and reliability. This calls for stringent requirement of environmental control. It must be appreciated that the magnitude of dust hazard is not the same for a semiconductor industry manufacturing ICs, transistors etc as that for the assembly of printed circuits. That is, the degree of cleanliness required is not the same in each of the processes.

The word cleanliness has taken a new dimension with the entry of the sub-micron technology in the electronics field. Even particles from the face powder or nail varnish from the operators present a real hazard in the miniature component fabrication and assembly.

## Precision tool of sophisticated electronics technology

**K. Barua**

The advances in control capability and contamination-free design have begun the age of clean room robots. The specially designed clean room robots will result in decreased particulate generation, minimised processing errors and increased process control and flexibility. This means a better yield and consequently more cost-effective production.

The effect of the contaminants in the electronic device fabrication is seen in degradation of the electrical characteristics such as open circuit, short circuit, low gain and even totally dead device. Again, in the final assembly of the circuits, the contamination may lead to low resistance or short between the multilayers of the printed circuit boards, hair line cracks, shorting or pin holes in the printed patterns. The extent of damage by the airborne contaminants, however, will not be of the same order as in device fabrication. Thus, in order to realise the inherent uniformity, low cost and reliability of electronic devices and circuits, the understanding of contaminant effects and their stringent control is a must.

### Definition

The clean rooms are designated to a certain class if there are less than a corresponding number of 17.97 microns/ $m^3$ (0.5 micron per cubic foot). This follows from the federal standard 209B, titled 'Federal Standard Clean Room Work Station Requirement Controlled Environment'. That is, a class 100 clean room will have less than 100 particles larger than 17.97 microns/ $m^3$ (0.5 micron/cubicfoot), a class 1000 less than 1000, and so on.

With the emergence of the ULSI (ultra large scale integration) and VLSI (very large scale integration), the requirement of cleanliness of the order of class 10, class 1 or even

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class 0 have become necessary. The classifications are being based on the extrapolation of 209B standard. But no official standard has yet been developed and the federal standards developed in 1960 for aerospace industry and revised in 1976 are once again under revision for a new definition for ultra-clean rooms.

**Identification and measurement of airborne contaminants**

The major contribution to the airborne particulate deposition in a factory environment is sedimentation, but the process becomes complicated by the effect of brownian diffusion, coagulation, inertia, turbulent flow, artificial agitation and other secondary forces. Gravity is, of course, the most commonly recognised mechanism for particulate movement and deposition. These deposited airborne particles have to be measured and identified for their effective control.

The examination of the product surface and the environment for the presence or absence of particles is the most direct type of measuring method. Visual examination with the aid of a microscope can provide not only quantitative information but can often lead to direct identification of the type of particles present. Such identification of particles is the first step in elimination of their source.

The simplest technique is to permit the particles to settle from the environment by gravity on a clean substrate, preferably glass, and analyse. This process however does not represent all particles existing in the environment air since only the larger particles ( > 5 microns) tend to settle down on surfaces within reasonable time. The time required to collect an adequate sample may be anywhere from two hours to several days, depending on the cleanliness of the working environment. Secondly, this technique tends to collect particles generated by people and processes in the immediate vicinity of the sampling spot. Of course, the sample is more typical of what the product sees, but not necessarily typical of the environment surrounding the product.

To quantify the finding, the sizing of particles using the microscopic method require the definition of a standard dimension of measurement. The ambiguity arises as the particles are irregularly shaped. For a particle shaped like a peanut, the conventional sense of diameter has no meaning. However, the word has come to apply to a measurement of such particles.

The most widely accepted diameter is the Martin's diameter which is the length of a line which divides a particle into two equal areas. The other, the Feret's diameter, is the length of a line drawn between two parallel tangents on the particle (Fig. 1). However, some constant direction must be chosen to measure the diameter.

Several other diameters have also been employed over the years and appropriate graticules and reticles have been fashioned for their estimation. Such diameters are often termed as statistical diameters because a large number of them must be measured and averaged before they become meaningful.

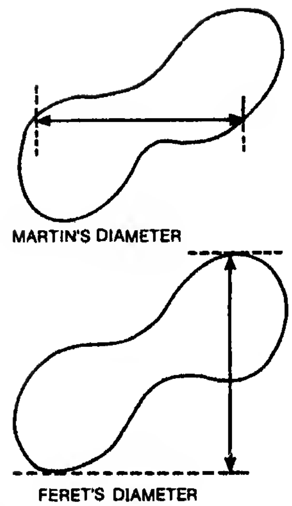



**Fig. 1: Particle diameter definition.**

The microscopic method can be both manual and automatic to some degree. In the automatic technique, the image analyser can count and measure number, area, some type of defined length, shape, optical density and perimeter with high speed using a sophisticated electronic system.

The most popular electronic particle counters are capable of performing in situ measurements. Light-scattering particle counters can instantaneously measure the airborne particles down to 0.3 micron. This technique provides only a secondary indication of surface cleanliness. It must be assumed that if a product is exposed only to a clean environment, the number of particles deposited on the product surface from the environment will be nearly zero. The limitation of this technique is that the integrity of light that is scattered by a particle depends to some extent on physical characteristics other than size, viz, the shape, colour and index of refraction.

Again, since particle counting instruments measure only the particle in a relatively small volume of air, the statistics of sampling can be applied to the resulting data. The statistical error is equal to $1/\sqrt{n}$, where n is the number of data. It is evident that 100 particles of a given size must be counted in order to reduce the error to ±10 per cent. At a class 100 condition one cubic foot of air must be sampled to achieve the ±10 per cent error. Hence, it follows that cleaner the environment, the larger the air sample that must be sampled for a given statistical accuracy.

The minimum particle size detectable with light-scattering instrument is about 0.3 micron because of electronic signal-to-noise ratio limitations. However, counters have been developed for measuring still smaller particles by indirectly determining the electrical mobility of a charged aerosol.

**Design considerations**

The required cleanliness in the clean room is achieved by a number of techniques. One technique is the exclusion of the contaminants from entering the environment either by filtering of the incoming atmosphere or isolating of the surface from the hostile environment. The principle of dilution can be used by passing contamination-free air through the given space in sufficient quantities to remove the contaminants generated within the space. Further, air distribution design prevents or atleast minimises the recirculating eddy currents. The reduction of contaminant generation within the space by both process and personal control is another way. Lastly, since contaminant deposition from the environment is time dependent, the advantage of this fact is taken by reduction in the time of exposure of the contaminant-sensitive surface. These techniques are judiciously used to control the airborne particulate matter.

Most clean rooms of higher order have 80-100 per cent ceiling coverage with high efficiency particulate air (HEPA) filters and lights which are designed for free air-flow. The vertical flow type rooms have a false ceiling on top housing HEPA filter in an air handling duct and pre-filters under the floor grating. The air handling units are provided on the sides in the plunum provided false ceiling (Fig. 2).

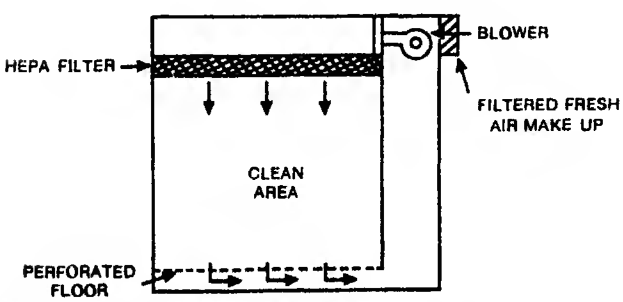



**Fig. 2: Vertical laminar flow room.**

In the horizontal wall-to-wall flow arrangement, a bank of HEPA filter on one side and pre-filters on the opposite side are fitted with the air handling unit and ducting on top inside plunum. In this laminar air distribution system, the flow of air column is almost in a parallel beam. The horizontal type assumes highest or desired cleanliness for the first line of work position only, while in the vertical laminar flow system it is possible to achieve the required cleanliness over the entire area (Fig. 3). The air-velocity in the laminar flow system is kept at 90-100 fpm.

Further, the clean rooms are maintained at a positive static pressure differential by proper air distribution with respect to the non-clean or relatively less cleaner areas. The

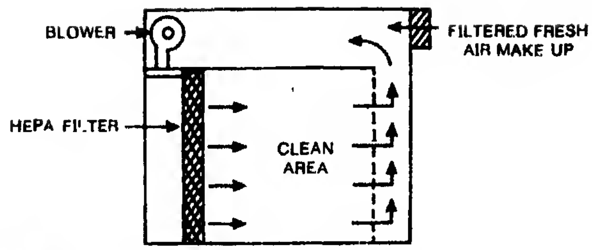



**Fig. 3: Horizontal laminar flow room.**

make-up air added to the clean room is pre-filtered to at least the same degree of cleanliness as the recirculated air. For small volume of rooms the fresh make-up air may be 5 to 20 per cent, but in rooms utilising a high volume of recirculated air, the fresh make-up volume should be decided on the number of operators working and calculated as 8.4948 $m^3$ (30 cubic feet) per minute per person. However, while deciding the fresh air make-up volume, the exhausted air due to chemical vapours should also be taken into consideration (Fig. 4).

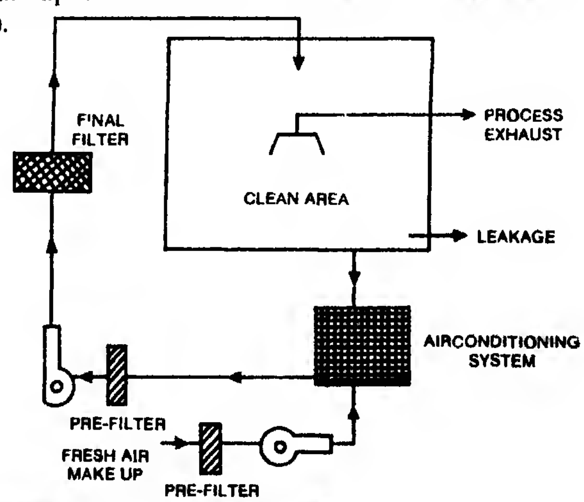
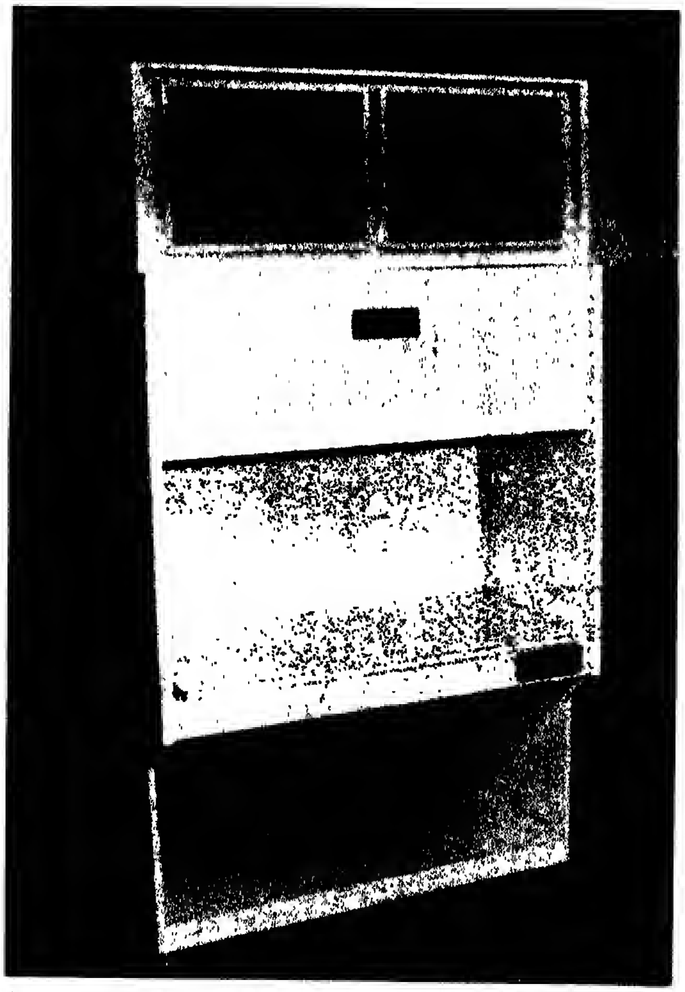



**Fig. 4: Schematic of air handling system.**

The selection of the right type of material for construction of clean rooms is very important. Materials which are liable to generate, harbour or attract foreign particles or fibres or need finishing or contain contaminants which through handling may be passed on to the product or released into the environment, should be avoided.

The room flooring of PVC material welded at the joints and covered at edges to seal the flooring to the partition are



**Vertical laminar flow bench: courtesy Clas Laminar Systems.**

of importance. For illumination, a translucent cover over fluorescent lighting gives a good diffused light with pleasing appearance and at the same time heat and maintenance are kept outside the controlled area.

Filters used for filtering the particulates are made of glass fibre/esparto glass paper type or electrostatic collector type. The electric filter works on the principle that dust particles drift towards the ioniser with a very high electrostatic charge. These particles, carrying very high potential positive DC charge, are made to pass through collector cell comprising positive and negative plates. These collector plates maintain constant electrostatic collection forces for stable operation. The collected dust/fume particles adhere firmly to the plates.

The glass fibre filters have a very high degree of efficiency and are also called absolute filters or HEPA filters. However, the pressure drop across this filter is greater than the electrostatic filter. Fibrous dry filter or viscous wet filters are used as pre-filters. The filter life depends on the location of the installation, operating conditions, efficiency of the pre-filters and season of the year. Electrostatic filters have the advantage of being reused after cleaning whereas the HEPA filters require replacement.

The ability of HEPA filters to provide particulate-free environment is tested by the DOP (dioctyl-phthalate) penetration test. By definition, an HEPA filter must demonstrate a minimum collection efficiency of 99.97 per cent for 0.3 micron thermally generated DOP dust cloud and a maximum clean filter pressure drop of 1.0 inch w.g. at its rated air flow capacity. This test is intended as a measure of the filter's ultimate ability to capture particles of any size at a practical operating pressure.

The other standard for testing is the British standard methylene blue test. A filter having a penetration of 0.03 per cent by DOP has a penetration of 9.95 per cent by methylene blue test. This indicates that methylene blue testing is more searching. The methylene blue cloud has particles ranging from 0.01 to 1.3 microns, the mean size being 0.5 micron. The aerosol produced by DOP has a mean particle diameter of 0.7 to 0.9 micron.

**Clean room accessories**

A number of peripherals are used to increase the efficiency of the clean rooms. The air shower or man cleaners are normally used for personnel cleaning before their entry into the clean area. The person stands in a closed cubical and is subjected to high velocity clean downward and sideward air flow. The air brushing action is obtained from the jets placed in the walls and ceiling. The air jet ensures that the scavenging air reaches the clothings of the person at the correct angle and sufficient force to dislodge the dust particles from the clothings. The particles are skidded off and not driven into the texture of the clothing. Once the particles are airborne they are trapped by the dust traps.

Normally, air showers are interlocked and only one door can be opened at a time. They also act as a buffer air lock between the clean areas and relatively lesser clean areas. Often a small room attached to the clean room preceding the air shower is used. This room maintains a positive static pressure between the clean areas and the outside hostile environment.

**Horizontal laminar flow bench: courtesy Clas Laminar System.**

For control of foot-borne dirt or contaminants, tacky mats with a special pressure-sensitive surface to pick-up dirt and dust from shoe soles and heels are used. Air curtains mounted at the entrance of the air lock acts as an invisible dust and temperature barrier by a down flow of filtered air.

Process materials from and into clean areas are taken through a small enclosed chamber with interlocking doors. Called pass box or hatch, it helps to limit traffic into the clean area. Similarly, the communication between clean areas and outside world is accomplished by electronic intercoms or speak-thrus. A speak-thru is a small device with a thin diaphargm which permits one to talk and listen with the diaphargm acting as a barrier between the clean and hostile environment.

### Garments

Garments used in the clean rooms also call for special attention. Lint-free dacron, nylon and polyester garments are used by the personnel for prevention of particulate contamination and to confine the innumerable biological fallouts shed by the operators. If nylon overalls are to be used, some means have to be provided to de-ionise the garments, thus making them non-electrostatic. The head covers must fit snugly and yet be comfortable enough to be worn for long periods of time. Use of gloves prevents skin flaking, perspiration and skin oils contaminating the product. Shoe covers must be of tightly woven fabrics to impede the passage of dust and dirt.

Cleaning mops used in clean areas should be highly absorbant polyurethane foam sandwiched totally between dacron covers. Dacron is preferred as it has low retentivity to static charges. To make the garments antistatic, an antistat chemical is dissolved in the final rinse water while washing the garments. On drying the garment, the antistatic chemical adheres to the fibres. This chemical has the property to pick-up moisture from the air and helps to reduce the static electricity. It is a surface agent and the quantity used decides the static reduction power. However, large quantity used will be more harmful as it is likely to flake in the clean areas during use.

The present trend is to use garment with silk texture polyester with an interwoven carbon thread for making them static-free. The garments need to be carefully designed. They should be fitting to eliminate abrasion against underneath clothing and thus avoid contaminant fallout. All seams should firmly envelope the raw edges of the material. The fabric must be tightly woven to minimise passage of dust and lint from the person's body and inner clothing to the outside.

### Summary

The importance of contamination control is not confined to the field of electronics but also in the manufacture or repair of space vehicles, human surgery/transplantation of organs, drug manufacturing, food processing and many other applications which are poles apart in their similarity. Even in these diverse industries, the method of contamination control has the common approach. It is quite unusual to think of the human body as a product or an operation theatre or as a factory but the engineering principles of manufacturing environmental control are applicable.

The control of infectious micro-organism in hospital operating theatres can be achieved in a manner identical to one used to protect airborne particles damaging the pattern generated in the electronic device fabrication. The only difference one can think of is that the human body will become infected due only to living contaminants or germs, while an electronic device can be 'killed'.

The study does not end here. Even a particle of a few microns can prevent the correct functioning of a delicate gyroscope mechanism. With every stride the mankind makes in any field, the word 'cleanliness' takes on a new dimension.

The design and construction of clean rooms to meet the demanding needs of electronic component manufacture and assembly is a complicated and costly task. The state-of-the-art expertise has to be incorporated to analyse and understand the specific requirements for a tailor designed clean room. A successful design must consider the features as process flow, operator flow, safety and above all cost effectiveness. It may be concluded that the clean room system is not a luxury as it justifies the system cost in terms of the high yield and reliability of the product. □