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NOISE AND VIBRATION CONTROL IN MICROELECTRONICS CLEAN ROOMS

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INTRODUCTION

The fabrication of high density microelectronic circuits requires the use of photolithographic equipment which is quite sensitive to vibration. Excessive vibration during the production process broadens the resolvable linewidth of circuits and introduces errors in the repeatibility of alignment of the optical mask. Yield is also reduced by contamination of wafers by particles in the air. The mechanical plant required to provide the relatively large volume of clean air, to an ever-increasing standard of cleanliness, results in a high level of installed power per unit area of production floor, and associated vibration and sound energy.

As the circuit linewidth reduces from 5μm to 1μm, and cleaner Class 10 environments are specified, the close proximity of service plant and sensitive equipment in a complex building makes the vibration aspects of the design process quite exacting. Noise is often less of a problem, with the conventional means of control more readily understood and available. An approach to the predominant vibration problem with also certain aspects of noise control, will be discussed in this paper.

VIBRATION CONTROL

Vibration Criteria

The minimum linewidth envisaged, together with the types of sensitive equipment proposed for these pattern geometries will determine the criteria to be adopted. There exists a maximum value of the relative motion between say the optical column and the image stage, that enables a desired linewidth to be adequately resolved. In some cases, manufacturers have determined the maximum floor vibration to which their equipment may be exposed without producing excessive relative motion between the critical elements. Sample curves are shown in Figure 1. Care is required however in interpreting such information, especially if the floor criteria have been derived via transfer functions which do not allow for the first few major modes of equipment vibration, as well as the rigid body modes on any inbuilt table isolation system.

Floor criteria have been expressed in terms of displacement, velocity and acceleration, with perhaps velocity the most appropriate descriptor overall, for the frequency range of 1 to 50 Hz or 100 Hz, which is usually of interest. Criteria ranging from 6 μm/sec to 50 μm/sec are in use with 25 μm/sec RMS or lower in the vertical direction,for a typical high technology product.

Site Evaluation

A building intended for silicon wafer fabrication should be sited on stable ground, as far as possible from known existing sources of vibration e.g. railways, roads, quarries, and as far as possible from existing or intended build-

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ings containing heavy machinery. If several potential sites are to be considered, then they can be evaluated in terms of the geotechnical characteristics of the ground, a comparison of existing foundations and building structures and the measured ambient vibration levels.

When an existing building is to be modified, guidance may be derived from transfer function measurements between proposed locations of the new plant and the new clean floor. Some care is required of course to allow for differences in static structural loading, realistic excitation force levels and existing ambient vibration levels.

BUILDING CONCEPT AND LAYOUT

Consideration should be given to minimising the vibration and shock disturbance during the planning stages of a new building or facility. The most stable clean room floor is obtained when it is formed directly onto the ground (or rock etc) at the site. In the case of a false floor, to cater for the return air, all sensitive equipment should be supported on a very stiff platform, connected rigidly to the base slab. When a suspended slab is used to achieve a high standard of airflow parallelism across a complete room area, or to house ancillary plant, the supporting columns must be relatively close together. Thick beam, grillage or waffle type floor constructions are required to achieve a high flexural stiffness at mid-bay, while allowing adequate open area for the airflow requirements. The floor must be sufficiently stiff to avoid major resonances being excited with the superimposed floor load, at typical plant excitation frequencies. Rigid connection between the clean room floor and the main structural frame supporting the mechanical services plant should be avoided. If the bearing capacity of the soil is such that piles are required, the piles carrying the columns supporting the clean room should be isolated from the building frame foundations.

Mechanical service plant should be located or supported as far away from the wafer fabrication areas if space permits, in order to benefit from natural attenuation effects at structural junctions. Some features of existing wafer fab layouts are given in Figure 2.

Since the economic operation of a wafer fabrication facility depends upon achieving a very low vibration environment, mathematically modelling is used in the design process. Some techniques that are used are described in the following sections.

VIBRATION ANALYSIS TECHNIQUES

Finite Element Modelling

The paths of vibration transmitted from the mechanical plant to the clean room floor are numerous. Different types of building elements such as structural columns, beams and floors, constituting a complicated three-dimensional situation may not be amenable to simple hand calculations. In this case, the building or part of it can be represented by a finite element model. Structural columns and beams are replaced by beam elements having axial and bending stiffnesses, whilst floors and walls by plate elements having bending and shear stiffness. The ASAS finite element package developed by Atkins Research and Development is suitable for predicting the dynamic response of a building structure (see Figure 3). This program allows the calculation of natural frequencies, mode shapes and response when the building structure is subjected to steady state or transient force excitation.

Response Of Clean Room Floor Structure To Plant Excitation

The prime objective of vibration control in a clean room is to provide an acceptable level of floor vibration for the sensitive equipment. It would be a simpler task if the clean room floor could be a thick solid slab on top of a rigid foundation. However, in order to provide a high degree of air purity sufficient air downflow is required to reduce airborne contamination. Typically the air flow may approach 0.5 m^3/s per square metre of floor area in a laminar flow clean room. This may require air extraction across the entire floor area, through a deep underfloor plenum. From a vibration standpoint, the perforated suspended floor with its edge or corner support conditions is substantially different from a thick solid slab continuously supported by the ground.

An analysis of the vibration characteristics of the clean room perforated floor structure may need to be carried out to validate design. The FE model uses beam elements to represent the perforated floor, the support columns, piles and the linking ground beams; plate elements for the return air plenum canopy and spring elements for the stiffness of the pile. The plenum structure is included in the model because it could significantly modify the stiffness between the column head and the waffle floor. The response of the clean room floor structure depends upon other factors such as the equipment mass distribution and structural damping, which must be represented in the model. With a proposed building configuration, the natural frequencies and response of the floor structure due to plant excitation, footfall and ambient ground motion can be computed by the ASAS program. The effects of different section sizes and building schemes, such as wider spacing of support columns, can be assessed by using the model with minimal additional effort.

Response Of Building Frame To Plant Excitation

For large plant items to be mounted above grade on steelwork, the design of the supporting steelwork as well as the selection of an appropriate isolation system becomes more critical than one mounted on grade. In this case, the flexibility of the supporting steelwork and the building frame, need to be taken into consideration when selecting suitable plant isolation systems. These plant items often include the main air recirculation fans. Preliminary hand calculations can be carried out to estimate the flexural stiffness and consequently the fundamental natural frequencies of individual steelwork members. These frequencies should be several times that of the fan running speed. Heavy structural steel bases fitted with spring isolation mountings incorporating suitable vertical and horizontal restraints are required. At this stage, a finite element model of the frame can be used to assess the suitability of the steelwork/mounting design. In the model, the supporting steelwork and the building frame are represented by beam elements, the fan and its inertia base as a rigid body and the mountings by spring elements. Inertia bases with a suitable mass ratio reduce assymmetry in mount loading, and give more stability to the fan.

Using the geometrical properties of these elements as input data, the dynamic responses at locations of interest on the steelwork can be predicted by the ASAS program. Reducing these responses by changing the design, to meet a specified vibration limit can be achieved by simply changing the input data. The ASAS model has demonstrated its flexibility for assessing the effect of different beam sizes and configurations proposed by the structural engineers. Changes in different inertia base masses and spring types are also readily investigated.

Rigid Body Modelling

Mechanical equipment with inherently large unbalance or vibratory forces is normally installed at grade or basement locations. Unfortunately, in many microelectronic facilities, these locations are situated within close proximity to the clean room floor. Equipment vibration can therefore be transmitted readily to the clean room via structural links such as columns and walls. This may demand a high degree of isolation from the mounting system and a stiff foundation. Although most equipment room floors are usually 10 or more times stiffer than equipment mounting systems, they may have undesirable floor resonances in the operating speed range of most HVAC equipment. To avoid possible resonance problems, dynamic analysis of large resiliently mounted equipment is advisable.

The chillers, major fans and pumps, compressors and boilers are the dominant vibration sources to be considered. Dynamic analysis of this equipment can be performed using the 12 degree-of-freedom ASIST computer program developed by Atkins Research and Development. The program uses block elements to represent closely the mass distribution of a large equipment item such as a chiller, its inertia base and the foundation (see Figure 4). Spring elements having the same stiffnesses and damping of the isolators are used at the proposed isolator locations. Foundation soil mass and flexibility is also included in the analysis. The locations of the predicted response can be specified at places where excessive vibration amplitude would be detrimental to the connections of equipment and pipework. Natural frequencies and vibration responses of the resilient mounted equipment and the foundation are predicted. Input data can be easily modified to assess the effect of different inertia block mass, shape and spring types and configurations.

Response To Footfall Excitation

Due to space limitations and the required interaction with other activities, the sensitive equipment in a clean room is often installed in areas close to foot traffic. Footfall induced vibrations can be more severe than ambient ground motions caused by vehicular traffic outside the building. It is therefore necessary to predict the floor vibration due to footfall excitation at an early stage in the design, since any structural modifications to the building after construction are costly.

The footfall impact depends mainly on the walking rate and the weight of the walking person. Conservative estimates of the floor response can be obtained from the analysis for the lowest-impedance point on the floor and for the lowest-frequency mode. The stiffness and the resonance frequencies of the floor structure as required in the analysis are readily available from the finite element model for the clean room floor, as discussed previously.

Rigid Body Response To Transient Excitation
With heavy equipment isolated on high deflection springs, the stability of the equipment subjected to transient excitation during start up or fault conditions should be considered. High power axial fans, mounted above grade in particular, should be checked for the peak displacements caused by torsional and vertical thrusts at the connections to the associated ductwork. Estimates of these displacements may be obtained by modelling the resiliently mounted equipment as an undamped single-degree-of-freedom system. The maximum response produced in such a system subjected to impulsive loading depends on the ratio of the impulsive duration to the natural period of the system. Manufacturer's data on the impulsive loading should be used where possible.

NOISE CONTROL

Major Noise Sources
Noise sources in clean room facilities include fans, chillers, boilers, compressors, pumps and cooling towers which transmit duct-borne noise to the clean room and airborne noise from the plant spaces. With the exception of the cooling towers, which are installed outside the building, these noise sources also give rise to flanking noise transmission.

Duct-Borne Noise
The dominant noise is often produced by the recirculation air handling units, together with the extract fans which remove contaminated air from service chase areas, and the primary air fans which supply the fresh make-up air. Space limitations often make it necessary that the high power recirculation air fans be installed adjacent to the clean room. These fans provide a large volume of air, changing the air in the room up to 100 times per hour, which is by comparison, 17 times that of an office building. The energy division at branch take-offs and the large system losses normally found in an office air supply system may not be present in this case. Splitter type attenuators are normally used in order to provide the required attenuation. As the highly filtered air must remain dust free, the attenuator splitters must be non-shedding, with the absorptive material hermetically sealed by a polyester membrane such as Melinex sheet. Laboratory tests show that the performance of a Melinex sealed and perforated metal faced attenuator can be seriously degraded at high frequencies. Reductions as much as 33 dB at 2 kHz, 20 dB at 4 kHz and 11 dB at 8 kHz have been recorded on tests carried out on a 1500mm long splitter silencer with 25% free area. It is recommended that manufacturers' guaranteed test results on Melinex faced attenuators be used for the attenuator selection, in order to avoid such a pitfall.

The high attenuation required from the attenuators and space limitations often dictate the attenuator selection. Splitter thicknesses of 200mm and above are often used. With an attenuator free area of 33% or less for the air to pass through, the typical pressure drop may approach 100 pascals. This calls for a close examination of manufacturers' regenerated noise data to ensure that the noise criterion in the clean room can still be met. For controlling flow induced vibration in the ductwork and regenerated noise, a low velocity system has to be adopted.

Airborne Noise

Many wafer fab users prefer to have the plant room extending to areas adjacent to the return air chamber beneath the production clean room floor. This poses a problem for containing the equipment noise within the plant area. Typical ceiling and wall constructions are of reinforced concrete and high density concrete blockwork. The transmission loss data for these construction materials may need some modifications to allow for the degration due to penetrations by services. Large numbers of penetrations on the plantroom structure in a wafer fab are necessary for the contaminated air extract ductwork, recirculated air return, water and chemical gaseous pipework and electrical cables. Sealing of services passing through the plantroom structure is critical. The seals are required to be airtight, with high sound transmission loss, resilient, non-shedding and chemical-resistant.

The noise radiated directly from air handling unit and fan casings into the plantroom or air space adjoining the clean room should be controlled to an acceptable level. If at all possible, the unit casing should be of sandwiched panels with double steel skins and a sound insulating core. The attenuator casing and ductwork should also be adequately stiffened. Ductwork with gauge material thicker than the values recommended in the HVAC Guide may be required. Duct lagging, normally provided for thermal insulation purposes, may need to be upgraded to provide the necessary insulation. The ductwork flexible connectors may be longer than normal owing to the fact that the plant is mounted on high deflection springs. Due to the additional length required, some flexible connectors may need to be of double skin construction to reduce noise breakout. To limit noise at source, maximum noise level data should be specified to the suppliers of equipment such as chillers, boilers, pumps and compressors.

Service equipment for the clean room production processes may also cause excessive noise level in the production area. Such items should be located away from the clean room, preferably in a separate mezzanine level plantroom, if process and space considerations permit.

Flanking Transmission

To control the flanking transmission of vibration and noise an impedance mismatch can be built into the structural transmission path. Various isolation methods are adopted, which may be classified as structural isolation joints, flexible connectors and supports for the services, and vibration isolators for the equipment.

Structural isolation joints in clean rooms provide discontinuities between the vibration affected areas and the clean room floor. Depending on the clean room design, the isolation joints can be provided at the perimeter of the clean room floor, the clean room ceiling and the plantroom floor.

Flexible connectors are required for all ductwork and pipework, at places where equipment is connected to services and where services pass through building elements associated directly with the clean room floor structure. As a general guide, the stiffnesses of the flexible connectors along three main axes should be at least 20 times less than the stiffness of the isolator supporting the equipment. Heavy electrical cables can develop significant stiffness and should be looped where possible to minimise vibration transmission.

Vibration isolators used in wafer fab facilities are mainly of helical steel spring type, in order to satisfy the high static deflection in the range 50-150mm, which may be required. Rubber-covered glass fibre isolators may be of use for less critical plant such as small pumps, low vibration boilers and static sections of some air handling units. Provision for bolting to the equipment, levelling and high frequency isolation are usually incorporated. Vertical restraints should be provided for equipment such as chillers, cooling towers and boilers, which may require fluid unloading. Care must be taken to ensure that high deflection spring isolators are actually loaded to the desired deflection for achieving the design isolation efficiency and are laterally stable when installed.

CONCLUSION

As the silicon chip marches toward very large scale integration circuitry, the provision of a lower vibration environment can be achieved at an acceptable cost.

The noise and vibration specialist's role is to ensure firstly that the analytical techniques currently available are applied in the early stages of design. Secondly he must ensure that proposals arising from the analysis are actually implemented in the final design.

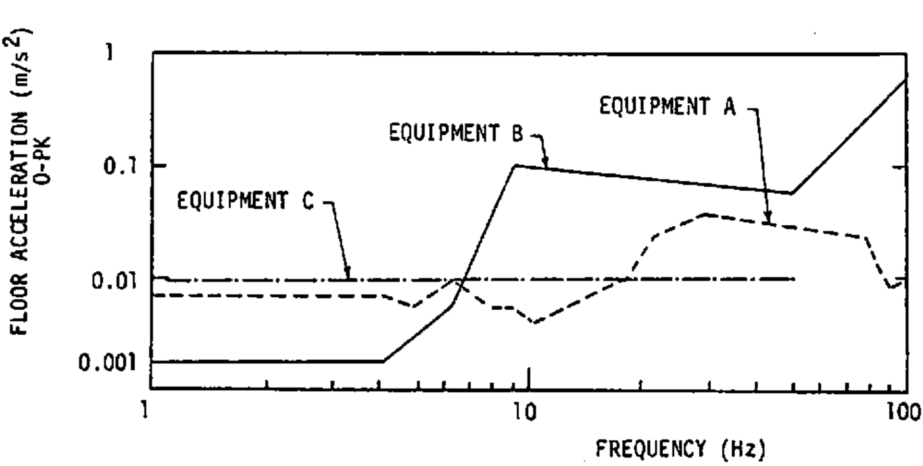

Figure 1. Floor vibration allowed for photolithography equipment

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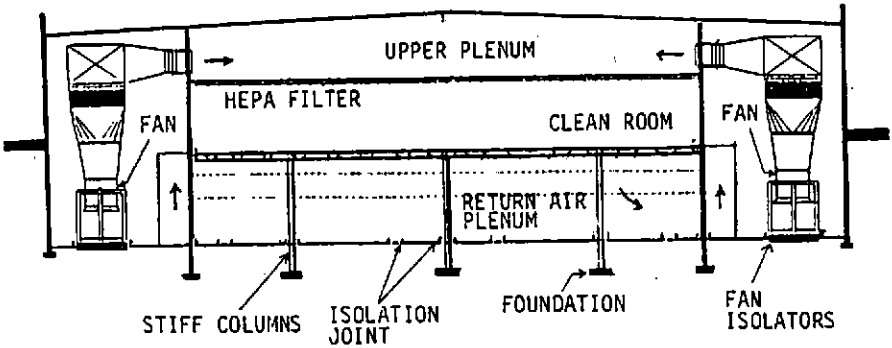

Figure 2. Typical Wafer Fab Layout

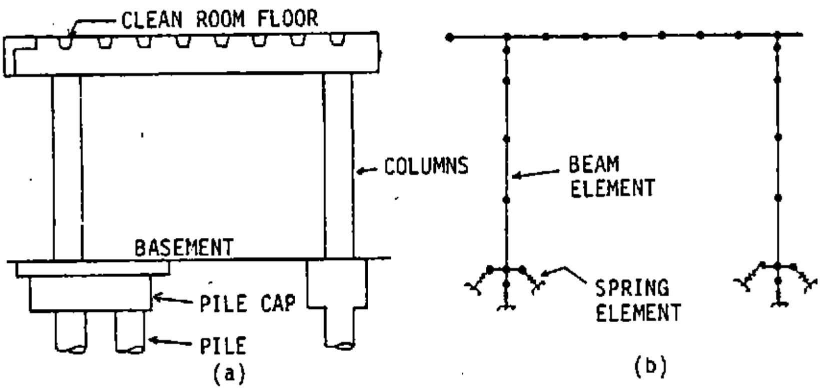

Figure 3(a) Floor Structure 3(b) ASAS FE Model

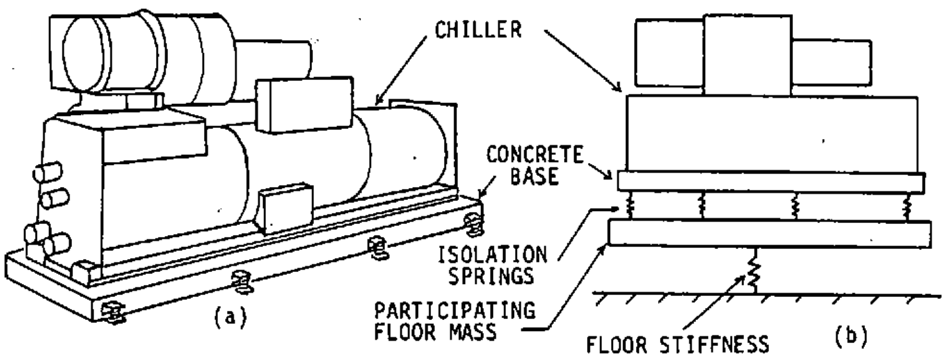

Figure 4(a) Resiliently Mounted Chiller 4(b) 12 DOF ASIST Model