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# A Discussion of Vibration and Noise Issues in a Cleanroom Design: Past, Present and Future

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## INTRODUCTION

Vibration-sensitive instruments are by no means a new phenomenon. Galileo reportedly experienced vibration problems with his telescope. In the context of the microelectronics industry, tool sensitivity to vibration and noise is an item of particular concern since they can substantially affect product yield. Also, of course, fab cleanrooms are very energetic in terms of installed mechanical systems. These systems have a propensity to generate vibration and noise.

Early on in our work with the microelectronics industry, there were no vibration criteria that one could use as a basis for facility design - nor were there even accepted methods for measuring vibration performance. Few, if any, tool makers had developed accurate performance requirements for their tools. Even at the present time, significant numbers of tools lack reliable vibration and acoustic specifications.

Because of the early lack of vibration standards and guidelines for microelectronics facilities, a set of criterion curves, commonly called the generic vibration criterion (VC) curves, were developed. These curves - now widely used throughout the world - are described in Reference 1. We have extracted Figure 1 and Table 1 from Reference 1, depicting the VC curves and their relationship to line width or feature size.

In this paper, we examine the evolution of vibration considerations in fab design. We discuss the present status, and elaborate on future needs, with specific reference to 300 mm conversion.

## VIBRATION DESIGN - THE PAST

The following table shows a limited view of the evolution of chip technology over the years, in terms of feature sizes and cleanroom class:

| Year | Clean Class | Line Widths | No. of Layers |
|---|---|---|---|

| | (typical) | (range) | (typical) |
|---|---|---|---|
| 1975 | 100 | 7 to 10 μ | 5 |
| 1980 | 100/10 | 2 to 5 μ | 7 |
| 1985 | 10 | 1 to 2 μ | 12 |
| 1990 | 1 | 0.8 to 1.2 μ | 15 |
| 1995 | ≤1 | 0.5 to 0.8 μ | 25 |
| Future | <1 | 0.10 to 0.35 μ | ? |

The above table is more typical to microprocessor chips. Metrology requirements are typically an order of magnitude finer than line widths shown. As class has become more stringent, the concentration of mechanical systems to achieve the cleanroom class has increased. At the same time, the line widths have reduced and the number of process layers involved in the product has increased. Not surprisingly, tool sensitivity has increased although not necessarily in direct proportion, mainly due to the fact that tool manufacturers have paid more attention to the vibration design of their tools and have opted to utilize more sophisticated vibration isolation mechanisms.

Throughout the migration to smaller feature sizes, vibration criteria consistent with Table 1 have been employed in fab design. For instance, fabs producing products using several-micron technology have been designed to VC-A (2000 microinches/sec) or VC-B (1000 microinches/sec). Of course at the present time, only back-end or some peripheral processes such as probe/test, assembly, CMP, and other manufacturing such as hard disk drive (which use greater than one micron feature size) utilize environments designed to VC-A or VC-B. More sophisticated submicron processes - such as microprocessors and DRAM - require much more stringent criteria which will be discussed later in this paper.

The same migration to smaller feature sizes has resulted in more sophisticated tools, which in turn, require more sophisticated and bulky hook-up components. The demand for utilities such as vacuum, chemicals, gases, conditioning, etc., have increased dramatically. All these have resulted in larger vacuum pumps, compressors, chillers, fans, etc., at the subfab or fab levels in close proximity to sensitive tools. The by-product of all this, of course, is greater vibration energy in the immediate vicinity of sensitive tools. This issue is even more exaggerated when we acknowledge the fact that many of these sources of vibration energy are packaged by tool vendors with little regards to their vibration design. Hook-up components are often poorly balanced and provided with little or no isolation. And of course, through this migration process, they have gotten larger and more numerous. In one operating fab we traced a very strong vibration tone to fans within a number of environmental chambers within which photolithography steppers were located. The tone could be seen in almost all areas of the fab.

The past needs of fabrication facilities have also evolved into sensitive and non-sensitive areas. Photolithography and metrology generally demand the quietest cleanroom spaces while other processes such as diffusion, implant, planar, etch, and thin films require little, if any, vibration control. Specific tool classes such as SEMs, TEMs, AFMs, FIBs, other inspection tools, and steppers demand the most control. Therefore, these tools located in analytical labs, and other spaces such as mask- or reticle-making facilities, require quiet environments. In the latter facilities, direct writing tools such as E-beams must also be added to the list. In our experience with mask-making facilities, AFMs and other inspection tools are more demanding than the E-beams. Also AFMs are more sensitive to sound pressure levels in the cleanrooms.

## VIBRATION DESIGN - THE PRESENT

The present-generation state-of-the-art fabrication facilities are manufacturing products using about 0.3 to 0.35 micron feature sizes. Consistent with the Table 1 guidelines, these fabs are generally designed to perform at or below VC-D (250 microinches/sec). Again, the performance requirement is driven by photolithography and metrology tools. This means that non-photolithography/metrology spaces may be designed to relaxed requirements as high as VC-A (2000 microinches/sec) depending upon the desire of the fab owners (some owners prefer to have two-tier requirement whereas others may want to have one criterion to gain added flexibility for their future retooling).

We should note that when we compare the specifications for present-generation tools to the VC curves, we find that most of these specification lie at or above VC-D. To our knowledge and experience, the VC-D curve has proven to be fairly adequate for present-generation state-of-the-art fabs.

During the last several years, the tool vendors have paid closer attention to the structural dynamics design of their tool. Some have employed experimental modal analysis along with finite element modeling to improve dynamic behavior of their tools. As part of this process, they have also resorted to using more efficient vibration isolation systems, such as active isolators. By these means, the migration to smaller line widths has been accommodated without significantly increasing vibration sensitivity.

Some tool vendors extend their tool specifications to frequencies as low as 1 Hz. This very low frequency requirement merits some discussion here. Assuming that the need to control the very low frequency vibration of the fab is real, let us examine the vibration sources which contribute to the vibration in this region. We believe that very low frequency vibration , say below 5 Hz, is dominated by two source categories. The first category is site ambient which includes the effects of near and distant traffic and the influence of site soil resonances which may be pronounced in some sites. We quantify the site ambient vibrations as part of the initial site study. We have found that The low frequency ambient vibration is unaffected by the presence of the building. The low frequency vibration cannot be mitigated significantly by foundation design, building loadings, trenches, or other means. The second category which affects the low frequency vibration comes from the horizontal fundamental resonance mode of the fab floor. The present-generation fabs usually have one or two levels of subfab which results in a low frequency horizontal resonance response due to the cantilever (or inverted pendulum) mode of the fab structure. This horizontal mode typically occurs in the range 2 to 6 Hz. It could even be lower than 2 Hz if horizontal stiffening elements such as shear walls, are not used. In fact, in geographical areas such as in Texas where the levels of seismicity is low, horizontal stiffening for seismic reasons may be minimal, resulting in a very low fundamental horizontal resonance frequency on the fab floor. To control this low-frequency response, we generally recommend structural elements such as shear walls, diagonal braces, etc.

We should reiterate the fact, as discussed earlier, that the tool hook-up components packaged with the present-generation tools have become significant sources of vibration while little regard has been paid to vibration control. Now-a-days, we see a significant change in the vibration performance of a fab floor in the "at-rest" condition (all tools operating) when compared to the "as-built" condition (no tool operating).

It is appropriate at this stage to discuss the pedestals on which the vibration-sensitive tools are mounted. Let us first discuss the vibration characteristics of the access floors. Every cleanroom usually has an access floor (to allow for air return and routing of utilities) varying in height from 12 inches to 36 or even 48 inches. These access floors are usually made of 24"x24" panels supported on aluminum (sometimes steel) pedestals. Access floors in general are very flexible, particularly in the horizontal directions. Their horizontal resonance frequencies are as low as 6 or 8 Hz. The vibration performance of an access floor is determined by the vibration-generating tools which are mounted on it, and by the effects of cleanroom personnel walking on it. We have found that the vibration levels on access floors are pretty much independent of the conditions on the fab floor. This means that access floors mounted on slab-on-grade floors (which have very low vibration), or mounted on column-supported (elevated) floors, have very similar vibration performance (assuming that the tool distribution on the access floor is the same). In our experience, the vibration performance of access floors lies in the range 4000 to 8000 microinches/sec. Obviously these performance levels are not adequate for vibration-sensitive tools. Therefore, access floors generally support non-sensitive tools while individual pedestals are designed to support vibration-sensitive tools. There have been recent discussions about the possibilities of designing raised access floors that are stiff enough to support vibration-sensitive tools. The concept is attractive since it would ease the process of tool relocation. Considering the fact that these future raised access floors would have to perform at a level some 30 times better than present floors, we believe that an acceptable, cost-effective, solution is unlikely at this time.

Now let us discuss the pedestals on which each vibration-sensitive tool must be mounted. Tool manufactures, in particular manufacturers of new-generation steppers, specify various combination of static stiffness and dynamic requirements on each pedestal. Let us define the problem here. Each pedestal has a height matching the adjacent access floors. The pedestal is independent from the adjacent access floor ( a ¼" air gap is typically provided). The pedestal is mounted on the fab floor which is performing at VC-D or there about. Therefore, the clear objective of the pedestal shall be to maintain the good vibration of the fab floor. In designing a pedestal for the above-stated objective, we treat the pedestal as a secondary structure attached to the primary structure of the fab. The pedestal is a multi-degree-of-freedom structure same as the fab structure. It has structural resonance modes which can interact with the structural modes of the primary structure (i.e. the fab) and its resonance modes can be excited resulting in the amplification of the "good" fab floor vibration. Therefore, the pedestal shall be rigid such that its fundamental structural modes are very high and removed from the frequency regions where the fundamental modes of the fab floor may occur and where significant vibration energy may exist (e.g. shaft speeds of hook-up equipment, etc.). Typically, structural tube sections or similar members are used for the design of these pedestals. Since steel has low damping, damping elements in the form of constraint-layer damping or other mechanisms may be incorporated to absorb vibration, especially at high frequencies.

## VIBRATION DESIGN - THE FUTURE

The future vibration needs of the microelectronics processes are to some extent unclear. We have a very good road map of how we have arrived to our present status. We can certainly use the experience gained to extrapolate and to elaborate as to the future vibration needs of these processes. The assumption must be that we will still be dealing with photolithography technology such as EUV, etc. In discussing the future needs, one must also discuss the transition to 300 mm wafers and the wafer handling and automation implications.

As we mentioned earlier, in recent years the vibration requirements on the fab floor have remained effectively constant while significant migration to smaller feature sizes has occurred. All this has been possible because of improvements made at the tools themselves (both better dynamic design of the tools, and the use of more sophisticated isolators). We speculate that the same trend will continue in the near future. We believe that fabs designed to VC-E (125 microinches/sec) will be adequate to handle technologies down to 0.10 micron and even beyond. We acknowledge, however, that tools for such feature sizes are not yet developed or are in their development infancy.

In fact, curve VC-E is very close to the ambient vibration conditions that exist in many sites. Even with the best available means of control over facility vibration, one cannot achieve a fab environment that is less than that of the site ambient. Now if we speculate that future migration to smaller feature sizes might outrun the limits of isolation and design improvements then what are the options?

The answer may be to isolate the fab building from the ground that supports it. The concept and the technology is now available to isolate the fab waffle structure. These isolators may be installed at the attachment of the fab floor to the fab columns. This isolation could potentially improve the fab floor vibration by about 10 times or more. For instance, if the ambient is at about 100 microinches/sec, the isolated fab floor could perform at about 10 microinches/sec. We should note that structural and other details should be worked out by performing R&D to materialize this concept. For instance, a fab floor which is typically made of concrete will have structural resonances which would degrade the attenuation provided by the fab floor isolators. R&D needs to be carried out to resolve this issue such as investigating ways of improving concrete damping characteristics. In this concept, the access floor will be supported independently of the isolated fab floor.

Now to discuss the future vibration needs of 300mm technology. We know that most of these tool sets are currently under development and are in pilot runs. To our understanding there are no inherent vibration differences between 200 mm and 300 mm tools. Aside from the fact that, larger wafers will demand larger (both in size and mass) tools which, in turn, will require the tools to be evaluated for these changes, to insure that their component resonances are not shifted to undesirable regions. Assuming that the tool manufacturers account for these changes in their design of the tools, the vibration requirements from the 300mm tools are expected to be similar to those of 200mm tools. In fact, at the present time, we have several 300mm fabs under construction which are designed to curve VC-D. The primarily driver on the criterion is still the feature size.

As part of the 300mm tool sets, integration and automation in wafer handling are essential. Automation systems and robotics can be significant sources of vibration one must consider. Many vendors are in the process of integrating metrology and inspection into each tool to allow for real-time and interactive inspection of the product. This is in contrast with the present practice where metrology and inspection occur independently from individual wafer processes. The present practice allows us to place vibration-sensitive metrology tools in locations that are removed from major vibration sources (which includes vibration-generating tools). Integration of metrology and inspection into future 300mm tools will bring vibration-sensitive tools to the close proximity of vibration-generating tools. This will have two effects: First, the fab environment has to meet perhaps the same vibration requirements throughout (as opposed to a two-tier criterion); the second effect will be the coupling of a vibration-sensitive component (i.e. the metrology) with a vibration-generating component. Here, it might be necessary to incorporate vibration isolation and dampening at the mounting of vibration-generating components of the tool. Additional measures may also become necessary.

## REFERENCES

1. Institute of Environmental Sciences, "Considerations in Clean Room Design," *IES-RP-CC012.1 (1993).*