

Facility Vibration Issues for Nanotechnology Research

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Abstract

The paper presents an overview of the vibration requirements of nanotechnology facilities, drawn from both the semiconductor world and that of precision metrology. Structural approaches are discussed which are commonly used to meet some of the special vibration needs of these facilities.

Introduction

Nanotechnology has been defined as research and technology development dealing with particles and systems with dimensions of approximately 1 to 100 nanometers. Some aspects of this work require extremely stable environments. In many cases, the environment typical for semiconductor production is appropriate. In other cases, it is not enough. In still other cases, it is too much, and not cost-effective.

This paper examines nanotechnology from the perspective of a member of the advanced technology building design team, the vibration consultant. It explores the variety of vibration environments required by different parts of the nanotechnology community, and how some of the more demanding of these environments are being provided.

Aspects of Nanotechnology

There are many aspects to nanotechnology research. They include theoretical studies, modeling, surface characterization, development of equipment for nano-scale manipulation, atomic manipulation itself, and nano-scale manufacturing. These branches require widely differing physical environments. The least demanding work may be done in a conventional office. The most demanding may require clean space, thermal stability, and quiet acoustic and vibration background.

In many ways, this range of physical demands is similar to that for semiconductor R&D,

but semiconductor research is often incorporated into large facilities where these functions can be physically separated. In addition, unlike the semiconductor environment, the people developing the specialty equipment may also be the end users of that equipment, and may require the stable environments for production and testing of the equipment.

A small nanotechnology R&D facility, such as that typically planned or in place at universities or government laboratories, may require several different environments. It is important that the planners and designers correctly assess the needs of the users, because good vibration environments are difficult to retrofit.

Processes Involved in Nanotechnology

Much of the fabrication process using semiconductor-style production is inherently vibration sensitive, but the requirements are well known, and the more sensitive equipment usually has built-in vibration isolation. In general, it can be stated that processes such as deposition or bulk surface characterization—where statistical uniformity is often the goal—may be less vibration-sensitive than processes requiring precise, repeatable positioning on a surface. The latter category includes electron and probe microscopy, lithography, and what might generically be called “atom pushing”.

Processes involving electron beams or probes are often trying to develop a relatively precise “image” of a surface, such that individual details or patterns may be identified. In order for this to work, the relative positioning of the beam or probe and the object being scanned must be stable and predictable. If the surface being scanned moves during a scan, then an object may appear to be in more than one location, or be entirely overlooked. In the case of atom repositioning, the positions of the starting and ending points must remain constant (or at least known) during the operation. Both

vibrations and excessive thermal variation can interfere with this stability.

Many sensitive tools used in nanotechnology have tool-specific vibration requirements. However, there are a number of reasons why it is undesirable to design specifically for individual tools. New tools are likely to be introduced over the life of the facility. Most design teams for advanced technology facilities are unfamiliar with the large variety of measurement methods and units associated with these criteria. There is a limited body of experience within the design and construction industry with regard to meeting these specialized needs.

Instead, it has become common practice to use a limited set of published “generic” vibration criteria which may be selected for a facility or space within a facility based upon the most demanding equipment likely to be used in a given process. The most popular of these criteria are defined in Table 1 and shown graphically (as velocity spectra) in Figure 1.¹ (3, 4)² Many of these criteria have been in use for 20 years in several advanced technology communities, providing an “experience base”, and have been applied to the design several nanotechnology facilities.

Generic Vibration Criteria

The generic facility criteria given in Table 1 that pertain to nanotechnology may be divided into four groupings, depending upon the application.

- Spaces in which human sensitivity is the only concern—Design the space to meet the “Office” criterion of the International Standards Organization (ISO). Vibrations meeting this criterion will be perceptible, but not intrusive.
- General laboratories in which low-to-medium power optical bench microscopes are used—Use vibration criterion VC-A; occasionally VC-B is used to accommodate higher-power bench microscopes.

¹ The generic criteria in Table 1 and Figure 1 are given in terms of RMS velocity amplitude as processed in one-third-octave bands of frequency. See Ref. 1.

² Numbers in parentheses refer to references at the end of the paper.

- Highly-sensitive spaces in which submicron processes are carried out—Use criterion VC-D or VC-E (both routinely used worldwide for semiconductor facilities). An alternative is NIST-A (used for “metrology” laboratory space at the Advanced Measurement Laboratory (AML) at the USA’s National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland). NIST-A is more stringent than VC-E at frequencies below 20 Hz. (3)
- Spaces requiring a better environment than can be provided even by a quiet site may have a “better than NIST-A” environment defined by NIST-A1. (3)

Generic Criteria for Nanotechnology Facilities

The goals of nanotechnology facilities differ somewhat from one to the next, and these differences can introduce some interesting facility design challenges. (For instance, project may involve placing viruses—which require biocontainment—on silicon wafers—which require cleanrooms. A biocontainment space requires negative pressure to prevent hazardous microbes from escaping. A cleanroom requires positive pressure to prevent contaminants from intruding. These two requirements are difficult to reconcile.) However, the task of assigning generic vibration criteria is somewhat more straightforward. Table 2 lists specific types of activities and the vibration criteria that can generally be assigned to areas in which those activities are carried out:

- Research offices, computer modeling, theoretical studies
- Generic laboratory space, optical microscopes, epitaxy, CVD
- Photolithography, nanofabrication: These spaces, we are assuming, require cleanroom space
- Metrology, surface characterization, SEM, SPM, AFM: These activities, we usually assume, do not require cleanroom space, unless they are to be performed “in-line” with photolithography.
- Instrument development

Besides vibration isolation to control vibrations from mechanical systems, the most important design aspect for achieving a stringent criterion is the

design of the floor. Table 2 also defines common structural approaches used to achieve these criteria. Precise dimensions depend upon the specifics of the building being designed. Appropriate methodologies are discussed in the literature. (2)

The boundary between the last two categories is somewhat indistinct. Instrument development may involve design, fabrication and testing of new-technology hardware (such as scanning probe devices) of unknown vibration sensitivity. In order that the vibration environment not limit the hardware's capabilities during design, it might be appropriate to provide a small area in which the vibration environment is better than what will be expected during routine use, as in metrology or characterization. Between the time of successful testing and routine use, the designers can develop adequate vibration isolation for the hardware. This approach has been incorporated in many spaces in the subterranean portion of NIST's AML, where new technologies will be developed for measuring nano-scale forces and dimensions, and will be used to a much lesser extent at Purdue University's Birck Nanotechnology Center, where part of their mission is to expand the capabilities of scanning probe systems.

Achieving "Better-than-Ambient" Conditions

In general, a properly designed facility intended to meet VC-D, VC-E, or NIST-A will be able to provide an environment no better than the ambient vibrations that exist with the building absent from the site. One would not want to place such a facility next to a rock quarry, for example, because the stiff building would simply vibrate the same as the soil beneath it. Even in a relatively quiet location, we have found that it is almost impossible to achieve an environment significantly better than VC-E or NIST-A.

In cases where a quiet location is not enough, one must resort to some sort of vibration isolation. Many commercially available instruments (such as SEMs, AFMs, etc.) are sold with internal vibration isolation, either passive or active. Equipment requiring a "better than ambient" environment may be developed on an optical isolation table, which can provide NIST-A1 or better, or the vibration isolation can be built into the facility, as they will be at NIST's AML and the Purdue facility. This may be implemented using a large inertia mass supported on pneumatic springs.

The top of the mass can be at the elevation of the surrounding floor, or below that level with a separate "walk-on" floor above it. The latter is shown in Figure 2, after Ref. 3, and was developed and studied for NIST.

Conclusions

The vibration requirements of various aspects of nanotechnology have been discussed, and appropriate generic criteria for facility design have been presented. Some of these criteria and the structural systems required for their implementation may be drawn from the semiconductor industry. Others are unique to precision metrology and process development. Applications at nanotechnology facilities now under design or construction have been incorporated in the discussion.

References

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Table 1. Common generic criteria.

Category	Criterion	Definition
Human Sensitivity	ISO Office	400 to 800 $\mu\text{m/s}$ (16,000 to 32,000 $\mu\text{in/s}$)
Generic General Laboratory	VC-A	50 $\mu\text{m/s}$ (2000 $\mu\text{in/s}$), relaxed below 8 Hz
	VC-B	25 $\mu\text{m/s}$ (1000 $\mu\text{in/s}$), relaxed below 8 Hz
Highly Sensitive	VC-D	6 $\mu\text{m/s}$ (250 $\mu\text{in/s}$)
	VC-E	3 $\mu\text{m/s}$ (125 $\mu\text{in/s}$)
	NIST-A	0.025 μm (1 μin) displacement for $1 \leq f \leq 20$ Hz; 3 $\mu\text{m/s}$ (125 $\mu\text{in/s}$, or VC-E) velocity for $20 < f \leq 100$ Hz
Ultra-Sensitive	NIST-A1	6 $\mu\text{m/s}$ (250 $\mu\text{in/s}$) for $f \leq 5$ Hz; 0.75 $\mu\text{m/s}$ (30 $\mu\text{in/s}$) for $5 < f \leq 100$ Hz

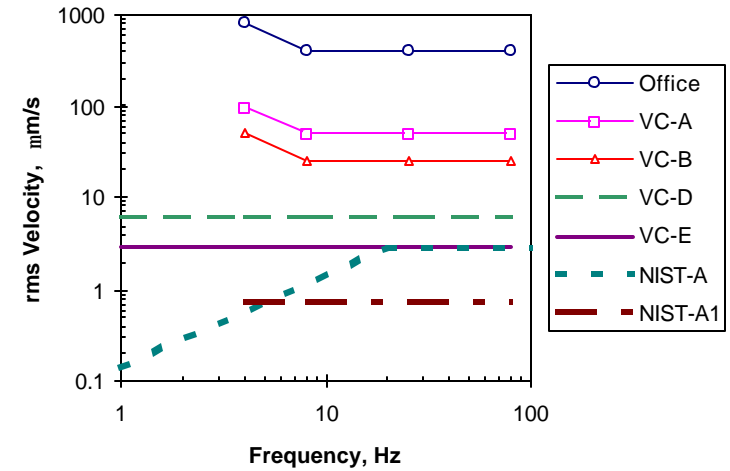


Figure 1. Common generic criteria in the form of velocity spectra.

Table 2. Generic criteria assignable to nanotechnology spaces, and the structural approaches to achieving them.

Space Type	Criterion	Structure
Research Offices, Computer Modeling	ISO Office	9 to 12 m (30 to 40 ft) spans, concrete slab on moderate-depth steel or concrete framing
Generic Laboratory Space, Optical Microscopes, Epitaxy, CVD	VC-A/B	6.5 to 10 m (21 to 33 ft) spans, concrete slab on deep steel or concrete framing
Photolithography, Nanofabrication	VC-D/E	Slab-on-grade; or concrete waffle or open grillage with 3.5 to 5 m (12 to 16 ft) column spacing
Metrology, Surface Characterization, SEM, SPM, AFM	VC-E or NIST-A	Slab-on-grade; or concrete waffle or open grillage with 3.5 to 5 m (12 to 16 ft) column spacing
Instrument Development	NIST-A1	Pneumatically isolated inertia slab

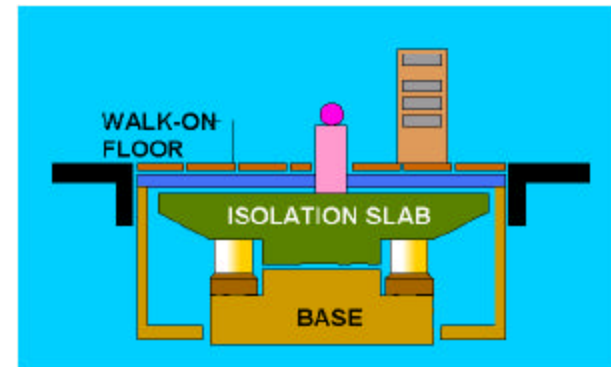


Figure 2. Schematic cross-section of NIST A1 isolation slab (3).