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Active Vibration Control in Fabs

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At a Glance

As device geometries go down, the need to isolate sensitive process tools from vibration increases. Building construction techniques and passive control methods can keep most of the vibrations under control, but low-frequency vibrations are still a problem. Adding active vibration control to the tool itself can cancel those problems.

Many processes in fabs are highly sensitive to vibrations. In optical and electron beam tools, they can generate internal relative motion along a beam path that either blurs an optical image or causes an electron beam to deviate from its intended path. Imperceptibly small vibrations from road traffic and passing workers as well as nearby machinery and air handling systems can have serious consequences such as lower resolution, reduced yields and reduced throughput. Also, mechanical devices like motors, pumps, fans and valves mounted on tools can introduce troublesome jitter. Vibrations on the order of a few micrometers per second can limit the minimum dimensions that many tools can resolve. The positioning and mounting of a tool can do as much to limit its performance as the design of the tool itself.

It is not uncommon to hear the question, "Why is vibration of greater concern in a fab than in a regular building?" A microelectronics cleanroom experiences about 100X the mechanical power per square foot that a conventional office building does, mostly because of the mechanical equipment. Also, critical process tools in the cleanroom are about 100X more sensitive to vibration than are the people who occupy the typical office building.

A number of trends indicate a need to re-examine the methods of protecting vibration-sensitive tools from vibration. One relatively new approach, active vibration control, can be implemented on individual tools to cancel those vibrations that can still make their way to the tool (Fig. 1).

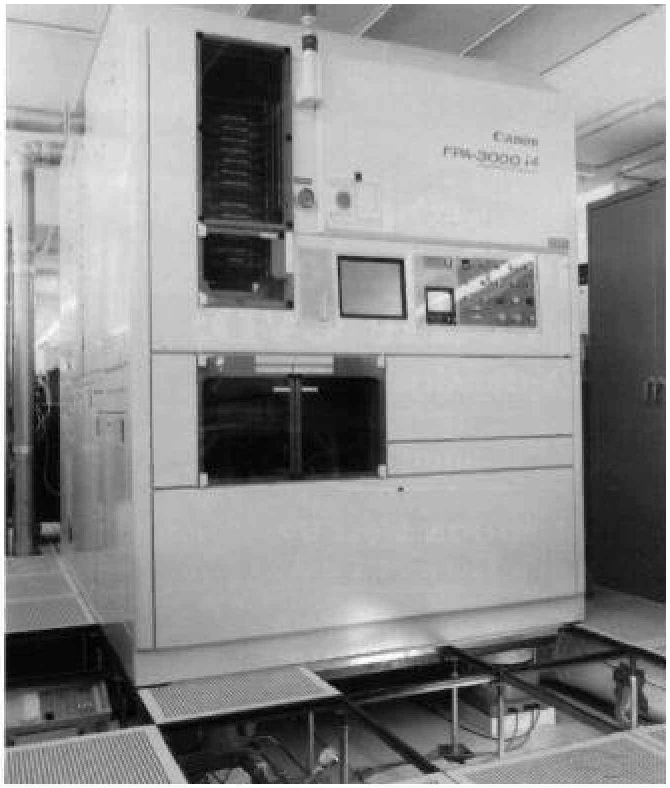

Figure 1. Actively controlled vibration isolators cancel the low-frequency vibrations that can limit the performance of tools like optical steppers.

TRENDS

Over the last two decades, the semiconductor industry has had to deal with progressively smaller line widths. At this time, typical cutting-edge line widths are about an order of magnitude smaller than in the mid-1970s, when the semiconductor industry was first becoming aware of problems caused by vibrations. Tools now under development are being designed to produce line widths of 0.1 μm. At the time of this writing, one such photolithography tool is producing 0.15 μm line widths on a consistent basis and 0.12 μm line widths intermittently. Industry groups predict that the trend toward increasingly smaller line widths will not abate in the foreseeable future.[1]

Because of the decreasing line widths, the criteria to which facilities are designed have become more stringent, as shown in Figure 2. Today, facility-induced vibrations can be so well controlled that the vibration environment is limited by the site itself. It is unlikely that ambient vibration rms amplitudes significantly below 3 μm/sec can be achieved using conventional construction. However, one industry group predicts that further reduction of vibration amplitudes will be required. Most likely, this reduction will have to be in the form of improved tool isolation.

Fab costs have increased dramatically with time. A relatively small part of that cost is associated with vibration control, but some are taking a look at ways to reduce that cost. Several fab owners are exploring ways to build fabs to less stringent requirements, accommodating the tool requirements in other ways, including active vibration control.

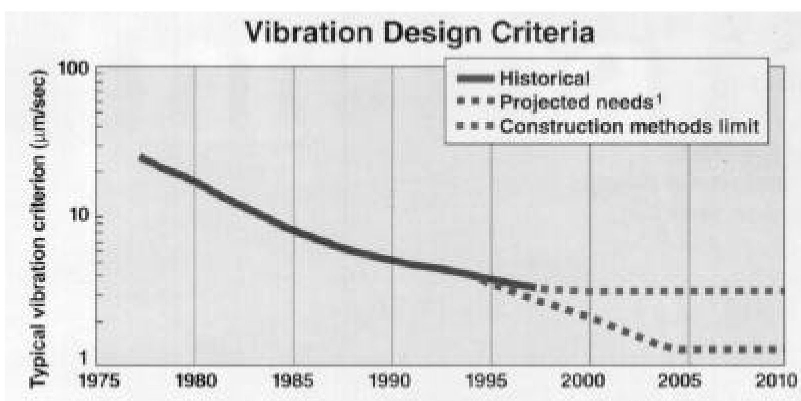

Figure 2. Vibration design criteria continue to become more stringent. Construction methods alone are reaching their limits.

Vibration concerns can limit an older fab's ability to be updated. In many cases, the facility may have adequate volume for new equipment, but the vibration environment associated with the existing structural floor limits the options. In other situations, owners add more and more process support equipment (such as vacuum pumps) to relatively recent fabs and degrade what started out as a high-quality vibration environment. Figure 3 shows how several major fabs, all built in the 1990s, changed over time.

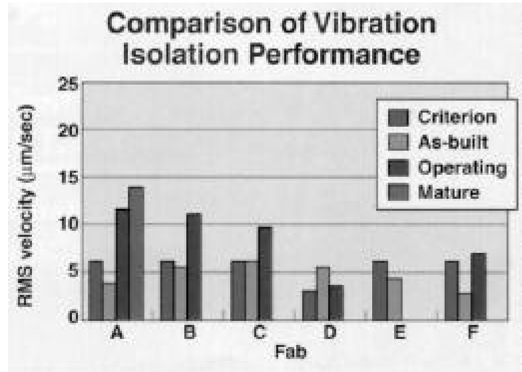

Figure 3. The vibration performance of several current-generation fabs over time shows the difficulty of keeping vibration under control over the life of the fab.

TRADITIONAL VIBRATION CONTROL

Owners and designers of semiconductor fabs employ extensive means to minimize vibration in the completed facilities. The means traditionally employed include the following:

- Locating plants in areas relatively free of vibration;
- Designing extremely stiff structures that attempt to replicate on-grade vibration performance despite the presence of one or more levels of basement below the fab;
- Planning site and facility layouts to maximize distances between mechanical vibration sources and vibration sensitive tools. This is becoming increasingly difficult as much of the process support equipment, such as vacuum pumps, must be placed quite close to tools. Quite often, this equipment is installed after the fab is operational and is usually the primary source of vibration in mature fabs;
- Incorporating structural isolation breaks between vibration-producing and vibration-sensitive portions of the facility;
- Avoiding placement of vibration-sensitive tools directly on access floors; typically tools are supported on stiff steel pedestals that rest on the structural floor and provide a bearing surface at the elevation of the access floor;
- Providing vibration isolation hardware on mechanical equipment, piping and ducting.

Structural rigidity of the building and the tool are not the only factors to consider in reducing the performance-limiting effects of vibrations. For most high-precision tools, some kind of vibration isolation system must be used as a part of the support structure. Equipment manufacturers typically add built-in vibration control systems to control internally induced vibration. However, additional vibration isolation systems, which reduce internally induced and floor vibrations, may be required to achieve adequate equipment stability and performance.

Traditional approaches to "stiff' design are much more limited with regard to horizontal vibrations than with vertical. The typical range of horizontal resonance frequencies is between 2 Hz and 6 Hz. It is virtually impossible to design a multilevel fab, with one or two levels of basement, to have a resonance frequency significantly above 6 Hz. Vibrations in this frequency range can be difficult to mitigate with conventional pneumatic tool isolation systems, since their resonance frequencies are in this same frequency range and may actually amplify these vibrations.

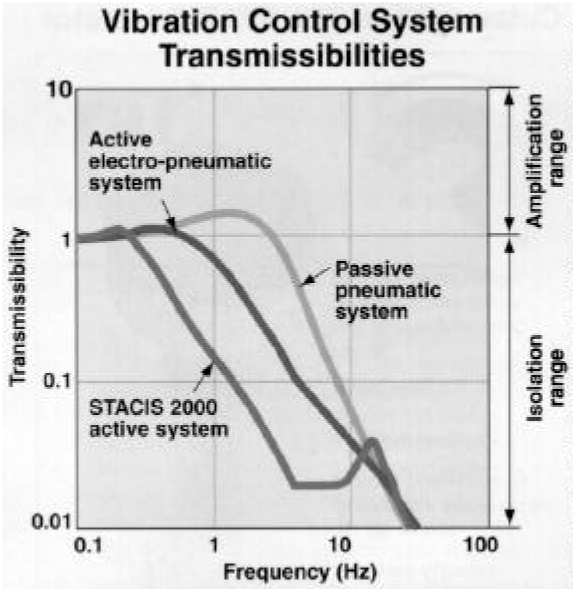

Figure 4. The vibration transmissibility of three isolation systems are compared at low frequencies. Note that the passive pneumatic system can amplify vibrations at frequencies above 2 Hz.

ACTIVE VIBRATION CONTROL

Active vibration control systems electronically sense and cancel vibrations in real time. In the last five years, advances in materials, electronics and vibration control technology have made active vibration control systems affordable for many precision applications.

Electronic isolators offer performance that is not physically possible for a pneumatic isolator. For example, pneumatic isolators offer no isolation below 1.5 Hz and may even amplify vibrations in this range (Fig. 4). Yet electronic sensing and actuator control enables active isolation starting at 0.3 Hz. This provides far better protection against low-frequency vibrations. With higher siffnesses, active control systems offer significant improvements in settling time after a disturbance (Table 1).

A hybrid system, using active vibration control for low frequencies and passive vibration isolation for high frequencies, can provide optimum isolation. It can work in combination with an internal pneumatic or active system, resulting in enhanced vibration reduction with no interaction effects. One such system is STACIS by Barry Controls. Tool compatibility is a major concern for such a system, but STACIS systems have successfully isolated stepper, scanner, SEM, FIB, photomask and metrology equipment from a variety of suppliers.

THE STACIS ACTIVE SYSTEM

Table 1. Stiffness and Settling Time Comparisons

	Stacis 2000 (20 Hz)	Elastomer isolator (10 Hz)	Pneumatic isolator (1.5 Hz)
Stiffness, lbs/in., 1000 lb load	40,000	10,000	<200
Settling time after step input (sec)	0.4	1.0	<3.3

The STACIS system combines active suspension based on piezoelectric actuators with passive isolation technology. The main components of the system consist of a user interface controller for data acquisition and diagnostics and three to four active, independent isolators positioned under the equipment they serve. As shown in Figure 5, each isolator houses five piezoelectric actuators, four vibration sensors and a passive elastomer mount.

The actuators control vibration along all three axes: one element for the x-axis, one for the y-axis and three for the vertical z direction. The piezoelectric actuators receive information on disturbances through absolute velocity sensors. This information from the sensors causes the actuators to expand or contract as required, diminishing or eliminating the impact of vibrations.

At high frequencies above 200 Hz, isolation is predominately passive, provided by the elastomer mount. The elastomer itself is formulated to provide a highly damped natural frequency of about 20

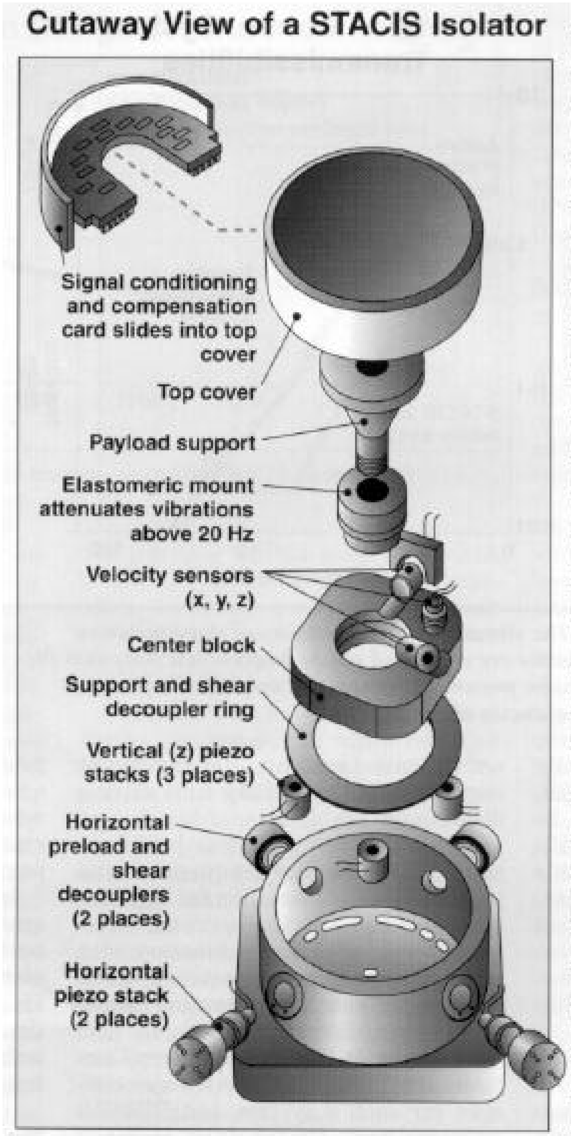

Figure 5. Cutaway view of a STACIS isolator.

Hz. The elastomer mount also functions to stabilize the system, decoupling the dynamics of the payload from those of the isolator.

Isolation is purely active at low frequencies between 0.3 and 30 Hz, and both the active and passive mechanisms are at work between 30 and 200 Hz. This combination provides isolation starting at 0.3 Hz, with about 80% isolation at 1 Hz and >90% isolation at frequencies above 2 Hz.

BENEFITS IN THE FAB

Active vibration control systems allow semiconductor equipment to operate at maximum speeds and throughput without excessive vibration or motion. As a result, fabs have greater flexibility in machine location. This is particularly important in fabs that do not meet stringent vibrational requirements. In existing or refurbished installations, active control systems may provide the necessary isolation, eliminating the need for expensive construction.

By reducing the amount of vibration transmitted from the floor, to the machine, active vibration control systems enable older fabs to use current, vibration-sensitive equipment. In addition to allowing older facilities to be upgraded, newer facilities can use this technology to expand lithography and metrology areas outside of their originally designed boundaries. This would allow fabs to respond more quickly to increased capacity demand.

With exceptional low-frequency isolation, an active vibration control system can provide the flexibility to place sensitive equipment on higher floors in a fab or in tougher vibration environments. Another benefit is the ability to increase the density of precision equipment to maximize the utilization of costly fab floor space. Finally, since it can be seen as part of the tool, the system moves with the equipment to prevent additional building reconstruction. An active vibration control system has very little adverse impact on the cleanroom environment.

As a result of a quieter, more consistently controlled environment, one possible lithography benefit is a more consistent, tighter distribution of the variances from optimum resolution and critical dimension repeatability over time. To understand vibration effects on performance, FINLE Technologies is working with Barry Controls to develop a vibration simulation module for the PROLITH lithography simulation package.

Benefits for OEMs

An active vibration control system can be used for a variety of applications, including steppers, SEM/TEM, mask aligners, mask inspection equipment, laser trimmers, crystal growing furnaces, mask/wafer repair and others. The system not only works with these systems, it may actually enhance their operations. With less tolerance required to compensate for vibration, a lithography tool can achieve finer line geometries or operate at higher speeds to increase throughput.

For example, an active vibration control system's low-frequency vibration reduction can help isolate a scanner's projection optics to achieve high resolution and tight overlay control. A vibration settling time of <0.3 see can also allow higher scanner throughput by allowing high-speed, high-acceleration synchronized scanning stages. By using information feed forward, this settling time can be decreased to less than 0.1 sec.

In another case, a stiff, non-pneumatic, active vibration control system can prevent leveling and floating issues for steppers and metrology machines. Since throughput is limited by the rate the wafer steps from one exposure or measurement to another, an active system can reduce the time the machine waits for vibration to settle between exposures or measurements. According to one lithography equipment manufacturer, this is even more important as the industry develops lithography equipment for heavier 300 mm wafers, which have a lower vibration frequency and a longer damping time.

Conclusion

Active vibration control offers an excellent means to control excessive vibration in a wide variety of applications. It is particularly useful when attempting to use a newer generation tool in an older-generation fab or other space not originally intended for semiconductor production. In many cases, it is a less expensive alternative to structural renovation of a facility. An active vibration control system that does not rely upon pneumatic isolators does not exhibit resonance amplification at frequencies near 1 Hz. They can be used in applications involving low frequencies, and they are compatible with tools that have their own internal vibration isolation systems.

The use of active vibration control does not remove the need for careful attention to vibration control in facility design or renovation. However, it can provide a cost-effective method of improving the vibration performance of existing facilities, or retrofitting for new generations of tools or products. Used in conjunction with proper facility design, active vibration control will also create a higher quality vibration environment at new facilities, providing a safety margin against eventual aging and obsolescence.

Reference

1. "The National Technology Roadmap for Semiconductors," Semiconductor Industry Association (SIA), 1994.