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Dynamics of Advanced Technology Facilities
A Historical Perspective

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ABSTRACT

The purpose of this paper is to set in perspective some of the issues involved in the dynamic of advanced technology facilities. By dynamics we mean vibration performance and vibration response. Through much of the paper, attention is focused on the microelectronics industry since vibration here is of critical importance and since this industry, more than any other, drives the world's economy at the present time. Hopefully, the paper provides a suitable introduction for the papers that follow.

INTRODUCTION

The definition of "advanced technology" has taken many forms throughout the ages. There is no doubt, however, that dynamics and vibration have often played crucial (often destructive) roles in the development of new ideas and technologies.

There is no doubt, for instance, that Roman chariots often succumbed to the dynamic stresses imposed on them by rough roads and poor designs and that design improvements were driven, in part, to overcome these dynamic deficiencies. It is certain, also, that Galileo's astronomical observations were hindered by the dynamic response of his telescope and of the framework and structure used to support it. Vibration has long been an issue in metrology, affecting the performance of microscopes, balances, inductive measuring systems, chronometers, etc.

The facility that houses the process or instrument is, generally, the source of the vibration. The instrument itself, however, plays a crucial role in limiting and withstanding the response. Both the facility and the instrument must be considered and dealt with if an optimum and cost-effective solution is to be devised.

In some cases vibration can be accepted as an occasional nuisance that can be "worked around." It is not uncommon, for instance, for university researchers to carry out particularly sensitive experiments at weekends and nights when sources of vibration are less intense. Excessive vibration, however, cannot be tolerated if it interferes with critical observations—in the case of diagnostic laboratories, for instance—or production. The microelectronics "chip fabrication" industry is an industry where "high production" and "high yield" (meaning low failure rate) conditions are essential.

Some facts about the microelectronics industry serve to illustrate its importance as the focus of this session:

- The factories that produce microelectronics chips consume about one-hundred times the mechanical power that is consumed by a “normal” building. At the same time the machines (tools) used to fabricate the chips are about one-hundred times more sensitive to vibration than are the people who inhabit the normal building.

- Current microelectronics fabrication facilities (megafabs as they are sometimes known) cost close to two billion dollars each when one includes the cost of the fabrication tools. About seventy-five percent of this cost is associated with the tools. The cost of the “average” tool in a contemporary facility is about four million dollars.

- The level of technology produced by the microelectronics industry increases steadily (and spectacularly) year by year. The demands placed on the fabrication process are constantly increasing and must be met if the manufacturer is to remain competitive and profitable.

- The microelectronics industry is preparing for a move to 300mm wafers, from the present 200mm wafer. This move means extensive retooling and many new challenges. Although vibration is only one of the several challenges that must be dealt with, it is a critically important one—one that involves the design of both facility and tools.

CHIP TECHNOLOGY

Developments in microelectronics manufacturing since development of the early integrated circuits have been, and continue to be, spectacular. Moore’s Law which predicts large and continuous rates of increase in device capacity, has been followed with remarkable accuracy over the years. The stunning evolution of computers made possible by microelectronic semiconductor developments is obvious to everyone. The microchip is increasingly endemic to everything we use—cars, house appliances, health aides, etc. The demand for microelectronics products—microprocessors, memory chips, application specific chips, etc.—continues to increase and, inevitably, will increase for many years to come.

The state of chip technology is generally characterized by the “minimum feature size” or “line width” that is incribed within the chip. The smaller the feature size the more information that can be imprinted on the chip. The process of forming a complete integrated circuit involves a series of layers of processing on a silicon wafer. Most of these layers involve photolithography in which a light source shines through a mask to imprint details of the layer on the wafer. As each layer is applied the issue of registration accuracy is critically important, since each layer must line up exactly with all preceding layers.

The following table illustrates the rate of development of circuit complexity through the years. Complexity here is defined in terms of the line width and the number of process layers. The table includes typical clean “classes” used to rate the cleanliness of the cleanrooms required for chip production.

A History of IC Chip Complexity

Approximate Year	1975	1980	1985	1990	1995	2000	2005
Line Width (micron)	5	2	1	0.8	0.5	0.2	0.12
Number of Layers	12	12	15	18	20	22	24
Typical Clean Class	100	10	10	1	≤ 1	< 1	< 1

These developments in chip technology have required continuous developments in all areas involved in the production process including circuit design, tool design, contamination control and facility design. Vibration is but one of many contaminants that can affect the outcome, but it is increasingly critical as processing line widths continue to shrink.

MICROELECTRONIC FACILITY DESIGN

The "factory" within which integrated circuits are manufactured is generally called a "wafer fabrication facility" or a "wafer fab." The space within which the critical processes occur is clean space in which the air is constantly recirculated, filtered and conditioned. The fabrication cleanrooms are surrounded by support spaces for wafer storage, change rooms, metrology, parts clean, etc.,

In the early days of microelectronics manufacturing the fab floor was generally located at grade level on an on-grade concrete slab. The tools and their support systems—vacuum pumps, compressors, etc.—were all located in the cleanroom which was divided into bays and chases. Recirculated air was driven by free-standing laminar flow units above the process, augmented by air handlers, often located on a fan deck above the cleanroom.

Even in these days cleanroom space was extraordinarily expensive and manufacturers started using basements (or sub-fabs)—sometimes partial basements—below the process floor to house the tool support systems. Sometimes the basement also housed major mechanical systems such as chillers. On sites where sub-grade construction was impractical or expensive, the process floor would be raised to second floor level and the sub-fab function located at grade level.

The introduction of the sub-fab—and the need for sub-fab space is now standard throughout the industry—had the consequence that the process floor structure was now supported on columns with all the disadvantages of limited stiffness, low damping and resonance response that such a "suspended" structure entails.

In recent years several manufacturers have taken the concept of the sub-fab a step further. In order to improve cleanliness in process areas, and to support the "ballroom" as opposed to "bay and chase" process layouts, a second level of "clean" sub-fab located immediately below the process floor has been introduced. Recirculated air now flows through the "transparent" structural floor of the process level into the clean sub-fab from where it is passed back to the recirculated air fans. The conventional sub-fab—often called the "utility" sub-fab—lies below the clean sub-fab. So now the process floor is column-supported above two levels of sub-fab on columns that may be close to 30 ft. long. As tools become bigger and more complex, sub-fab heights increase, adding to the problem of dynamic control.

As fabs become larger, more complex and more expensive the idea of "stacking" fabs one above the other has become popular, especially in areas—like Singapore and Taiwan—where real estate is in short supply. Such a structure, incorporating two process levels complete with utility and clean sub-fabs and interstitial spaces could have an overall height approaching 100 ft., and entail the use of long, deep trusses to support the upper process level.

All developments since the days of the simple slab-on-grade process floor have increased the susceptibility of the process floor to vibration disturbance. And of course, this is happening at the same time as the fabrication process is itself becoming more demanding, tools are becoming bigger and mechanical power consumption continues to increase.

FABRICATION TOOLS

Of the many processes involved in the fabrication of microelectronics product, photolithography has traditionally been the most sensitive to vibration disturbance. In the microelectronics "factory" the photolithography tool lies at the heart of the mass production process. Problems here can affect the viability of the total process.

In the early days the photolithography tools mimicked the process of contact printing used in conventional photography. A light-sensitive emulsion (photoresist) was applied to the wafer, a "mask" (negative) carrying the information for the next process layer was set on top of the wafer and exposed to a light source. Contact lithography soon gave way to projection lithography and, finally, to stepper lithography in which each chip on the wafer is exposed in sequence and advanced projection optics and light sources are used to reproduce the exquisite detail required for state-of-the-art product.

A rather unique feature of the microelectronics industry is the rate at which the fabrication industry dictates technology development by the toolmakers. New tools are often created and enter the market with little time for development and optimization. The fact that vibration amplitudes on the floor of the toolmaker's laboratory are generally much less than the vibration amplitudes on the fabrication process floor can mean that a tool that works perfectly prior to delivery may not work satisfactorily after delivery.

Vibration sensitivity of tools has always been a problem and the fact that fabrication technology has progressed from feature sizes of 5 microns in 1975 to 0.35 micron now, says much for the design ingenuity of the toolmakers. Their task, of course, is to control vibration sensitivity by structural design within the tool and by the use of increasingly sophisticated vibration isolation systems.

Nowadays, the photolithographic stepper is not the only tool that exhibits vibration sensitivity in the cleanroom environment. Increasingly, metrology systems—scanning electron microscopes, atomic force microscopes, critical dimension measuring systems, etc.— are an integral part of the production process and are located within the heart of the cleanroom. Metrology tools are often also sensitive to acoustic noise and noise control becomes another design issue.

In the last several years robotic systems that handle the wafers—loading them into tools and transferring them between tools—have become essential components of the operating wafer fab. Vibration can also affect these systems, causing wafers to become misaligned and leading, in extreme cases, to wafer breakage.