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ENVIRONMENTAL NOISE CONTROL FOR SEMICONDUCTOR MANUFACTURING FACILITIES

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INTRODUCTION

This paper summarizes the authors' experience in modeling and controlling environmental noise from more than 30 semiconductor manufacturing plants ("wafer fabs") within the past six years. This type of facility typically has a large number of concentrated noise sources because of the unusually large amount of intake and circulation air required to maintain cleanroom conditions, the complex exhaust and pollution control equipment necessary to handle many specialty gases and chemical products, and high heating and cooling load requirements. Furthermore, these facilities are most often located in populated areas, making noise control important, as well as challenging. Modeling and noise control details for specific types of equipment (make-up air and exhaust fans, cooling towers, ventilated boiler and chiller rooms, piping, valves, etc.), as well as other considerations—such as site building layout with respect to sensitive residential areas—are discussed.

FAB NOISE SOURCES

The typical "campus" for semiconductor manufacturing contains buildings of several different functions. There is necessarily one or more fab building, in which the primary manufacturing process is carried out. This building is typically three to four stories in height to accommodate and separate vibration sensitive processes on one level, and cleanroom air movement systems plena and other mechanical equipment at other levels. Due to the vibration sensitivity of the process, it is common to have the most energetic building services equipment (boilers, chillers, major process fluid pumps, etc.) located in a separate "energy center" or "central utility building" ("CUB"). Noise-generating equipment might also be located in yards outside the CUB. Many facilities have open-air air separation plants that produce process gasses (nitrogen, oxygen, etc.). Finally, there is usually one or more administration buildings on site. In most respects, these are similar to typical office buildings, although they may also contain light manufacturing or laboratory facilities.

Associated with these facilities are many environmental noise sources. These include:

Exhaust fans. Large centrifugal fans are used for scrubbed acid exhaust, heat or "general" exhaust, volatile organic compounds (VOC) exhaust, and for other gasses and functions. These fans are typically located on the roof of the fab building, but are also often found on CUB and office buildings. A typical campus may have 30 or more exhaust fans with a total flow of more than 2 million m^3/h. Noise is primarily radiated from the stack exhaust openings with a significant degree of directivity. In addition, noise can be radiated from the fan ductwork ("breakout"), and from the fan motors (this is only an environmental noise concern if these sources are located outside).

Make-up air units and other air handlers. Make-up air fans supply outside air to the cleanroom recirculation air systems. These are located typically on the roof of the fab building. It is not uncommon to have several of these units, which most often employ "plug" (plenum) fans, supplying a flow of 90,000 to 180,000 m^3/h each. In addition, the campus will typically have several smaller units supplying air to the non-process levels of the fab, office, and other buildings.

Cooling towers. A bank of cooling towers is typically located in an equipment yard near the CUB building. Occasionally these are located on rooftops, but this is usually not done because of their large size (it is common to have up to 20 units with a motor power of 20 to 80 kW each). Most often induced-draft propeller fan units are used, but occasionally forced-draft centrifugal units are used. Cooling towers produce both “waterfall” and fan noise.

Boilers. Several large boilers with capacities on the order of 700 boiler horsepower are located inside the CUB building. Due to requirements for combustion air, one or more sides of the boiler room is typically louvered, allowing the noise from the boilers and associated pumps to radiate to the outside.

Compressed air vents. Air separation plants typically have several associated air vents, periodically producing mid- to high-frequency noise. These release excess gasses back to the atmosphere. One also finds vents outside the CUB building, associated with the oil-free air (OFA) compressors.

Emergency generators and continuous power supply (CPS) units. These sources are typically located outside or in well-ventilated rooms inside the CUB. The generators themselves are relatively quiet in comparison with the diesel engines that power them. The diesel engines typically only operate in emergency situations, and are exercised periodically for test purposes. With “standard” emergency generators there is no noise unless they are being exercised or during power outages, but with CPS units, the generator runs continuously and can generate significant noise from its cooling fan. Up to four of these units may be required for each wafer fab on the campus.

Pumps. Most process and building facility pumps are located within the buildings and are, therefore, not environmental noise contributors. However, certain pumps are typically located outside, including those used for condenser water supply to the cooling towers and chemical feed pumps associated with outdoor storage tanks.

Miscellaneous sources. Other noise sources include tank piping valves, degasifier towers, delivery truck traffic, etc.

Generally speaking, it is useful to characterize the nature of wafer fab noise. Nearly all fabrication facilities operate 24 hours a day, 365 days per year. Most of the noise sources associated with building services (air, water, process materials, etc.) produce continuous noise day and night. Exceptions may be cooling towers and boilers that operate in accordance with the varying heat load in the building, and emergency equipment, such as smoke exhaust fans and emergency electricity generators. Blow-off vents at air separation plants are periodic sources that occasionally “punctuate” the continuous noise.

The continuous sources produce noise throughout the audible frequency range. In most cases, the periodic sources (vents and valves) tend to generate mid- to high-frequency noise. All of these sources are likely to be audible near the plant. But since the high-frequency portion of the continuous noise, and most of the venting and valve noise, tends to be well attenuated by air absorption at larger distances from the plant (say, over 300 meters), one tends to hear, primarily, continuous low-frequency noise. Thus, when receivers are located near the fab, many sources of several types may be the subject of noise control; for communities at relatively long distances from the fab, it is most often the dominant producers of low-frequency noise (e.g., large exhaust fans, cooling tower fans, and boilers) that are the subjects of noise control.

ENVIRONMENTAL NOISE CRITERIA

Due to the need for highly-trained and educated personnel, wafer fabrication plants are most often located near populated areas large enough to support institutions of higher education. Even when located remotely, it is not uncommon for residential areas to develop near the plant to house employees and people working in support industries. Combined with the large numbers of noise sources described in the previous section, this is the reason why control of environmental noise is a concern and a challenge.

Throughout the world, environmental noise criteria and regulations take many forms. Although we can provide some general characteristics, reference must be made to local, state, national, and international ordinances. Noise criteria may vary depending on whether the site has existing developments or is a previously undeveloped site. Well-written ordinances will refer to potential receivers of noise in terms of land use, e.g., residential, commercial, or industrial. Most ordinances regulate continuous noise; some also account for time-varying noise exposure (for example, by the use of the equivalent energy (L_{eq}) metric), and others explicitly acknowledge, with stricter regulation, that intermittent and tonal noise can cause greater annoyance. Other variations include: reference to a fixed criterion level versus the ambient noise level; the use of other indices such as statistical centile levels (e.g., L_{10}, L_{50}, and L_{90}) and day-night noise levels (L_{dn}); and references to the property line of the noise generator versus that of the noise receivers. These details, along with the existing ambient noise levels on site, must be accounted for in any environmental noise control design.

A detail that is often omitted from environmental noise regulation, but which must be considered, lest the needs for noise control be underestimated, is the effect of meteorological conditions on the propagation of noise. In many instances, due to the large size of the fab campus, the sensitive receivers may be located at significant distance from the noise sources. When the receivers are located at distances of 100 meters or more from the primary noise sources, it is important to consider the effects of the variations in temperature, humidity, and wind speed and direction on the propagation of noise. Under certain conditions, meteorological effects can cause variations in noise level of 10 dB or more.

It is often difficult to obtain specific meteorological data for sites. While this is available from most airports and certain other authorities, it rarely contains wind and temperature data as a function of altitude, and, of course, it does not account for local variations at the site, caused by terrain, ground conditions, etc.

When the meteorological conditions under which noise control design is to be carried out are not specified by regulation, we typically take one of two approaches that must be agreed to in advance by the concerned parties. The first is to define noise control based on "nominal" conditions: average temperature and humidity for the area, and average wind conditions. When wind direction varies such that time in opposite directions is nearly equal, the implication is that wind can be ignored, on the average. The second approach is to use arbitrary "worst-case" conditions, where conditions most favorable to propagation towards the sensitive receivers are used. The word "arbitrary" is used, because, due to the non-stationary random nature of weather conditions, there will always be a worse "worst-case". In this sense, it is pointless to use maximum conditions. It should also be borne in mind that the most extreme conditions are not suitable for evaluation of noise (such as in wind speeds greater than 5 m/s). Therefore, conditions are selected such that most of the time, the design noise levels are within the criterion. Under certain conditions, the International Standards Organization recommends the use of the arbitrary wind speed of 1 to 5 m/s within $\pm 45^{o}$ of the direction of the receiver, as one example [1].

NOISE CONTROL

Layout. If noise control is addressed early enough in the project, the simplest solution is to control noise by advantageous layout of the campus buildings and external noise sources. The following are some general principles used to reduce noise propagation to sensitive areas:

(1) Identify surrounding noise-sensitive areas (neighborhoods, hospitals, parks, etc.)—including potential future developments of these areas. Also identify less-sensitive surroundings: roadways, railways, and industrial facilities. Arrange the campus buildings such that the noisy facilities (CUB, equipment yards, etc.) face the less noise-sensitive areas, and are shielded from the noise-sensitive areas by large, relatively quiet buildings (e.g., the office buildings).

(2) Locate equipment yards and air separation plants inside a "courtyard" formed by the CUB, fab, and other buildings, so that these buildings will act as noise barriers. Face boiler room combustion air intakes and other noisy CUB building services (compressor vents, etc.) inwards towards this courtyard.

(3) Utilize building feature barriers whenever possible. On rooftops, locate sources at lower elevations than building parapets. For buildings without parapets, it is sometimes possible to utilize the roof edges as a barrier if receivers are located nearby and the sources are located on the roof as far from the receivers as possible.

General modeling considerations. It is rarely possible to control all semiconductor plant noise sources by advantageous layout. In many cases, the layout is dictated by zoning, access, aesthetic, economic, and other considerations. Control of individual or groups of sources is often necessary.

In most cases, we have found that semiconductor facilities are not well represented by simple models that depict only a few of the most significant sources. This is because there is often a large number of "secondary" sources that contribute substantially to the overall noise level at receiver points. We therefore use a modeling package that can contain details about a large number of sources (between 40 and 80 in a typical fab campus), as well as a detailed representation of the building masses, ground contours and types, and meteorological conditions, since all of these play a major role in the prediction and control of noise in this situation.

Sources may be modeled differently depending on the nearness of the receivers. For distant receivers, the sound power of less significant and proximate (to each other) sources can be combined to reduce computation time (although this reasoning is becoming less relevant with fast computers). When the receivers are nearby, more detail about the radiation characteristics of sources (such as the various sources of noise from a cooling tower) must be modeled separately. In addition, certain forms of noise control, such as partial barriers, require more accurate definition of the radiation and directivity characteristics of sources.

General philosophy. When excessive noise levels are predicted, the general philosophy is to find the most cost-effective solution out of several possible solutions. The best solution will depend on whether there are a few dominant sources, or many sources with similar noise levels. The determination must be made whether noise control is most cost-effectively applied to certain significant sources, or to groups of sources simultaneously.

The most significant sources are identified using the noise model. In the model, noise control is applied to the worst-case sources in turn, until the noise goals are met.

Methods. The following discussion can apply to facilities in the design stage or in the operating stage. In the latter case, one has the advantage of being able to use measured sound power data in the noise model. For the former, equipment manufacturer's submittal data or standard prediction algorithms can be used to develop sound power data for the sources, but of course with less precision.

Exhaust fans (stack-radiated noise). Especially in the case where receivers are nearby, it is important to apply a directivity correction to the sound power radiated from exhaust stacks. This index is a function of stack diameter, among other parameters.

For control of this source, there are a number of different silencer configurations that can be used, including standard dissipative silencers, stack inserts, and active noise control. With dissipative silencers, care must be taken to ensure that fill materials are compatible with the chemical content of the emissions and the rigors of temperature and flow velocity. Sometimes the use of refurbishable or packless silencers is specified. Proper location of the silencer within the stack is important to avoid creating system effects that can reduce the effective insertion loss and increase pressure drop through the silencer.

In at least one case, where receivers were in very close proximity to a group of stacks of short height upon a tall roof, a barrier was effective in reducing the noise levels by several decibels as required. With this solution, one has to balance path-length increases that increase attenuation, with decreases in attenuation that may occur by placing the top of the barrier in higher noise regions dictated by the directivity of the source.

Exhaust fans (casing-radiated noise). The most effective control of this source is by full enclosure. Partial enclosures or barriers can also be effective at reducing noise, especially when high frequency motor noise is a problem. Lagging the ductwork and fan casing can provide some benefit.

Make-up air units and other air handlers. Often, with air handlers, it is most efficient to apply noise control within the unit itself at the manufacturing stage. Manufacturers typically have several means of reducing the noise radiated from their units, including advantageous fan wheel sizing, the use of plenum liners, splitter silencers, and fan inlet flow straighteners. In other cases, external silencers and barriers can be applied as appropriate.

Cooling towers. For design of noise control for large cooling towers, it may be necessary to distinguish between fan and water noise in the model. The simplest control solution is often modification of tower operation modes. When a greater number of towers can be operated at lower fan speed, the total fan noise will be reduced. It may be possible to use barriers in some cases, but barrier design is often complicated in this case due to height and air flow requirements.

Boilers. As much as possible, isolate other significant CUB internal noise sources, such as chillers, pumps, and compressors from the boiler room, which will necessarily be open to the environment to a large degree due to combustion air requirements. Acoustic louvres can be applied to boiler room vents, although these are usually of limited effectiveness at the low frequencies characteristic of large boilers. Absorption can be applied within the boiler room to reduce the noise available for radiation; this should be designed to work well at low frequencies.

Compressed air vents. A number of manufacturers make dissipative/reactive-type silencers specifically for control of blow-off noise sources.

Emergency generators and CPS units. Use full acoustically-lined and sealed enclosures with intake and exhaust silencers in the most critical applications. Partial enclosures and barriers will have a significantly more limited effect, but may be acceptable in less critical situations.

Pumps. The most effective control of this source is by full (ventilated) enclosure. Partial enclosures or barriers will also work in less critical situations.

Valves and piping. Standard noise control for these sources is acoustical lagging. A more effective solution for valve noise is to construct a sealed enclosure.

SUMMARY

This paper outlines various considerations undertaken in an oftentimes-complex noise control problem: a facility with many noise sources that is usually located near residential and other noise-sensitive areas. The problem is best addressed by taking an overall viewpoint, using a computer-based model that includes all of the relevant source details. In this way, practical and cost-effective noise control measures can be employed, whether the facility is in the design stage or in operation.

REFERENCE

1. "Acoustics—Attenuation of sound during propagation outdoors—Part 2: General method of calculation" International Standards Organization ISO 9613-2 (1996)