Immaculate Conception

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Can you conceive of a speck of dust only 0.1 microns across? Ten thousandth of a millimeter in diameter, it cannot be seen with the naked eye. Yet the Japanese semiconductor industry must contend with this invisible enemy, for shutting out such dust particles from semiconductor plants is a critical condition for creating the world's highest performance chips.

On the most advanced VLSI chips now available, 1-megabit DRAM (dynamic random access memory) chips, the circuits themselves are only one micron across; if a speck of dust a tenth that wide sticks to the threadlike circuit, the circuit may short out and the DRAM be rendered useless. The consequences of using such a defective chip in a rocket or guided missile are obvious.

A semiconductor plant producing high-quality chips must be, in effect, one big clean room. Moreover, as the level of integration increases from 4 megabits to 16 megabits, 64 megabits and even 256 megabits, the cleanness requirements become even more exacting; the diameter of the dust and other particulates that must be excluded shrinking from 0.06 microns to 0.04 or even 0.025 microns.

The future looks good for clean room demand. Conventional silicon semiconductors have nearly reached their maximum performance. To achieve even faster and more powerful chips, the industry may have to shift from silicon technology to biochips made of enzymes or microorganisms, and such bioelectronics applications will naturally require even cleaner clean rooms.

This is not a distant future prospect. Toshiba has already embarked upon mass production of 1-megabit chips. Hitachi, Texas Instruments Japan and NEC also plan to begin mass production later this year. Shipments of sample 4-megabit chips are in the offing, and a simple biosensor, the first stage toward realizing the biochip, may become commercially feasible in the early 1990s.

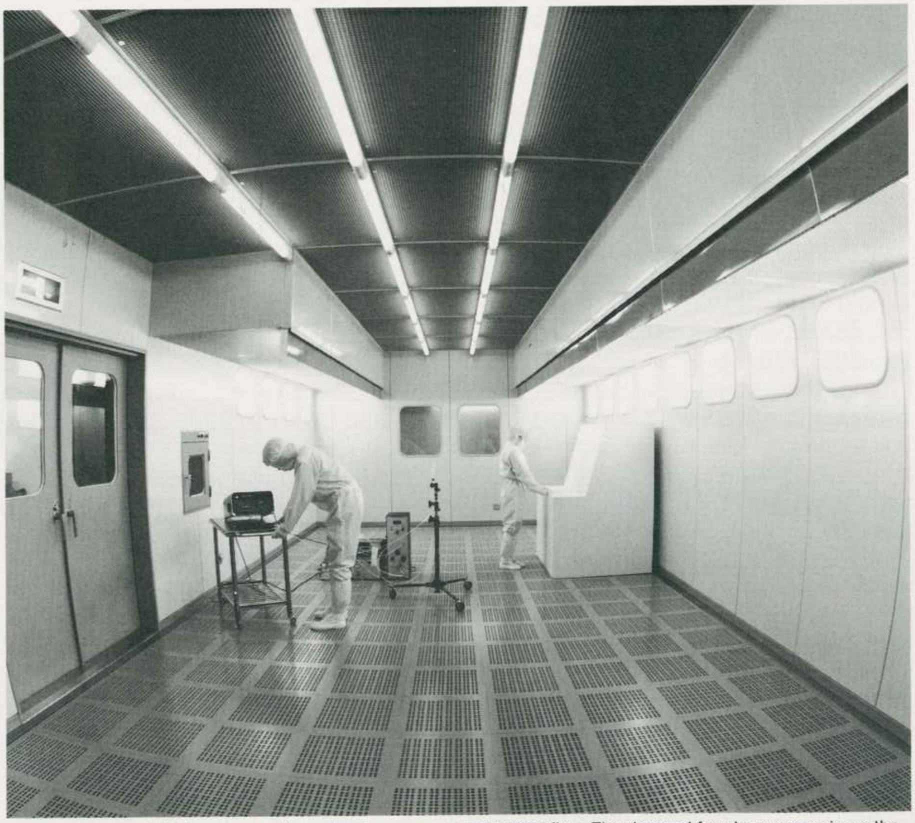
The clean engineering industry has been enjoying strong 20–30% annual growth as it becomes an increasingly crucial basic technology for all of the high-tech industries. Microelectronics now leads in clean engineering use, but biotechnology, food processing, chemistry, pharmaceuticals, clinical medicine and new materials also offer potential applications.

As the range of industries using clean rooms suggests, clean engineering is a highly diversified industry. Because it is primarily comprised of divisions within companies rather than independent firms, however, it is difficult to assess market size accurately. Still, rough estimates have been provided by the Japan Management Association, which will this autumn hold its third Clean Engineering Show in Tokyo, the largest show of its type in the world. At present, the association estimates, the market for clean engineering has reached ¥400 billion (about $2.2 billion at the rate of $1/¥180), and it is expected to grow to ¥1 trillion (about $5.6 billion) by 1990.

The super clean room

A clean room is technically defined as a room in which floating particulates, toxic gases, microorganisms and other microcontaminants are controlled to below a fixed level. To achieve that level of cleanliness, all room conditions, including air velocity, air pressure and humidity, are measured and controlled. Clean rooms originated in U.S. aerospace technology and have been used in such fields as precision machinery, microelectronics and fine ceramics. It was extensive adoption by the semiconductor industry in recent years, however, that provided the big push for clean room usage.

Clean rooms are subdivided into two groups, the industrial clean rooms used



Testing in the model clean room of a major Japanese construction firm. The demand for clean rooms is on the upswing.

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Integrated Circuit Size and Particulate Tolerance

Size of Integrated Circuit (in bits)	Smallest Circuit Width (microns)	Harmful Particulate Diameter (microns)
64K	3	0.3–0.6
256K	1.5	0.15–0.30
1M	1.0	0.1–0.2
4M	0.6	0.06–0.12
16M	0.4	0.04–0.08
64–256M	0.25–0.20	0.05–0.020

in the electronics, mechatronics and new materials industries, and the bioclean rooms primarily used in applications involving pharmaceuticals, chemistry and foods. In both groups, clean room engineering must provide precision control of room air conditioning, decontamination, microvibration and anti-static electricity, as well as, in some cases, electromagnetic shielding, superconductivity and supervoltage technologies. Given the sophisticated technologies involved, constructing a clean room is a complex, high-level systems engineering project requiring input from textile, construction materials, industrial robot, computer and other industries, as well as the major general contractors. And once built, the clean room requires stringent and constant quality control and maintenance. By its very nature, the clean engineering industry is a highly sophisticated and complex industry that has taken years of time and vast sums of money to develop.

Companies involved in the clean engineering industry are continuing to invest heavily in clean room research and development, despite the current slump in the semiconductor industry. Engineering firms such as Hitachi Plant Engineering & Construction and Chiyoda Chemical Engineering & Construction are racing to strengthen their clean engineering divisions and establish themselves in what they believe will become a growing market, particularly since their usual market for electrical power and petrochemical plants has peaked.

Semiconductor plants manufacturing 1- to 4-megabit chips need class 10 clean rooms—meaning that the room may have no more than 10 particles of dust 0.5 microns or greater in diameter per cubic foot. The clean room must have equipment to remove the gases generated by the chemicals used in processing semiconductor chips, and the human workers must, of course, wear electrically nonconductive and contamination-free garments. Their entering and leaving the room, and even their actions inside it, are also strictly limited.

To give an example of the degree of fastidiousness required, it was once standard practice to restrict the introduction of contaminants by placing toilet facilities outside the clean room. That, however, actually increased the risk of contamination as well as requiring a cumbersome two-stage changing room system. Recently, Toto and other top manufacturers of sanitary ware have developed fully automatic, sensor-controlled "clean toilet facilities" that eliminate the need for toilet paper and hand towels and do not splash water droplets into the air.

The production of chips with more than 4 megabits, however, will make the toilet problem moot by requiring class 1 rooms so clean that no human beings will be allowed in. Class 1 requires that there be no more than one particle 0.1 micron or greater in diameter per cubic foot. The super clean room will be a clean fully-automated factory, the exclusive stomping ground of clean robots, whose movable parts do not generate dust or static electricity, and of completely sealed, fully automated wafer carriers. When human participation is needed in an ancillary facility, the operators will have to don class 1 garments.

Toray Industries has gotten a jump on other firms by being the first to announce a line of class 1 clean wear. Clothes, of course, do not make the megachip, but the technology for class 1 clean rooms is almost entirely in place today, ready for application in the production of 4-megabit and larger chips.

Draft wine?

In Japan, the use of bioclean rooms has spread beyond the medical and pharmaceutical fields into the food processing industry. In the production of beer, wine, cheese and other fermented foods, for instance, pasteurization or other heat treatment during the production process can damage quality by killing off useful along with harmful bacteria. Yet if contamination by harmful bacteria could be prevented in the first place, no heat processing would be necessary, and firms have been turning to clean rooms for this. Not only draft beer but "draft wine" is a possibility under clean room conditions.

Clean room technology is also effective in keeping processed foods mold free. *Mochi* or glutinous rice paste is one of Japan's traditional festive foods; made in a clean room, it will not mold. In the United States, clean room technology is being introduced in ham processing plants and plants producing *surimi,* a fish paste that has been gaining popularity as an inexpensive health food.

Not needing to meet the same stringent standards, bioclean rooms for food production are not as expensive as industrial clean rooms. Nonetheless, the high cost of a bioclean room is still a barrier to widespread use. The clean engineering industry is working to develop reasonably priced, easily maintained bioclean rooms.

Clean rooms have become essential to improve product quality and raise yield ratios. But, "users must recognize that clean rooms are just one factor," says Hiromichi Hagiwara, chief construction engineer at Taisei, a major construction company that has recently built super clean rooms for VLSI production in its engineering research laboratory. "Clean rooms are designed to improve the production environment, but they do not guarantee improved yields."

Even a fully automated clean room does not ensure that a manufacturer will be able to turn out world-class semiconductors. High-quality production requires a host of other elements as well —the appropriate construction technology, production equipment, production technology, raw materials, plant utilities and overall production environment. Above all, it needs engineers and highly skilled workers to manage the system and use it well. Recognizing that clean rooms must function as part of a complex production system, several of Japan's high-technology firms have begun to market clean engineering technology packaged as complete production systems with all the essential factors designed in. Their approach shows an increasingly sophisticated understanding of clean engineering's potential—and how to market it successfully. ●