# Moisture Control in Photolithography Areas

Lewis G. Harriman III
Cargocaire Engineering Corporation, Amesbury, Massachusetts

One of the process variables of importance in lithography areas is the atmospheric humidity level. Standard mechanical system engineering practices have in the past allowed this variable to fluctuate within a wide range. In order to achieve more repeatable results in photolithography areas, many wafer fab managers are narrowing the range of permissible humidity fluctuation in the processing environment. Designing moisture control equipment for these industrial tolerances demands a better understanding of the nature and dimensions of moisture loads that must be removed from the space. This article discusses the application of industrial dehumidification equipment in photolithography areas. Such equipment has the large moisture removal capacity necessary for maintaining tight humidity tolerances.

IN MANY PHASES OF SEMICONDUCTOR INTEGRATED CIRCUIT and circuit board manufacturing, humidity must be maintained within close tolerances. The specific reasons for this control vary widely by process and production technique. One area that is universally sensitive to wide swings in atmospheric moisture is the photolithographic processing area in typical wafer fabrication and multilayer circuit board machine rooms. The adhesion, exposure and development of photoresist compounds can be affected by moisture extremes.

Generally, humidity levels below 20% RH at 70°F are undesirable because some resists, notably Diazo or "positive" resist compounds require some small amount of atmospheric moisture in the exposure and development phase. Also, static electricity can be a problem in such areas, and the problem appears to increase below 20% RH due to the nature of the equipment and materials used in wafer fabrication. On the other hand, humidity levels above 40% RH at 70°F can adversely affect the adhesion characteristics of some resist compounds to the silicon surface. Lengthy trial and error experience of some of the major manufacturers of integrated circuits has often led them to a compromise control level between 30% to 35% RH at 70°F, with a tolerance of ±2% RH. The question that confronts the design engineer is how best to achieve and maintain that control level within the allowable tolerances.

### Defining the Loads

The basis for the mechanical equipment design is the amount of moisture which must be removed from the clean room. In typical industrial environments with relatively well defined processes, the calculation of moisture load is fairly straightforward. The difficulty in designing for semiconductor processes is that the technology and equipment used to fabricate integrated circuits can change very rapidly. The addition of a new piece of processing equipment that requires a large exhaust air volume can substantially alter the original design criteria in terms of moisture load. These changes even occur in the short time between concept and actual cleam room construction.

Atmospheric humidity loads are described in terms of pounds of water vapor generated per hour. The units typically used are grains (gr) of water vapor, and one grain is $\frac{1}{7000}$ of a pound.

In this application, the moisture loads imposed on the space come from five main sources:

1. *People*—At a condition of 70°F/35% RH, a person doing light work at a bench contributes between 1500 and 3500 grains of water vapor (about ¼ to ½ lb) per hour to the load.
2. *Door/Airlock Openings*—Each time a door or airlock opens between the controlled room and the space around it, moisture flows into the room. Most wafer fab areas have airlock vestibules installed which greatly reduce this moisture load, usually cutting it in half. However, the load can still range between 3000 gr per door opening to 1000 gr per door opening depending on the configuration of the door and what sort of pressure and moisture differential exists across it.
3. *Evaporation from Wet Surfaces*—Normally this is a small amount of moisture, but in large wet processing stations it must be allowed for. Actual loading can run

from 140 gr/ft²/h to 700 gr/ft²/h, depending on the temperature of the wet surface and attitude of the air flow in relation to it.

4. *Moisture Infiltration through Walls and Cracks*—Typical clean rooms are very tightly constructed because of the need to control particulate contamination as well as moisture. However, not all ductwork is vapor-tight and some allowance must be made for the leakage associated with construction joints and sheet metal imperfections.
5. *Moisture in Make-Up Air*—As air is frequently exhausted from processing areas for vapor contaminant control, it must be made up by air coming (ultimately) from the outdoor environment. This air can add substantially to the load. In fact, it is by far the largest load in the room. As an example, an airflow of 1000 CFM of outside air in San Francisco contains 130,500 gr/h of moisture that must be removed from the air in order not to add to the humidity already in the room. In Phoenix, that same amount of air adds 256,500 gr/h to the load, and in Florida it would be over 346,500 gr/h.

**Table I—Physical Characteristics of Wafer Fab Area**

| | | |
|---|---|---|
| Room/Dimensions: | 16'W × 32½'L × 10'H | |
| Total Air Flow Required to Maintain Laminar Flow: | 51,228 ft³/min | |
| Total Internal Sensible Heat Load: | 154,000 BTU/hr | |
| Moisture from: | | |
| People | 10 @ 3000 gr/hr = 30,000 gr/hr | 30,000 |
| Doors | 1000 gr per Opening × 15 Openings/hr = 15,000 gr/hr | 15,000 |
| Wet Surfaces | 10 ft² @ 500 gr/ft²/h | 5,000 |
| Infiltration | 3 ft. of Cracks & Pin-holes = 35,000 gr/hr | 35,000 |
| Total Internal Load . . . . . . . . . . . . . . . . . . . . . (gr/hr) | | 85,000 |
| Make-up Air: | 4 Wet Stations @ 400 CFM each @ 95 gr/lb = 410,400 gr/hr | 410,000 |
| | 1000 ft³/min to Maintain Room Pressure | 292,500 |
| Internal Plus Make-up Air . . . . . . . . . . . . . . . . . (gr/hr) | | 702,500 |

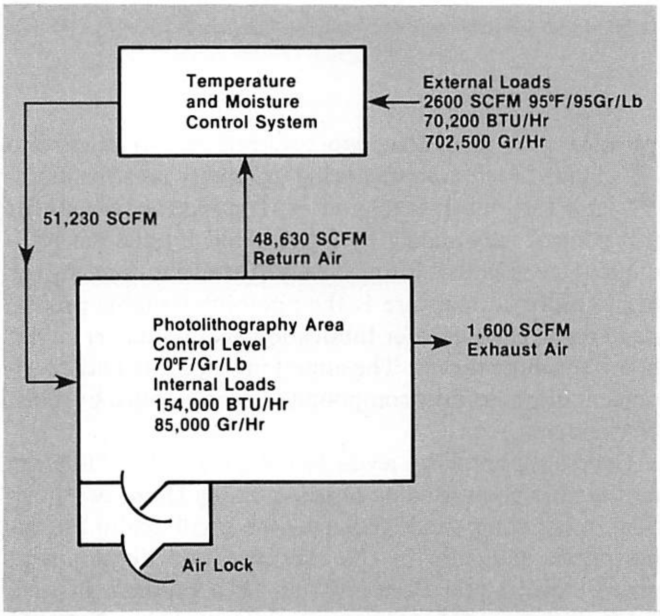


*Fig. 1—Airflow and load schematic.*

**Achieving Humidity Control**

Once the loads have been defined as well as possible, one is confronted with two technologies available for controlling moisture. Moisture can be removed from air, either by condensing it out on a cold surface (refrigeration), or by attracting it to a substance with a low vapor pressure (a desiccant). Each technology has its individual advantages and disadvantages, but in this situation, they are about equal in cost and operational efficiency. It has become common practice to use a combined or integrated dehumidification system to optimize between the conflicting goals of lowest cost and highest capacity.

The efficient design concept takes advantage of the best characteristics of each technology. Dehumidification by condensation is least costly and most efficient at high humidity levels. Desiccant dehumidification is more cost-effective at lower levels.

It is instructive to examine a typical set of circumstances. A wafer fab line with a substantial area devoted to photolithography (Fig. 1) has the characteristics shown in Table I.

As a design principle, it is typically most efficient to remove the moisture as close as possible to its source. In this example, it is clear that the moisture coming into the room from weather air represents 88% of the total load. It is most efficient to remove as much as possible using condensation type dehumidification. The outside air is cooled below its dewpoint in order to remove a large portion of its moisture content. After it is cooled to 50 °F, it has 72% of the moisture it formerly carried. when it is further dehumidified using a desiccant dehumidifier, it becomes dry enough to act as a "sponge" to remove the remaining moisture load within the room. In this case, the outdoor air can be dried to a moisture content of 25 gr/lb, which gives it a moisture removal capacity from the space of:

$$2600\text{ SCFM} \times 60\text{ min/h} \times 0.075\text{ lb/ft}^3\text{ Air Density} \times (38\text{ gr/lb Room Moisture} - 25\text{ gr/lb Air Moisture}) = 152{,}100\text{ gr/h}$$

This allows ample additional moisture removal capacity for unprogrammed increases in internal moisture loads due to process changes. In fact, the outdoor air can easily be dried down to a moisture content of less than 5 gr/lb to provide an even greater degree of insurance.

A common alternate method of achieving moisture control is to use a condensation dehumidification system exclusively. This can be successful if there are no unprogrammed increases in moisture load within the space. Moisture removal by condensation type systems is typically limited by the point at which condensate turns to frost. As a practical matter, outdoor air is not normally cooled below 40 °F temperature in order to avoid this problem in some parts of the cooling system. The moisture content of air at a 40 °F

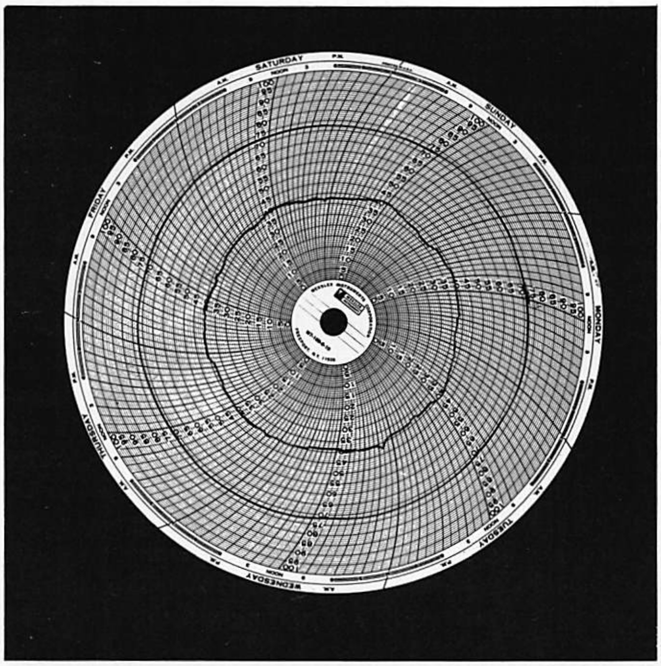

*Fig. 2—Refrigeration producing borderline 40% RH prior to addition of desiccant D/H equipment.*

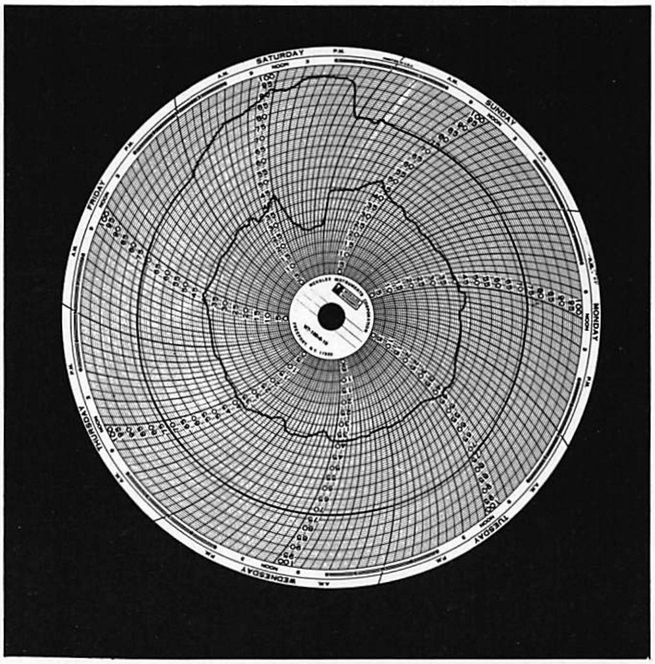

*Fig. 3—Typical control problems with refrigeration compounded by equipment control problems.*

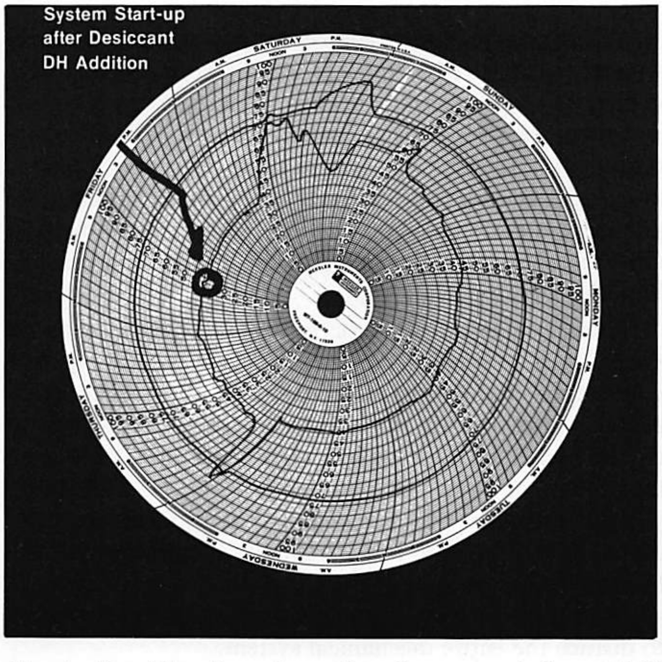


*Fig. 4—Humidity shows immediate drop upon desiccant D/H start-up.*

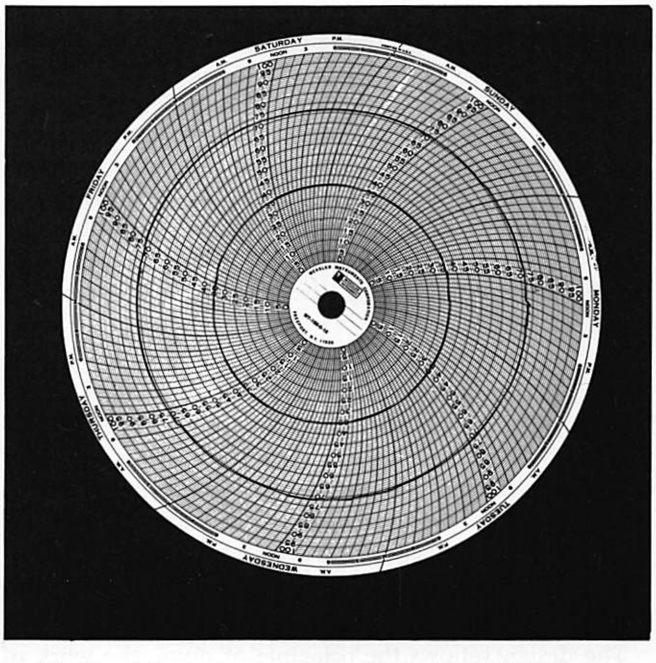

*Fig. 5—After system retrofit with desiccant D/H.*

dewpoint is 36 gr/lb. If one were to use this method, dehumidifying only the fresh air, the moisture removal capacity from the room would be:

$$2600 \text{ SCFM} \times 60 \text{ min/h} \times 0.075 \text{ lb/ft}^3 \times (38 \text{ gr} - 36 \text{ gr}) = 23{,}400 \text{ gr/h}$$

Given the circumstances described above, the outside air does not have enough capacity to remove the internal load, and thus the moisture level in the room will rise above the set point of 35% at 70 °F until there is enough differential between the room condition and the delivered air to remove the load. In this case, that level can be approximated as follows:

$$2600 \text{ SCFM} \times 60 \text{ min/h} \times 0.075 \text{ lb/ft}^3 \times (Y - 36 \text{ gr}) = 85{,}000 \text{ gr/h Internal Load}$$
$$(Y = 43.2 \text{ gr/lb})$$

43.2 gr/lb corresponds to 40% RH at 70 °F. The room will then be out of specification. This is very frequently the cause of such difficulties. A graphic demonstration of this typical problem is shown on the accompanying charts (Figs. 2–5).

The data that follows were taken from a wafer fab clean room during the summer of 1981. The facility in question is located in Phoenix, Arizona, and 1981 was a particularly difficult summer for that part of the country, with high temperatures combining with high moisture levels in the ambient. The mechanical system was designed using refrigerationn to dehumidify the outdoor air to 40 °F dewpoint.

The capacity of the system was designed around load data that was correct for normal operation. The summer of 1981 however, produced abnormally high moisture loads. Also, the internal load rose beyond original design data due to process changes and other special circumstances. Charts show the effect of these changes on the refrigeration-only moisture control system.

The chart in Fig. 2 indicates the temperature of the room as being relatively constant at 71.5 °F. The moisture content of the room fluctuates slightly, according to the internal load, since the capacity of the system is fixed.

The chart in Fig. 3 indicates what happened as ambient moisture levels and temperatures increased. In an effort to increase system capacity, controls were adjusted and equipment malfunctions contributed to erratic performance.

The system was retrofitted on an emergency basis as the multi-million dollar room was soon to be idle. A desiccant dehumidifier was placed downstream of the outdoor air cooling coil on July 30 and turned on at 8:00 a.m. on July 31. This had the effect of adding 1,296,000 gr/h moisture removal capacity and as evident from Fig. 4, the humidity immediately dropped from 42% RH to 35% RH.

Figure 5 was taken from the room at the end of the following week and indicates typical system performance following the July 31 installation of the desiccant dehumidifier. The system had no difficulty maintaining the humidity specification within one percent RH and in fact, the variation is not detectable with the standard chart recorder employed here.

The installation described is typical of many, in that the summer performance of the mechanical system (concerning humidity) is not as controlled as the spring and fall. Likewise, in the winter, such systems can require the addition of moisture to the make-up air in order to prevent the room from going out of spec on the low side of the humidity range. Taking all of these factors into account, the design schematic shown in Fig. 6 has proven to be economical and reliable in maintaining close tolerance humidity specifications.

The design follows the principle of doing the work of moisture removal where there is the most work to be done. The outside air enters the moisture controller through a louver that protects the system from rain, birds, etc., then through an adjustable damper that allows the air system to be properly balanced. The air is then filtered to remove gross particulates. The cooling coil removes a great deal of the moisture in the air by condensation. The air is then dried to a very low moisture content by a desiccant dehumidifier.

The moisture controller dries the outside air below the moisture level of the room in order to remove the internal moisture load generated by people and door openings. The capacity of the moisture controller can be varied according to how much is put through the desiccant dehumidier. When the outside air becomes too dry, humidity is added to the air

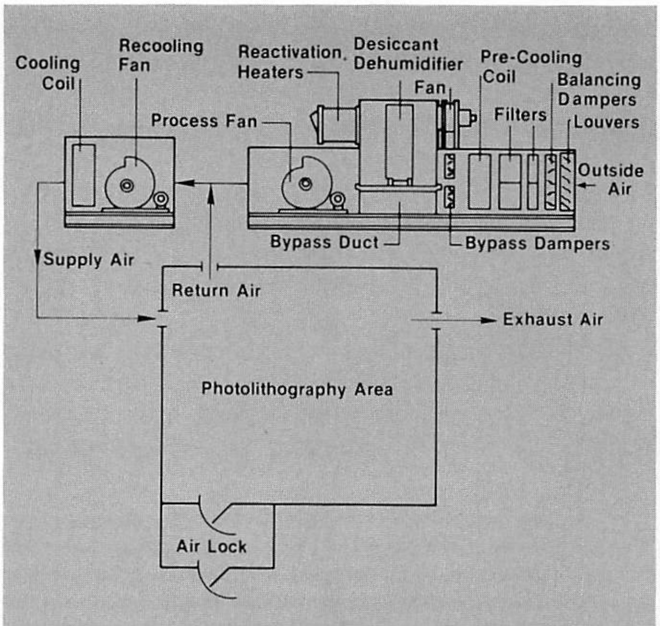


*Fig. 6—Humidity and temperature control system arrangement.*

stream to prevent the room from falling out of specification.

The conditioned air then proceeds to the main air handler, where it is combined with the return air from the room and cooled to remove sensible heat from the space.

This schematic offers several advantages over the alternative of refrigeration equipment alone. First, sensible heat and latent (moisture) heat loads are handled separately. Control systems are simple, reliable and can work to very close tolerances. Heating and cooling, humidifying and dehumidifying do not overlap.

Secondly, the use of a desiccant dehumidifier allows the system to have a much greater moisture removal capacity with unexpected changes in room load. The design is inherently safer in terms of moisture capacity because the air can be made much drier than with refrigeration equipment alone.

Finally, systems of this type are ideally suited to retrofit existing facilities when lower humidity levels are required. Precise moisture control can be added to the mechanical system simply by treating the outside air. There is no need to disturb the entire mechanical system.

**Lewis G. Harriman III** is the Market Manager for semiconductor and electronics manufacturing facilities at Cargocaire Engineering Corporation in Amesbury, Massachusetts. He has been with Cargocaire since 1976, working with equipment that creates precision temperature and moisture control conditions in industrial manufacturing environments. His prior experience includes five years with the U.S. Air Force, Directorate of Engineering and Services at Strategic Air Command Headquarters in Omaha, Nebraska. Mr. Harriman received his degree from Dartmouth College in 1971.