Semi Conductor Thermography

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Abstract

In today's high tech world, more companies are building clean room environments to produce product. This provides a great potential profit for thermographers to expand their business. Clean rooms provide many unique challenges and difficulties that most thermographers have never seen and that must be overcome to successfully perform thermography.

This paper will discuss some of the issues and obstacles as well as give an overview of what a clean room is, the classifications and types of clean rooms, micro contamination, Personal Protective Equipment (PPE) use in a clean room environment, reflectance, (the thermographer's nightmare and it's everywhere), hazardous chemicals used in the process, where not to put the imager if you want it back, target modification (don't even think about getting that can of spray paint out), the cost associated with semi conductor manufacturing and why infrared thermography is so important to the semi conductor industry.

Discussion

A semi what?

A semi conductor is what most people call a computer chip. The manufacturing of silicon chips is a very complicated process. It involves building millions of transistors on a little square piece of silicon called a die. This die is so small that you can easily hold it on the end of your fingertip.

When we have finished building and connecting all the transistors together, we get our silicon chips. The chips we make are used as microprocessors; these are special chips and are the brains inside the computer. We also make memory chips that are used by computers to store memory.

Silicon is an element like oxygen or copper and is found in rocks and sand. We use silicon because it is a semiconductor and is ideal for building transistors. The silicon is extracted from the sand and is then purified into ingots. The ingots are sliced into thin circular wafers.

So what is a clean room and why is it so important?

Basically, it is exactly what it sounds like - a clean room - or it should be called a very clean room; we need this very clean environment because the transistors we are building on the silicon are 500 times smaller than the width of a human hair. Any speck of dust or dirt falling on the wafers would ruin the microchips.

Clean rooms are classified according to the maximum number of particles bigger than one-half of a micron that would be allowed in one cubic foot of clean room air.

- Width of a human hair 100 microns
- Normal office building 10,000 microns
- Hospital operating room 1000 microns
- Clean room 1 micron or 100^{th} the size of a human hair

It takes a lot of equipment to make air that clean; make-up air handlers, recirculation air handlers, de-humidifiers and humidifiers and a whole bunch of filters.

It also takes a lot of air flow and air exchangers to keep the area clean. People are the number one contaminant in the clean room. The tools in the clean room sit on a raised floor, the air enters the room from the ceiling and down flows at a velocity of 24 feet per minute and exits under the floor. 24 fpm probably does not sound like much, but when you consider the total area it takes (8,100,000 cubic feet per minute at the inlet) to maintain that air flow over the 135,000 sq. ft. clean room.

All this air is supplied to the building by 8 make-up air handlers each the size of 2 school buses put together. They also maintain the air at a constant temperature of 72 degrees at 40% relative humidity no mater what the outside weather conditions are.

It's practically impossible to visualize that much of anything, let alone something as intangible as air.

So try this instead: Imagine a rectangular water tank that is 209 feet by 209 feet (one acre) at the base, about as tall as an 18-story building (185 feet), and filled with 60 million gallons of water. Now imagine a pump emptying that tank in just 60 seconds, at the rate of a million gallons being pumped every second — gives the word "fast" a whole new meaning, doesn't it?

Bunny suits and other strange alien contraptions

Since the room and all material being placed in it have been cleaned, it should be easy to maintain, right? Well, not exactly. We have to add one more item to the equation, people, you and me, we are the greatest threat to the clean room environment.

People are giant particle emitters, we breathe out particles, we shed particles and we are particles. So to keep us from contaminating the room, a nice suit was developed made of Gore-Tex. This is a non-linting, non-breathing, anti-static suit (in other words, very hot) but it does come with a matching hood and boots, all exposed skin except for the face is covered, but don't worry, there are masks to cover the mouth and nose to catch those particles and still allow you to breathe.

So it all comes down to: dirt is bad for business. The average cost per wafer is 100,000 US dollars. If precautions are not taken, several wafers can be lost due to contamination. Try to explain to your insurance broker how much damage you caused today?

OK, so now we have the room clean. Let's work on the other issues.

Chemicals and copper contamination

The microprocessor manufacturing process begins with "growing" an insulating layer of silicon dioxide on top of a polished wafer. This oxide layer also acts as an electrical "gate" that either enables or prevents the flow of electrical current within the microchip. The silicon dioxide is grown on the surface of the wafer in a furnace at a very high temperature. The thickness of the oxide layer depends on the temperature and the amount of time the wafers are in the furnace.

Photolithography, the process in which circuit patterns are printed on the wafer surface, is next. First, a temporary layer of a light-sensitive material called a "photoresist" is applied to the wafer. Ultraviolet light shines through the clear spaces of a stencil called a "photomask" or "mask" to expose selected areas of the photoresist. Masks are created during the design phase and are used to define the circuit pattern on each layer of a chip. Exposure to light chemically changes the uncovered portions of the photoresist.

The exposed areas of photoresist are removed, revealing a portion of the silicon dioxide underneath. This revealed silicon dioxide is removed through a process called "etching." Then, the remaining photoresist is removed, leaving a pattern of silicon dioxide on the silicon wafer. Additional materials, such as polysilicon, which conduct electricity, are deposited on the wafer through additional lithography and etching steps. Each layer of material has a unique pattern. Together, they will form the chip's circuitry in a three-dimensional structure.

In an operation called "doping," the exposed areas of the silicon wafer are bombarded with various chemical impurities called "ions," which provide positive and negative charges, thereby altering the way the silicon in these areas conducts electricity. The electrical charges help the transistor to turn on and off, thereby passing electrical current through the transistor's gate.

To provide a link to the additional layers put on the wafer, "windows" are formed by repeating the masking and etching steps. This layering is repeated 20 to 25 times over a period of several weeks. This process creates a skyscraper effect of layers on top of the wafer.

Metal is applied to fill in the "windows," thereby forming electrical connections between the chip's layers. Intel introduced copper metal on its 0.13-micron process technology, the most advanced microprocessor process generation in production today. Previously, Intel used aluminum metal in its 0.18-micron and older process technology. Copper and aluminum are excellent electrical conductors.

Needless to say, it takes a lot of nasty chemicals and gases to strip and build up material on a wafer, some of the these chemicals cannot be removed from surfaces or tools, so before you set the imager down on what you might think is a clean surface or reach up and borrow the screwdriver sitting on the tool box, ask if the tool box is copper contaminated or you will not be getting the imager back. That's right, it just became a permanent fixture in that area.

Rule #1

Do not set your imager down. If you inadvertently place the imager on a chemical or copper contaminated surface, you will not get it back, and many times you do not want to get it back. That's right, hang onto it until you have cleared it with the tool owner.

Rule #2

Reflectance, get over it. Stainless steel is used on just about every possible surface in the Fabrication facility, non-oxidizing, easy to keep clean, perfect for clean room use and well, just darn shiny.

And now for the bad news, you are not going to be able to modify the target, with the exception of electrical terminal lugs which can be wrapped with black electrical tape. Just remember, the cardboard tube the tape comes on is not allowed in the clean room. It is available, however, on plastic spools. Ask the tool owner - they should have some available near the tools.

Rule #3

Listen to the tool owner. They are responsible for the tool. Have them remove the covers, energize and bring the tool up to operating temperature. Make adjustments or repairs. Most of the tools range in the millions of dollars so do not touch - just take the images and provide the report to the tool owner.

Another great idea is to show them the image while you are at the tool, if they can see the difference for themselves they become interested and believe in the technology, so take the smoke and the mirrors out of the picture and let them see how it is done, they are your greatest ally in the manufacturing facility.

Another point to remember is the tool owner is not an electrician, they are highly specialized in how the tool works but they are not electricians and do not have a good understanding of power distribution, so if they say that the tool is off for you to work on, always check that the power really is off and locked out before touching.

Rule #4

Temperature: it's a relative thing, since most of the time you will not know the emissivity of the object and will not be allowed to modify or touch to try to determine it. Tell them up front that this is a comparison of like components under similar loads; most of the tools have more than one set of each component (most have 2 or 3). Also ask if they have the specification sheet for the temperatures. These are usually calculated before the tool was placed on line and show a temperature based upon a 0.95 emissivity.

Rule #5

Document, document, document. I know the lawyers do not like this, but ask the tool owner for a copy of the inspection procedure and follow and document exactly what you did, along with the findings. The document should have the report criteria and who to send it to listed. Give one copy to the tool owner.

My main reason for saying this is a meeting called the Post Mortem, or commonly referred to as a "something went wrong, cost a bunch of time and money and the fingers are pointing everywhere". If you followed the procedure and provided the documentation as needed they will not be pointing at you.

Rule #6

Ask before you start the scan what hazards are involved for you or your equipment. Over the years we have been asked to take some very unusual scans. This normally happens after the tool has been having a problem and the owner does not know what the answer is, so they remember that guy with the funny looking camera and you get a call and they would like to see if you can find anything. Many times we have found clues that lead to the problem, but other times you have to refuse unless they are willing to purchase a new imager. We have had requests to scan components inside an operating tool in environments that are designed to deposit layers of metal and sometimes strip away surfaces. Just think what this will do to your imager.

Money $$$

That's right, even with all of the difficulties, wearing a non-breathable sweat suit and having to deal with procedures that seem to be designed for your failure, there is a big cost savings to be had by performing infrared thermography.

Electrical failures are common, the equipment is cycled through a wide variety of loads, taken apart and put back together many times; most of the components get disturbed many times during a year. All this leads to electrical failures. A failure not only costs parts but it can also cost extended down time; some tool sets can cost a company $1 million per hour of down time or can cause the loss of millions in product during the failure.

This makes infrared thermography the prime tool to use: non-contact, non-intrusive, does not provide a source of contamination and can be done in some cases with the tool in operation, thus saving production time.

The average cost savings expectation per year based on 135,000 sq. ft. of manufacturing space: minor problem 3K to repair, major exception 30K to repair.

Oregon	625K
New Mexico	438K
Arizona	520K
Israel	630K
Ireland	450K

Losses

Electrical fire in Litho tool: 1.3M loss. Parts, labor, product and production time.
Electrical short in Diffusion Furnace: 1.8M in parts, labor and production time.

Conclusion

The bottom line is infrared thermography saves a lot of money. Hopefully, this has given you a little insight into the magic realm of semi conductor manufacturing. There are many opportunities for saving production losses, but the main hurdle is to show the Production Manager the benefits of the program. I hope that you now have enough information to do so.