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It's the hardware. No, software. No it's ESD!

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For anyone who has ever spent days, even weeks, troubleshooting random wafer-processing equipment problems, here is solid information about the effects of ESD-caused problems. The straightforwardness of its detection may put this information at the top of your troubleshooting checklist.

When semiconductor process equipment stops working, lights flash, beepers sound, and technicians move quickly to find and correct the problem. Periodic problems are usually the easiest to solve since they involve a well-defined operational or process problem. Sometimes, however, even with self-diagnostic capability on advanced tools, technicians are left with unclear or misleading information. This is a first clue that the cause of the problem may be unrelated to equipment operation.

Random equipment halts are difficult to troubleshoot. Their frequency varies from once an hour to once every six months or longer. Their occurrences are usually not correlated to any equipment action, making it more difficult to determine the cause.

To anyone familiar with microprocessor-based equipment, it is not uncommon first to "blame the hardware," then "blame the software," or vice versa until a "seeming" cause for the problem is found. Often, with severe problems, the tool manufacturer's field service joins the "hardware vs. software" repair process.

There is no question that some equipment problems really are the result of hardware design flaws or software bugs. These may take a significant amount of time to uncover and correct. Another common cause of equipment problems, though, is electromagnetic interference (EMI) generated by electrostatic discharge (ESD) [1]. The ultraclean and dry environment of the cleanroom produces surprisingly large static charges that can be transferred between objects, creating static discharges. These discharges occur so fast, typically in nanoseconds, that they radiate EMI extremely efficiently.

Test equipment can identify the presence of EMI, but it is rarely used at the beginning of the troubleshooting process for an equipment problem. Finding the source of EMI is difficult. While it may

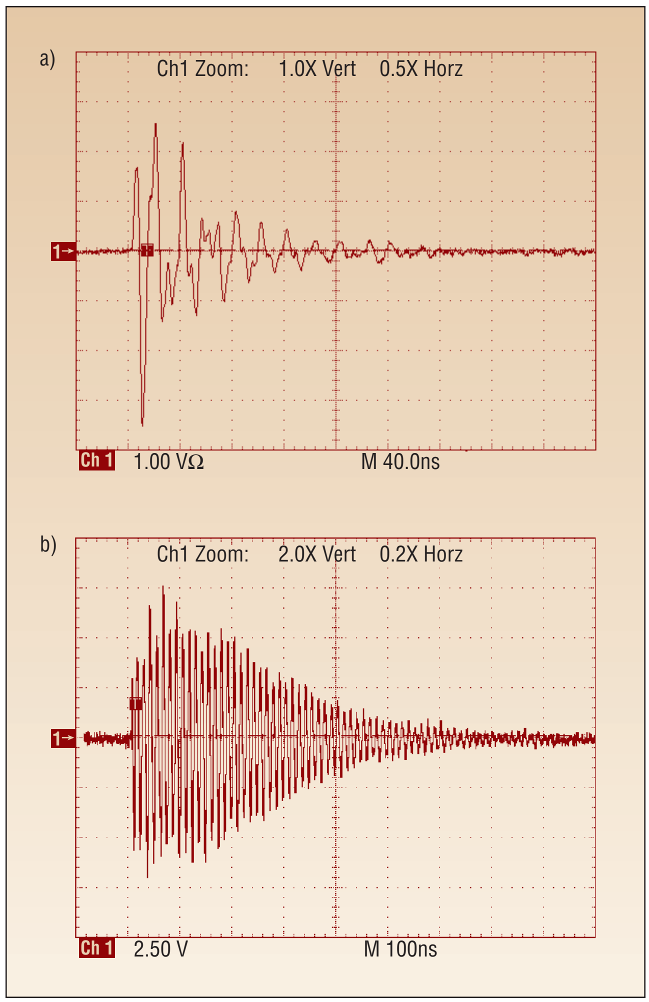

Figure 1. High-speed storage oscilloscope measurement of a) conducted and b) radiated EMI from an ESD event. The conducted measurement was made on a neutral power line 9m from the ESD event, the radiated measurement on an antenna 3m away.

The authors’ experiences that have connected fab problems with ESD events
Wafer transfer robots that stop or drop wafers
Shutdowns of diffusion furnaces
A wafer fab experiencing so many lockups that its software-engineering staff could not keep up with its work load
Track system lockups
Stepper alignment errors and lockups

be internal to the equipment experiencing a problem, it may also be generated elsewhere in the cleanroom.

Once an ESD event injects EMI into a tool, it is efficiently transmitted through the electronic circuitry. Good high-frequency electronic layout is necessary for the proper operation of modern microprocessors that employ hundred-plus MHz clocks. This results in circuitry that distributes high frequencies efficiently throughout the equipment. It is important to realize that for EMI to cause an error it must be induced in the circuitry simultaneously with a critical circuit operation. Thus, many EMI events can occur before one causes a tool error to occur.

The tool error, typically called a lockup, may be accompanied by a difficult-to-interpret error message. Equipment diagnostics are usually adequate for analyzing known equipment malfunctions, but they cannot identify a problem caused by a random externally generated signal. They succeed in making the problem look like a software bug rather than EMI from an ESD event [2].

Conducted vs. radiated EMI

When an ESD event occurs, the rapid transfer of charge results in currents that may be measured in hundreds of amperes. While some of the energy is dissipated as heat, a significant portion becomes electromagnetic radiation at 25MHz–2GHz. This can be conducted (Fig. 1a) away from the site of the ESD event through metal structures or power lines or can radiate (Fig. 1b) through air. In either case, it can affect equipment a considerable distance from the location of the ESD event.

ESD immunity testing

All wafer-processing equipment gets CE testing for ESD immunity because manufacturers will ship some of their equipment to Europe [3]. Generally, semiconductors in production equipment must withstand a direct discharge of 4kV, typically from a 150pF capacitor, and an air discharge of 8kV at a distance of 10cm. Most equipment manufacturers strive to have equipment ESD immunity that exceeds these levels.

In semiconductor manufacturing, ESD events occur routinely at levels considerably higher than those used for testing ESD immunity. Contact and separation of materials, particularly during wet cleaning processes, can easily generate static voltages in excess of 20kV. Larger objects, such as cassettes and SMIF pods, exceed 150pF of capacitance. This problem will only get worse with the anticipated shift to 300mm wafers, and is already a significant problem for flat panel display manufacturers handling large glass substrates.

Interestingly, ESD immunity testing only requires that the equipment should not catastrophically fail due to an ESD event. A resettable equipment interrupt is not considered an equipment failure, although it often has significant consequences during actual operation of the equipment in a semiconductor facility.

Identifying ESD-caused EMI

The difficulty in identifying an equipment lockup due to ESD is illustrated by the following case history:

A manufacturer of microprocessors was experiencing random equipment problems with one of nine steppers, which commanded the attention of in-house engineers and the equipment manufacturer’s field service engineers for almost six months. Software upgrades and major components were replaced without finding a solution. Measurements with a 500MHz digitizing oscilloscope finally detected a spurious signal on the power supply line of the stepper that had not been seen with lower-bandwidth test equipment. The random nature of the signal finally pointed to EMI as the possible cause of the problem.

Using an electrostatic measurement tool to determine the presence of static charge located the cause of the problem in less than an hour. The factory static control program specified using static dissipative wall panels to avoid the presence of charged insulators, but one of the wall panels above the stepper was not connected to ground. When charged, this large isolated conductor discharged to the nearby grounded wall framing. The conducted EMI from the ESD event was causing the equipment interrupts.

A high-speed digital storage oscilloscope (DSO) is an invaluable tool in tracking such problems. Due to the frequency range of the signals, an oscilloscope with at least a 500MHz bandwidth and a 10^9 samples/sec speed is recommended. While direct oscilloscope connections will locate conducted EMI, a wideband antenna connected to the oscilloscope is needed to detect radiated interference.

For field applications, more portable and lower-cost EMI detectors [4] are sometimes used. In many applications, a device designed to detect short pulses (<1μsec) of wide bandwidth (>200MHz) noise can be used to determine the presence of ESD-related EMI. While the EMI locator does not provide detailed amplitude information useful to find the source of EMI, it can be used effectively by noting what other actions occur synchronously with the EMI.

Electrostatic voltmeters and field meters can be used to locate the presence of static charge on objects being handled in production equipment. Due to the ability of EMI caused by ESD to propagate over significant distances, it may be necessary to extend the search for charged objects beyond the equipment that is experiencing problems.

Our experiences have revealed other scenarios where EMI was causing process equipment problems (other examples are listed in the table):

- In several facilities, tool problems were related to discharges from ungrounded ceiling panels that were supported by a

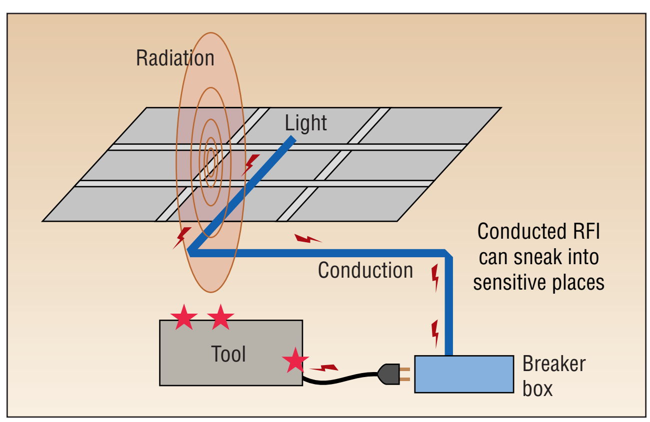

Figure 2. Conducted and radiated EMI from ceiling panels.

grounded ceiling grid. Signals were radiating from ESD events at the corners of the panels and were conducted through power lines to overhead lighting to the circuit breaker box and then out to the tool being affected. This conduction path was a serious problem because the signal could be transmitted over a large distance without the $1/r^2$ attenuation that is characteristic of transmitted EMI. In one case, the tool was a wafer prober and it was reporting calibration failures. The problem was located with a DSO and a wideband antenna test set. Grounding the ceiling panels eliminated the tool problem.

- In a 2000 ft^2 photolithography area, four steppers were experiencing unexplained lockups, one a number of times each day, the others randomly. Measurements with an EMI locator indicated signals throughout the room, particularly near the ceiling channels. Not surprisingly, the highest-level signals were found in the vicinity of the stepper experiencing the most frequent lockups. Checking the equipment grounding revealed a top cover panel that was not attached, but rather rested on the top of the equipment, and was very close to one of the ceiling-mounted air ionizers. When this panel was removed, all the EMI signals in the room disappeared and there were no further lockups in any of the steppers. It was apparent that the ungrounded panel was being charged by the nearby ionizer, and was then discharging to the grounded frame of the stepper near the ceiling. This ESD event signal was picked up and conducted around the room by the ceiling channel (Fig. 2).

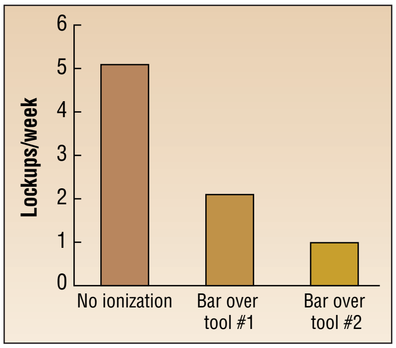

Figure 3. Rate of equipment lockup on a reticle inspection system with and without ionization in the load/unload station.

- There are many instances where conductive parts of wet benches are isolated from ground by attaching them to insulating materials. Inevitably these conductors become charged triboelectrically due to contact with other materials. Once charged, they will discharge the next time another conductor contacts them. The result is random lockups of the wet bench control electronics.
- A reticle inspection unit was locking up approximately five times per week. It was theorized that when reticles or reticle pods come into the tool highly charged, ESD events are inevitable. Under the assumption that the unexplained lockups were ESD-related, an ionizing bar was installed in the load/unload station of the tool. Since the reticles and pods are both composed of excellent insulators (plastic and quartz), grounding them will not eliminate charge. Charge neutralization with ionizers is the only option. When the rate of lockup with and without the addition of ionization was analyzed, it revealed a 50% reduction with the latter (Fig. 3). To investigate the origin of the residual lockups, ionization was placed on the ceiling of the room in the vicinity of the inspection station. This resulted in a second 50% reduction in the lockup rate. This indicates that ESD events even in the adjacent area tools were also causing the tool under investigation to lock up. Owing to the large distance from the adjacent tools to the one experiencing the lockups (~4m), the EMI path was almost certainly conducted.
- A wafer-transfer tool was locking up frequently. It was determined that the wafer cassette loaded into the tool came from a spin-rinser-dryer. The cleaning process in this tool resulted in wafers and Teflon cassettes charged to over 20kV. Placing the cassettes on a work-in-progress rack under an ionizing bar for 120sec before putting them into the transfer tool eliminated the lockups.

Conclusion

Equipment lockups will continue to occur despite the best efforts of the software and hardware designers to anticipate the complexity of the semiconductor-manufacturing process. With increasing frequency, however, equipment interrupts are coming from other sources, such as EMI due to ESD. Many equipment failures are the result of random ESD events and a great deal of production and engineering time is wasted pursuing phantom software problems.

In semiconductor manufacturing, charge generation is unavoidable because of the presence of easily charged insulating materials. It is impossible to ensure that everything is continuously connected to ground and that ESD events will not occur. Pretending that the laws of physics do not apply to a semiconductor facility is not as effective as a well-designed and executed static control program, including personnel education, grounding, static dissipative materials, ionization, and program auditing [5].

Ionization of the air or process nitrogen is an important component of an effective static control program. Insulators cannot be removed from the semiconductor- (or flat panel display) manufacturing process, because they are an essential part of the product itself. In the cleanrooms required for semiconductor manufacturing, and in many other areas, ionization is the only effective method of neutralizing charge on insulators. Equipment manufacturers continue to rely on equipment designers who believe they can avoid using ionization to solve static problems on insulators. This will only guarantee many hours in the field spent arguing about problems caused by “the hardware — or is it the software — or maybe it’s ESD?” ■

References

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2. SEMI E78-0998 “Guide to Assess and Control Electrostatic Discharge (ESD) and Electrostatic Attraction (ESA) for Equipment,” September 1998, SEMI.
3. The requirements are contained in European Norm directives EN61000-4-2 and EN50082-2, 1995. Test methodologies are defined in IEC standard 1000-4.
4. For example, Lucent Technologies’ Model T-100, and Credence Technologies’ EM Eye or Sanki ES-81V.
5. S. Galatowitsch, “Terminating Static in the Cleanroom,” *CleanRooms,* April 1998.

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