

RUDI VAN DRUNEN

## chips and static electricity



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**THERE IS ALWAYS A WHOLE LOT OF** discussion about the effects and dangers of static electricity for electronics. In this article I will try to explain the issues involved with static electricity, the myths connected to the phenomenon, the dangers for your systems, and how to avoid them.

Static electricity has been known for a very long time. In the seventeenth century, people began to build machines to generate static electricity artificially. Benjamin Franklin demonstrated the effect of static electricity with his famous kite experiment in a lightning storm. As lightning is a form of electrostatic discharge on a very large scale, you can imagine what discharges on a small scale can do to the sub-micron-sized patterns on a chip. To explain just this effect, I first have to describe the way chips (i.e., integrated circuits) are built and then describe the properties of electrostatic discharge (ESD) and their impact on the chips. The last part of this article describes the measures you can take to minimize the damage to your hardware due to ESD.

### Chips

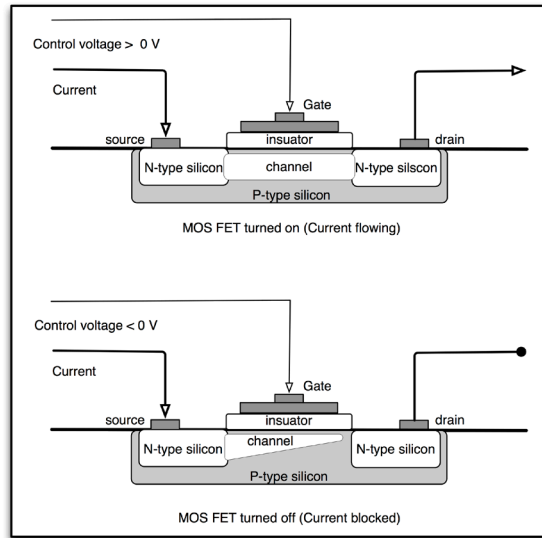
A chip, or, better, an integrated circuit, is a device built out of transistors that are created in different forms of silicon on a silicon substrate (a wafer). The different forms of silicon are the N type, with an extra electron in the shell around the molecule, and the P type, where the shell is short one electron.

A transistor is an electronic element that can actively control the flow of current. A simple transistor has three terminals: an input, an output, and a control terminal. If you apply a voltage to the control terminal, you turn on or off the “switch” between the input and the output of the transistor. The current flowing is many times larger than the current you need to control the switch/gate. That is why it is said that transistors can amplify current.

There are a number of different transistors. The current amplification type (that actually needs a current on the control terminal) is called a bipolar transistor, whereas others that just need a static voltage (an electric field) to switch current on or off are called field effect transistors. Field effect transistors are commonly used to build digital logic integrated circuits, as found in your computers.

A field effect transistor (FET) is created on a chip by virtually building a channel in a well of P-type silicon in the substrate. This channel is the “con-

ductor” for the current (electrons) that will flow through when switched on. Then a very thin insulating layer on top of the channel separates the gate or control electrode from the current channel. When voltage is applied to that electrode, an electric field is formed within the channel, preventing the current from flowing through (see Figure 1).



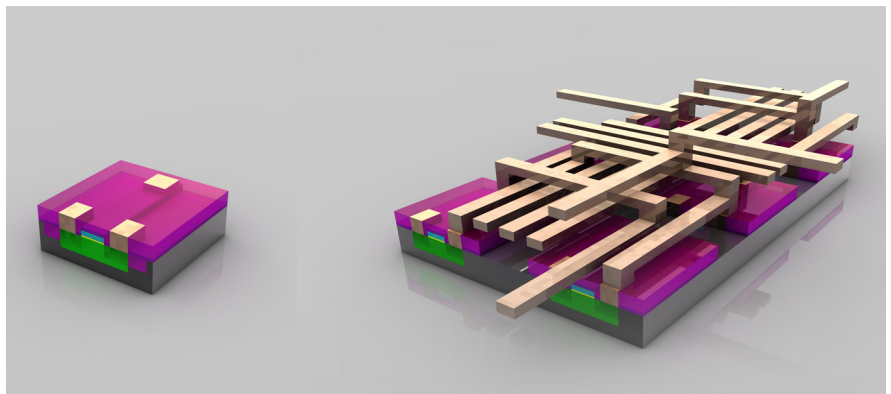
**FIGURE 1: OPERATION OF A MOSFET TRANSISTOR**

The type of insulation between the gate and the channel is related to the name of the device. Most current logic chips are fabricated using a MOSFET technology (Metal Oxide Semiconductor Field Effect Transistor).

Typically, a transistor on a chip takes about 3 units of space, where a unit of space is related to the technology the chip manufacturer uses. State-of-the-art manufacturers are now able to make 15 nm patterns, resulting in a transistor size of 45 nm (1 nm equals approximately 0.00000004 inch).

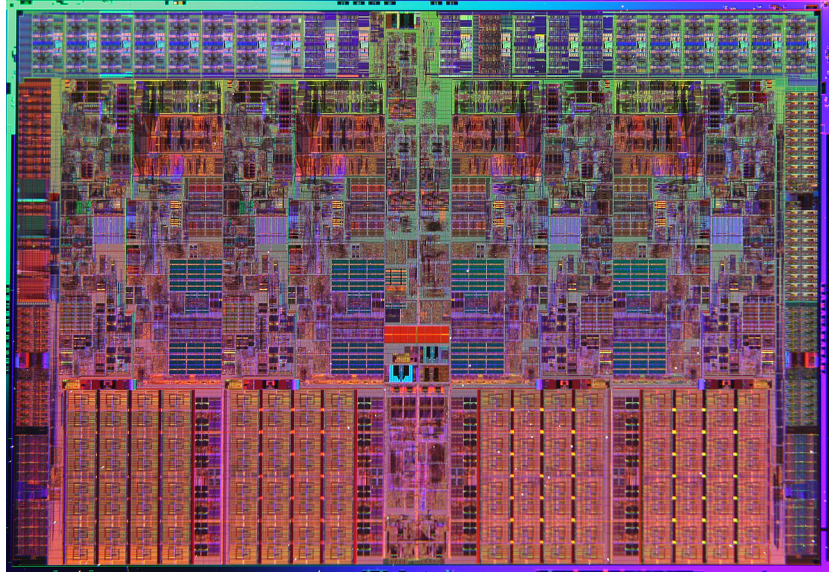
The transistors are interconnected by conductors in different layers, often made out of metal (see Figure 2). These transistor circuits form basic logic elements that build functional blocks.

Creating those patterns on a piece of silicon is a very complex lithographic and chemical process which takes place in multi-million-dollar clean rooms and takes a complete article to describe.



**FIGURE 2: SCHEMATIC DRAWING OF A SINGLE TRANSISTOR ELEMENT AND INTERCONNECTS BETWEEN THE ELEMENTS (SOURCE: INTEL)**

A logic chip is composed of functional blocks (counters, adders, etc.). These blocks can be described by functions that then are implemented on the chip level by a number of transistors. A modern, high-end CPU contains about 2,300,000,000 transistors (an 8-core Nehalem-EX server processor from Intel). Figure 3 shows an example of the patterns on a chip.



**FIGURE 3. A DIE PHOTOGRAPH OF A 4-CORE NEHALEM PROCESSOR (SOURCE: INTEL)**

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## Design of a Chip

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Nowadays, the design process of a digital integrated circuit is comparable to writing a piece of software. The functional requirements are implemented using a hardware design language such as VHDL or VeriLog. The VHDL code then is simulated to verify functionality. Once approved, the code is run through a silicon compiler that generates the actual chip artwork for the lithographic process.

To verify the functionality on the physical hardware level, there are chips containing programmable arrays of logic blocs, where the VHDL program is used to make interconnects between standard blocks. These chips (field-programmable gate arrays [FPGAs]) can be used as an intermediary (verify, prototype) stage before the actual production of custom silicon. Although far less dense than full custom chips, these devices can be the solution for smaller series or prototyping.

As you might imagine, those tiny traces on a chip and tiny insulating layers are extremely fragile and susceptible to overvoltage or overcurrent. Both overvoltage and overcurrent on the chip can be the result of an electrostatic discharge.

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## Static Electricity: Charging

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Static electricity can be thought of as a difference in the electrical charge between two (non-conductive) bodies. This electrical charge is often the result of a friction between two substances. That friction will lead to exchange of loosely coupled electrons from the one substance to the other. One part will become negatively charged (with an excess of electrons), while the other part will become positively charged (with fewer electrons). This process of charg-

ing is called triboelectrification and is the most common way that static charges are built up.

In addition, a strong electric field in the neighborhood (e.g., the high voltage of a CRT tube) can separate electrons in a body, and this builds up a charge on components, a process known as inductive charging. The net charge of the complete device will not change, but it now has regions of excess positive and negative charge. Touching these regions with a tool that has a neutral charge will result in an ESD.

The last method of charging a body is conductive charging, where there is physical contact between a charged body and a body with a different potential. The charge will transfer from one body to the other, leaving them both equally electrically charged.

The difference in charge that builds up can be big—many thousands of volts. The charge depends on the materials and the friction between them. For example, lightning, a discharge of static electricity that is built up by friction between clouds, can reach 100,000 volts.

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### Static Electricity: Discharging

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Discharge of electrostatic charges can be achieved by having the charge bleed off to ground. This can occur slowly and with a low current (due to high impedance to ground) or quickly with higher current with a direct contact: for example, you can charge your body by walking over nylon carpet and then discharged by touching a grounded object (e.g., a door knob).

Another form of discharging is corona discharge. This effect occurs only when working with very high electric fields and high voltage charges. The high voltage creates a high electric field around the charged object. When a grounded object enters the field, the difference in charge is so high that a spark occurs on the sharp edges of the object (where the field has the highest density). A spark is triggered when the electric field strength exceeds approximately 4–30kV/cm.

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### Problems

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Static discharge will both apply a very high voltage on a chip and, as the charge is flowing away, impose a high current through the sensitive semiconductor. Due to the high voltage and the high current, problems on the chip can occur. Traces (connections) between transistors can be burned away completely, and partially destroyed traces can eventually lead to failure. These problems will emerge later in the component's life, when traces that are partially cut by the discharge fail completely due to heat because they are thinner now, causing the same current in the chip to heat up much faster in operation. A device can be subjected to a number of weak ESD pulses, with each successive pulse further degrading a device until, finally, there is a catastrophic failure. There is no known practical way to screen for walking-wounded devices. Figures 4 and 5 show some of the serious issues that can occur due to an ESD pulse on a chip.

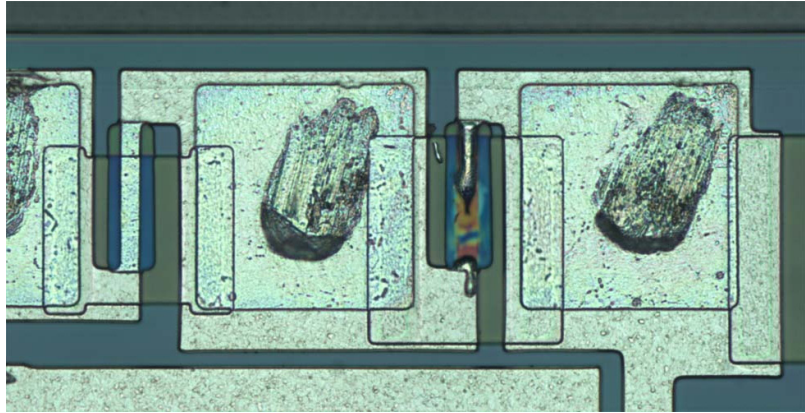
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### Latch-up

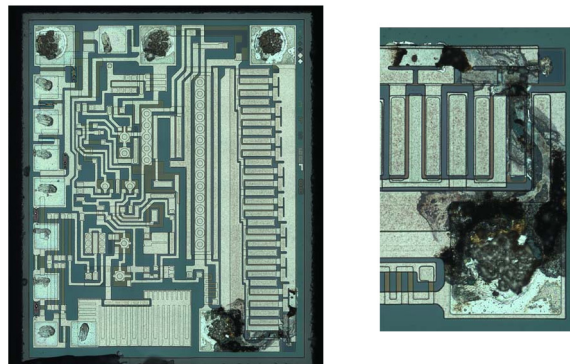
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Another problem that can occur on a chip that is hit by a relatively mild ESD that does no physical harm is what is called “latch-up.” This is an effect caused by unwanted structures that are on the chip as a result of other

structures. Design and placement of transistors on a chip should avoid this, but often they cannot be avoided, or only at high chip area-cost. These structures form stray semiconductors that are triggered by out-of-bound voltage spikes (not only ESD, but also power supply spikes, especially when turning on the power supply) and can prevent other transistors from working once triggered. Power-cycling the device restores the chip to its default state.



**FIGURE 4: INTERCONNECT BURNED AWAY (SOURCE: BUNNIE, [HTTP://WWW.BUNNIESTUDIOS.COM/BLOG](http://www.bunniestudios.com/blog), WITH PERMISSION)**



**FIGURE 5: SERIOUS DEFORMATION OF CHIP PATTERN THROUGH ESD (SOURCE: BUNNIE, [HTTP://WWW.BUNNIESTUDIOS.COM/BLOG](http://www.bunniestudios.com/blog), WITH PERMISSION)**

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### How Much?

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Often ESD leaves no trace whatsoever. You often do not feel, hear, or see anything, but there is a discharge that may harm your systems. The table below shows the voltage that is related to the ESD vs. the traces it shows.

Feel static discharge	> 3000 volts
Hear static discharge	> 6000 volts
See static discharge (spark)	> 9000 volts

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### Protection

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Almost all chips have diodes and other measures built into their design to protect against static discharges on the leads by bleeding them off, but they

cannot protect against all static discharges. And some chips cannot have these protections since the chips' functionality would be affected by them. Examples of this are very low-voltage and low-current chips, radio front ends, and analog or touch devices.

The first measure in ESD protection is to minimize the buildup of static electricity; the less charge there is, the less likely that it will harm your electronics. Often this is done by being careful not to use materials and fabrics in the environment that build up static electricity easily, such as nylon clothing and nylon carpet. Friction between nylon and almost any other material will quickly produce static charge. It would be useful to post warning signs in work areas and rooms where you have your equipment operating. The more conductive the material is, the less static buildup you will face.

Another factor in the buildup of static electricity is relative humidity. This is especially true in winter (or in the summer in desertlike areas). With low humidity comes low air conductance, so static charges are not able to leak to earth and will build up fast, making dangerous electrostatic charges about 10 times more likely to occur than in humid air. Other problems can occur if you run your systems in a data center that has too low relative humidity; the airflow within some systems can cause buildup of static electricity on the components in the machine.

A third measure is trying to let the static charge bleed away to ground or at least have your system on the same charge level as the operator or your tools. This can be accomplished by using a wristband when operating and fixing internals of your systems. The wristband will ease out the potential that your body holds to the potential the machine is on. In the wristband cable there is a resistor to prevent high currents and sparks when connecting the wire.

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## Practical Tips

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The following are practical tips to minimize the damage due to ESD.

- Be aware of clothing, footwear, and carpets. These are by far the most likely cause of charge buildup on your body. There are special conductive (enhanced with carbon particles) garments, shoes, furniture, and carpets. Avoid nylon in all cases. The non-conductive wheels of office chairs can be pretty nasty, too.
- When handling equipment, always touch both the grounded machine and the rack to be sure that all are at the same level.
- Keep your hardware grounded at all times, to prevent buildup of electrostatic charges. You can do that by keeping the chassis grounded by a small wire and alligator clips or keeping the chassis physically connected to the grounded rack.
- Be careful with styrofoam. Do not let pieces of packing foam get close to the printed circuit board. Some manufacturers use styrofoam that has conductive particles in it, which has less static buildup.
- Use grounding wristbands and connect them to the earth/chassis.
- Leave components in their ESD-protective carriers as long as possible. If you need to have them on your desk, sometimes the back of a mouse mat has conductive rubber, so it is wise to leave them on the mat before handling. Also, components that you remove from your machine need to be protected.
- If you need to ship ESD devices, use ESD-protective bags or wrap them in aluminum foil and put them in an antistatic plastic bag. Note that if there is a battery on the board you should not use aluminum foil, as you may short-circuit things.

- If the humidity in the room drops below 30%, use an air humidifier or adjust your air-conditioning systems accordingly.

If something ESD-related happens and you notice that there is a static discharge, either by feeling it or noticing a spark, mark the components and machine that you think might be affected so that you can relate problems with these devices or components later to this event.

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### Conclusion

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Integrated circuits of all sorts are susceptible to ESD. When handling devices, you should always be aware that ESD pulses can occur and should minimize the likelihood of it. Chips can be seriously impaired, even without a visible spark, resulting in problems later on. There are a number of simple measures to take to prevent static buildup and ESD.

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### ACKNOWLEDGMENTS

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