IR Application Note AN-955

TITLE:

Protecting IGBTs and MOSFETs from ESD

Notices:
(HEXFET is the trademark for International Rectifier Power MOSFETs)

Summary:

Most power MOSFET users are very familiar with this warning. The problem is that familiarity may breed contempt, especially if one has never destroyed a power MOSFET by improper handling. Statistically, it is unlikely that a particular MOSFET will be destroyed by Electrostatic-Discharge (ESD). However, when thousands of MOSFETs are handled, even a statistically small number of failures may be significant. In view of the fact that IR rejects less than 100 parts per million (ppm) at outgoing Q.A., it is evident that destroying 1 or 2 parts per 1,000 during incoming handling will have a significant impact on the "perceived" quality of the units.

Any effective ESD Control Program is very detailed and specific by nature. But its basic underlying concepts may be summarized by ten simple rules:

1. Always store and transport MOS-FETs in *closed* conductive containers.
2. Remove MOSFETs from containers only after grounding at a Static Control Work Station.
3. Personnel who handle power MOSFETs should wear a static dissipative outer garment and should be grounded at all times.
4. Floors should have a grounded static dissipative covering or treatment.

5. Tables should have a grounded static dissipative covering.
6. Avoid insulating materials of any kind.
7. Use anti-static materials in one-time applications only.
8. Always use a grounded soldering iron to install MOSFETs.
9. Test MOSFETs only at a static controlled work station.
10. Use all of these protective measures simultaneously and in conjunction withtrained personnel.

International Rectifier has an outstanding ESD control program in place in their HEXFETâ manufacturing facility. This Application Note will discuss how HEXFET users can implement and benefit from similar ESD control programs.

What is ESD?

ESD is the discharge of static electricity. Static electricity is an excess or deficiency of electrons on one surface with respect to another surface or to ground. A surface exhibiting an excess of electrons is negatively charged, and an electron deficient surface is positively charged. Static electricity is measured in terms of voltage (volts) and charge (coulombs).

When a static charge is present on an object, the molecules are electrically imbalanced. Electrostatic-Discharge (ESD) takes place when a re-establishment of equilibrium is attempted through the transfer of electrons between one object and another that is at a different voltage potential. When an ESD-sensitive device, such as a power MOSFET, becomes part of the discharge path, or is brought within the bounds of an electrostatic field, it can be permanently damaged.

Generating Static Electricity

The most common way of generating static electricity is triboelectrification. Rubbing two materials together will cause triboelectrification, as will bringing two materials together and then separating them. The magnitude of the charge is highly dependent upon the particular material's propensity toward giving up or taking on electrons.Dissimilar materials are particularly susceptible, especially if they have high surface resistivity.

Another way of placing a static charge on a body is by induction. Induction could be caused, for example, by placing a body in close proximity to a highly charged object or high-energy ESD.

ESD Failure of the Power MOSFET
Failure Mode

One of the biggest operating advantages of the power MOSFET can also be the cause of its demise when it comes to ESD ultra-high input resistance (typically > 4 x 109 ohms). The gate of the power MOSFET may be considered to be a low voltage (+ 20V for HEXFETs) low leakage capacitor. As can be seen in Figure 1, the capacitor plates are formed primarily by the silicon gate and source metallization. The capacitor dielectric is the silicon oxide gate insulation.

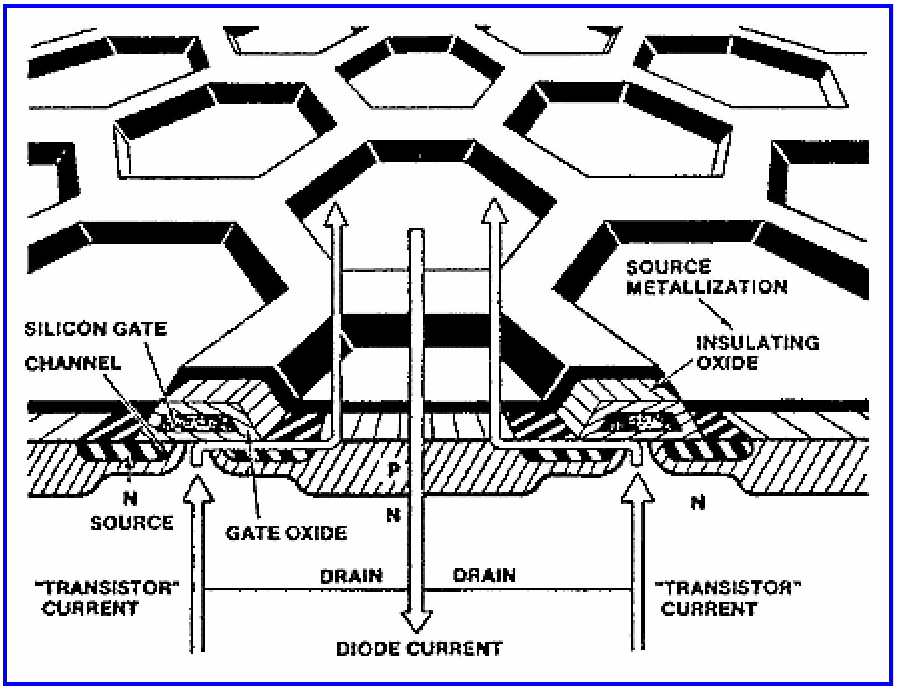

Figure 1. Basic HEXFET Structure

ESD destruction of the MOSFET occurs when the gate-to-source voltage is high enough to arc across the gate dielectric. This burns a microscopic hole in the gate oxide which permanently destroys the device. Like any capacitor, the gate of a power MOSFET must be supplied with a finite charge to reach a particular voltage. Since larger devices have greater capacitance they require more charge per volt and are therefore less susceptible to ESD than are smaller MOSFETs. Also, immediate failure usually will not occur until the gate-to-source voltage exceeds the rated maximum by two to three times.

A typical ESD destruction site can be seen in Figure 2a. This was caused by a human body model charged to 700 volts being discharged into the gate of the device. This photo was taken at a magnification of 5,000 with a scanning electron microscope after stripping the surface of the die down to polysilicon. The photo of Figure 2bshows that no damage was visible on the surface of the die prior to stripping. The actual failure site shown in Figure 2a is only about 8 microns in diameter. The electrical symptom of ESD failure is a low resistance or a zener effect between gate and source with less than ±20 volts applied.

The voltages required to induce ESD damage can be 1,000 volts or higher (depending upon chip size). This is due to the fact that the capacitance of the body carrying the charge tends to be much lower than the Ciss of the MOSFET, so that when the charge is transferred, the resulting voltage will be much lower than the original.

Electrostatic fields can also destroy the power MOSFET. The failure mode is ESD but the effect is caused by placing the unprotected gate of the FET in a Corona Discharge path. Corona Discharge is caused by a positively or negatively charged surface discharging into small ionic molecules in the air ($CO2^+$, H^+, $O2^-$, OH^-).

Is ESD Really a Problem?

As previously mentioned, when dealing with small quantities of MOSFETs, ESD may not seem to be a problem. The results in this case may be occasional unexplained failures. When dealing with very large quantities, particularly when quality is of prime consideration, ESD can be a real problem.

The graph in Figure 3 gives a good graphical illustration of the magnitude of the problem and its solution. This graph was derived from data taken at an internal point of International Rectifier's manufacturing facility and does not represent the much lower AOQL levels. Between April 1982 and October 1983, gate-related failure dropped by nearly a factor of 7 at this inspection point as a direct result of the institution of ESD protective measures.

Materials and Methods for ESD Control
Direct Protection Method

In protecting any power MOSFET from ESD or any other excess gate voltage, the primary objective is to keep the gate-to-source voltage from exceeding the maximum specified value (±20 for HEXFETs). This is true both in and out of circuit.

Direct protection of the MOSFET could involve methods such as shorting the gate to the source, or applying zener protection gate-to-source. While effective for in-circuit or small quantity applications, the direct method is usually impractical in the manufacturing

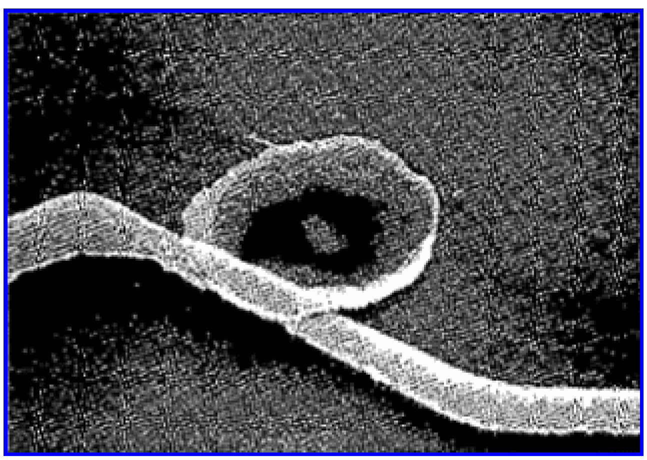

Figure 2a. Typical ESD Failure

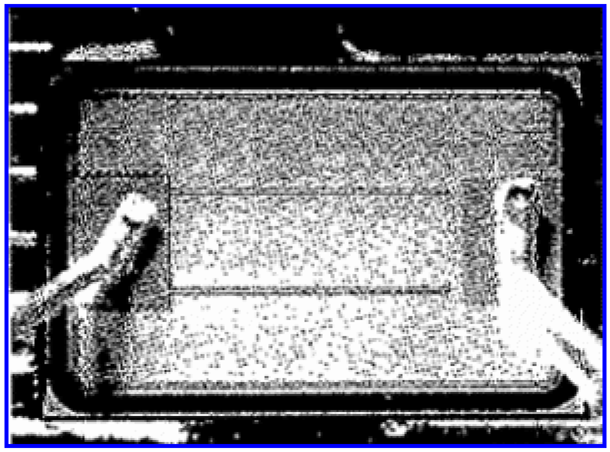

Figure 2b. ESD Damaged Device at Low Magnification before Stripping

environment because of the large volume of power MOSFETs involved. The basic concept of complete-static protection for the power MOSFETs is the prevention of static build-up where possible and the quick, reliable removal of existing charges.

Materials in the environment can either help or hinder static control. These may be placed into four categories of surface resistivity: Insulating (>1014 ohms/Sq.*), Anti-Static (109-1014 ohms/Sq.*), Static-Dissipative (105-109 ohms/Sq.*), and Conductive (Ideally, to protect the HEXFET, one should have only grounded conductive bodies in the facility. Additionally, all personnel involved in the manufacturing process should be hard grounded. Unfortunately the humans involved in the manufacturing process would then become vulnerable to electrocution by faulty electrical equipment. Also, when traveling long distances, it can be difficult to maintain a ground connection. Consequently, protective materials and methods must be chosen based on the situation.

Insulating Material

Because of their propensity for storing static charges and the difficulty with discharging them, it is imperative to keep objects made of insulating materials away from power MOSFETs and out of the environment entirely, if possible. Since electric current cannot flow through an insulator, electrical connections from an insulator to ground are useless in controlling static charges.

Insulating materials include: polyethylene (found in regular plastic bags), polystyrene (found in Styrofoam cups and packing "peanuts"), Mylar, hard rubber, vinyl, rnica ceramics, most other plastic, and some organic materials.

When plastic products must be used in a power MOSFET handling facility, use only items impregnated with a conductive material and/or treated with anti-static compounds.

Anti-Static Material

Anti-static material is resistant to the generation of triboelectric charges, but does not provide a shield from electric fields. Corona Discharge will pass right through an anti-static enclosure, possibly destroying any MOSFETs which are inside. Because of its high surface resistivity, grounding anti-static material is not very effective for removing a charge.

Some plastic insulators can be treated with anti-static agents which chemically reduce their susceptibility to triboelectrification and lower their surface resistivity. Most anti-static agents require high relative humidity (RH) to be effective. Therefore, the RH of facilities where power MOSFETs are handled should be kept above 40%. Also, anti-static agents tend to wear off or wear out after a period of time, and most of them use reactive ionic chemicals which can be corrosive to metal. Anti-static plastics should be limited to short-term use in one-time only situations, such as Dl P and TO-3 tubes and packing materials for shipping.

** The size of the square does not effect the surface resistivity.*