Reliability and Quality for IGBTs

ON Semiconductor®

www.onsemi.com

APPLICATION NOTE

Introduction

In today's semiconductor marketplace two important elements for the success of a company are product quality and reliability. Both are interrelated − reliability is the quality extended over the expected life of the product. For any manufacturer to remain in business, their products must meet and/or exceed the basic quality and reliability standards. ON Semiconductor, as a semiconductor supplier, has successfully achieved these standards by supplying product for the most strenuous applications to perform in the most adverse environments.

It is recognized that the best way to accomplish an assured quality performance is by moving away from the previous methods of "testing in" quality and embracing the newer concept of "designing in" quality. At ON Semiconductor, we use a two-fold approach toward reaching the ultimately achievable level of quality and reliability. First, we develop and implement a process that is inherently reliable. Then we exercise meticulous care in adhering to the specifications of the process every step of the way − from start to finish. This allows the development and application of inspections and procedures that will uncover potentially hidden failure modes. It is this dedication to long-term reliability that will ultimately lead to the manufacture of the "perfect product."

ON Semiconductor approaches the ideal in IGBT product reliability by instigating a four-step program of quality and reliability:

1. Stringent in-process controls and inspections.
2. Thoroughly evaluated designs and materials.
3. Process average testing, including 100% QA redundant testing.
4. Ongoing reliability verifications through audits and reliability studies.

These quality and reliability procedures, coupled with rigorous incoming inspections and outgoing quality control inspections add up to a product with quality built in − from raw silicon to delivered service.

RELIABILITY TESTS

ON Semiconductor IGBT's are subjected to a series of extensive reliability tests to verify conformance. These tests are designed to accelerate the failure mechanisms encountered in practical applications, thereby ensuring satisfactory reliable performance in "real world" applications.

The following describes the reliability tests that are routinely performed on ON Semiconductor's IGBT's.

High Temperature Reverse Bias (HTRB)

The HTRB test is designed to check the stability of the device under "reverse bias" conditions of the main blocking junction at high temperature, as a function of time.

The stability and leakage current over a period of time, for a given temperature and voltage applied across the junction, is indicative of junction surface stability. It is therefore a good indicator of device quality and reliability.

For IGBT's, voltage is applied between the collector and emitter with the gate shorted to the emitter. I_{CES}, $V_{(BR)CES}$, I_{GES}, $V_{GE(th)}$, and $V_{CE(on)}$ are the dc parameters monitored. A failure will occur when the leakage achieves such a high level that the power dissipation causes the devices to go into a thermal runaway. The leakage current of a stable device should remain relatively constant, only increasing slightly over the testing period.

Typical conditions:

V_{CE} = 80−100% of maximum rating
V_{GE} = 0 V (shorted)
T_A = 150°C or Tj maximum
Duration: 1,000 hrs for qualification

High Temperature Gate Bias (HTGB)

The HTGB test is designed to electrically stress the gate oxide at the maximum rated dc bias voltage at high temperature. The test is designed to detect for drift caused by random oxide defects and ionic oxide contamination.

For IGBTs, voltage is applied between the gate and emitter with the collector shorted to the emitter. I_{GES}, $V_{GE(th)}$, and $V_{CE(on)}$ are the dc parameters monitored. Any oxide defects will lead to early device failures.

Typical conditions:

V_{GE} = ±20 V or 100% rated V_{GE}
V_{CE} = 0 (shorted)
T_J = 150°C or T_J maximum
Duration: 1,000 hrs for qualification

High Temperature Storage Life (HTSL) Test

The HTSL test is designed to indicate the stability of the devices, their potential to withstand high temperatures and the internal manufacturing integrity of the package. Although devices are not exposed to such extreme high temperatures in the field, the purpose of this test is to accelerate any failure mechanisms that could occur during long periods at storage temperatures.

The test is performed by placing the devices in a mesh basket, then placed in a high temperature chamber at a controlled ambient temperature, as a function of time.

Typical conditions:

T_A = 150°C on plastic package

Duration: 1,000 hrs for qualification

High Humidity High Temperature Reverse Bias (H^3TRB)

The H^3TRB test is designed to determine the resistance of component parts and constituent materials to the combined deteriorative effects of prolonged operation in a high temperature/high humidity environment. This test only applies to nonhermetic devices.

Humidity has been a traditional enemy of semiconductors, particularly plastic packaged devices. Most moisture related degradations result, directly or indirectly, from penetration of moisture vapor through passivating materials, and from surface corrosion. At ON Semiconductor, this former problem has been effectively addressed and controlled through use of junction “passivation” process, die coating, and proper selection of package materials.

Typical conditions:

V_{CE} = 80−100% of maximum rating

V_{GE} = 0 (shorted)

T_A = 85°C

RH = 85%

Duration: 1000 hrs for qualification

Typical conditions:

$V_{GE} \geq 10$ V

ΔT_J = 100°C

$R_{\theta JC}$ = Device dependent

T_{on}, $T_{off} \geq 30$ seconds

Duration: 10−15k cycles for qualification

Unbiased Highly Accelerated Stress Test (UHAST)

The UHAST is designed to determine the moisture resistance of devices by subjecting them to high steam pressure levels. This test is only performed on plastic/epoxy encapsulated devices and not on hermetic packages (i.e., metal can devices). Within the chamber a tray is constructed inside to keep the devices approximately two inches above the surface of deionized water and to prevent condensed water from collecting on them. After achieving the proper temperature and atmospheric pressure, these test conditions are maintained for a minimum of 24 hours. The devices are then removed and air dried. Parameters that are usually monitored are leakage currents and voltage.

Typical conditions:

T_A = 131°C

P = 14.7 psi

RH = 100%

Duration: 72 hrs for qualification

Intermittent Operating Life (IOL)

The purpose of the IOL test is to determine the integrity of the chip and/or package assembly by cycling on (device thermally heated due to power dissipation) and cycling off (device thermally cooling due to removal of power applied) as is normally experienced in a “real world” environment.

DC power is applied to the device until the desired function temperature is reached. The power is then switched off, and forced air cooling applied until the junction temperature decreases to ambient temperature.

$$\Delta T = \Delta T_C + R_{\theta JC} P_D \quad \text{(eq. 1)}$$

$$\Delta T_J = 100^\circ C \quad \text{(eq. 2)}$$

(typically, which is an accelerated condition)

$$\Delta T_C = T_{C\,HIGH} - T_{C\,LOW} \quad \text{(eq. 3)}$$

The sequence is repeated for the specified number of cycles. The temperature excursion is carefully maintained for repeatability of results.

The Intermittent Operating Life test indicates the degree of thermal fatigue of the die bond interface between the chip and the mounting surface and between the chip and the wire bond interface.

For IGBT’s, parameters used to monitor performance are thermal resistance, threshold voltage, on-resistance, gate-emitter leakage current and collector-emitter leakage current.

A failure occurs when thermal fatigue causes the thermal resistance or the on-resistance to increase beyond the maximum value specified by the manufacturer’s data sheets.

Temperature Cycle (TC)

The purpose of the Temperature Cycle Test is to determine the resistance of the device to high and low temperature excursions in an air medium and the effects of cycling at these extremes.

The test is performed by placing the devices alternatively in separate chambers set for high and low temperatures. The air temperature of each chamber is evenly maintained by means of circulation. The chambers have sufficient thermal capacity so that the specified ambient is reached after the devices have been transferred to the chamber.

Each cycle consists of an exposure to one extreme temperature for 15 minutes minimum, then immediately transferred to the other extreme temperature for 15 minutes minimum; this completes one cycle. Note that it is an immediate transfer between temperature extremes and thereby stressing the device greater than non-immediate transfer.

Typical Extremes

−65/ + 150° C

The number of cycles can be correlated to the severity of the expected environment. It is commonly accepted in the industry that ten cycles is sufficient to determine the quality of the device. Temperature cycling identifies any excessive strains set up between materials within the device due to differences in coefficients of expansion.

Low Temperature Storage Life (LTSL) Test

The LTSL test is designed to indicate the stability of the devices, their potential to withstand low temperatures and the internal manufacturing integrity of the package. Although devices are not exposed to such extreme low temperatures in the field, the purpose of this test is to accelerate any failure mechanisms that could occur during long periods at storage temperatures.

Typical conditions:

T_A = −65°C on Plastic package

Duration: 1000 hrs for qualification

The test is performed by placing the devices in a mesh basket, then placed in a high temperature chamber at a controlled ambient temperature, as a function of time.

Steady State Operational Life (SSOL) Test

The SSOL test is designed to indicate the integrity of the chip and/or package assembly at steady-state continuous operational life conditions.

For IGBT's, parameters used to monitor performance are thermal resistance, threshold voltage, on-resistance, gate-emitter leakage current and collector-emitter leakage current.

Typical conditions:

$V_{GE} \geq 10$ V

$\Delta T_J = 100°C$

$T_A = 25°C$ Duration: 1,000 hours for qualification

A failure occurs when thermal fatigue causes the thermal resistance or the on−resistance to increase beyond the maximum value specified by the manufacturer's data sheet.

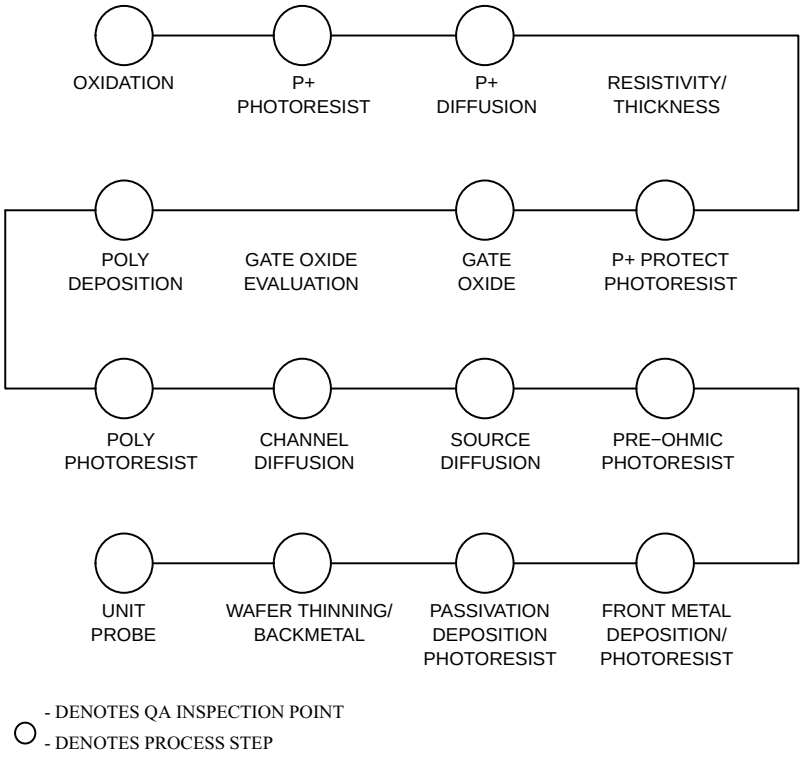

Figure 1. IGBT Wafer Fabrication

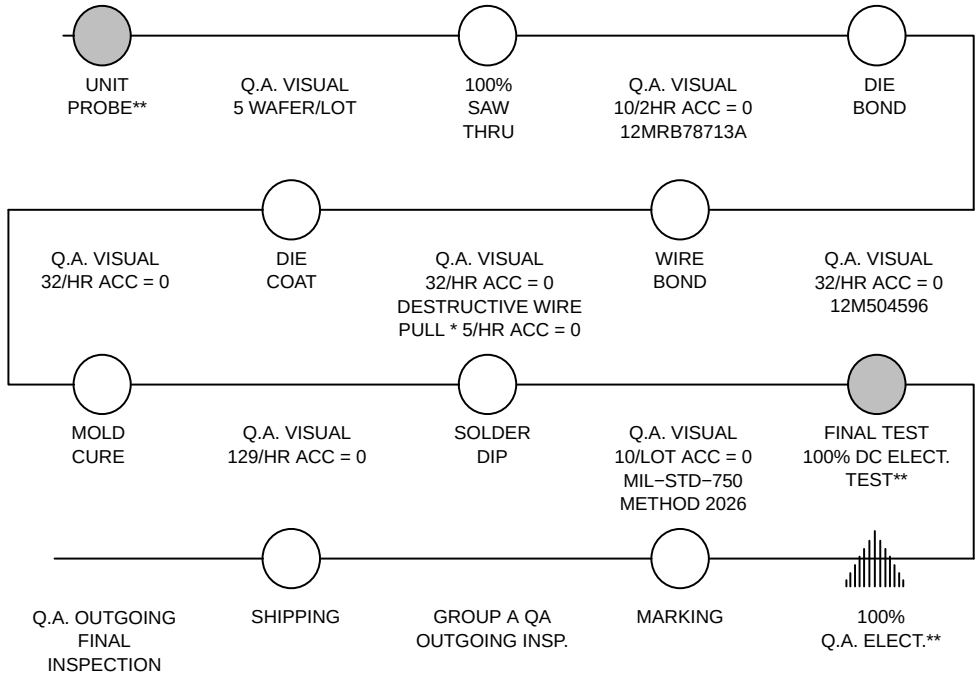

Figure 2. Assembly Process Flow

Environmental Package Related Test Programs:

A. Physical Dimensions − This test is performed to determine the conformance to device outline drawing specifications.
B. Visual and mechanical examination − A test to determine the acceptability of product to certain cosmetic and functional criteria such as marking legibility, stains, etc.
C. Resistance to Solvents − A test to determine the solderability of device terminals.
D. Terminal Strength − This test is a lead bend test to check for lead strength.

Every manufacturing process exhibits a quality and reliability distribution. This distribution must be controlled to assure a high mean value, a narrow range and a consistent shape. Through proper design and process control this can be accomplished, thereby reducing the task of screening programs which attempt to eliminate the lower tail of the distribution.

Accelerated Stress Testing

The nature of some tests in this report is such that they far exceed that which the devices would see in normal operating conditions. Thus, the test conditions “accelerate” the failure mechanisms in question and allow ON Semiconductor to predict failure rates in a much shorter amount of time than otherwise possible. Failure modes that are temperature dependent are characterized by the Arrhenius model.

$$AF = \frac{EA}{K}\left(\frac{1}{T2} - \frac{1}{T1}\right) \quad \text{(eq. 4)}$$

AF = Acceleration factor
EA = Activation energy (eV)
K = Boltzman’s constant ($8.62 \times 10E^{-5}$ eV/K)
T2 = Operating temperature, K
T1 = Test temperature, K

Therefore, the equivalent device hours are equal to the acceleration factor (as determined by the Arrhenius Model) times the actual device hours.

Review of Data

High Temperature Reverse Bias (HTRB) indicates the stability of leakage current, which is related to the field distortion of IGBT’s. HTRB enhances the failure mechanism by high temperature reverse bias testing, and therefore is a good indicator of device quality and reliability, along with verification that process controls are effective.

High Temperature Gate Bias (HTGB) checks the stability of the device under “gate bias” forward conditions at accelerated high temperature, as a function of time. This test is performed to electrically stress the gate oxide to detect for drift caused by random oxide defect. This failure mechanism appears in the infant and random zones of the reliability “bath tub curve” at a very low rate of defect.

Intermittent Operating Life (IOL) is an excellent accelerated stress test to determine the integrity of the chip

and/or package assembly to cycling on (device thermally heated due to power dissipation) and cycling off (device thermally cooling due to removal of power applied). This test is perhaps the most important test of all, along with simulating what is normally experienced in a “real world” environment. IOL exercises die bond, wire bonds, turning on the device, turning off the device, relates the device performance, and verifying the thermal expansion of all materials are compatible. ON Semiconductor performs extensive IOL testing as a continual process control monitor that test relates to the “device system**” as a whole. ON Semiconductor also performs extensive analysis and comparison of delta function temperatures. ON Semiconductor has determined that to effectively stress the device a delta T_J of 100°C is necessary which far exceeds many customers’ application and determines the reliability modeling of the device.

Temperature Cycling (TC) is also an excellent stress test to determine the resistance of the device to high and low temperature excursions in an air medium. Where IOL electrically stresses the “device system” from internally, temperature cycle stresses the “device system” thermally from external environment conditions.

High Temperature Storage Life (HTSL), High Humidity Temperature Reverse Bias (H^3TRB), Thermal Shock (TC) and “Pressure Cooker” (Autoclave) are routinely tested, however it is felt by ON Semiconductor Reliability Engineering that HTRB, HTGB, IOL and TC are of primary importance. ON Semiconductor has been in the semiconductor industry for many years and will remain there as a leader with continued reliability, quality and customer relations.

RELIABILITY AUDIT PROGRAM

At ON Semiconductor reliability is assured through the rigid implementation of a reliability audit program. All IGBT products are grouped into generic families according to process technology and package types. These families are sampled quarterly from the raw stock at final test, then submitted for audit testing. The extreme stress testing, in real-time for each product run, may uncover process abnormalities that are detectable by the in-process controls. Typical reliability audit tests include high temperature reverse bias, high temperature gate bias, intermittent operating life, temperature cycling, and autoclave. To uncover any hidden failure modes, the reliability tests are designed to exceed the testing conditions of normal quality and reliability testing.

Audit failures which are detected are sent to the product analysis laboratory for real-time evaluations. This highly specialized area is equipped with a variety of analytical capabilities, including electrical characterizations, wet chemical and plasma techniques, metallurgical cross-sectioning, scanning electron microscope, dispersive x-ray, auger spectroscopy, and micro/macro photography. Together, these capabilities allow the prompt and accurate analysis of failure mechanisms − ensuring that the results of the evaluations can be translated into corrective actions and directed to the appropriate areas of responsibility.

The ON Semiconductor reliability audit program provides a powerful method for uncovering even the slightest hint of potential process anomalies in the IGBT product line. It is this stringent and continuing concern with the reliability audits that gives positive assurance that customer satisfaction will be achieved.

IGBT RELIABILITY AUDIT PROGRAM

Test	Conditions	S/S	Frequency
HTRB	V_{CE} = 80 −100% Max rating V_{GE} = 0 V T_J = 150°C Duration = 168 hours (short), 1,000 hours (long)	77pcs	Qty
HTGB	V_{GES} = ± 20 V V_{CE} = 0 V T_J = 150°C Duration = 168 hours (short), 1,000 hours (long)	77pcs	Qty
IOL	D T_J = 100°C V_{CE} ≥ 10 V Duration = 5000 cycles (short), 15,000 cycles (long)	77pcs	Qty
Solder Heat	1 cycle @ 260°C for 10 seconds followed by:	77pcs	Qty
Temperature Cycle	100 cycles (short) 500 cycles (long) −65 to +150°C Dwell time ≥ 15 minutes	77pcs	Qty
Pressure Cooker	P = 15 psi, T = 121°C Duration = 48 hours (short), 96 hours (long) (plastic package only)	77pcs	Qty
HTSL	T_A = 150°C, 168 hrs	77pc	Qty

Essentials of Reliability

Paramount in the mind of every semiconductor user is the question of device performance versus time. After the applicability of a particular device has been established, its effectiveness depends on the length of trouble free service it can offer. The reliability of a device is exactly that − an expression of how well it will serve the customer. Reliability can be redefined as the probability of failure free performance, under a given manufacturer's specifications, for a given period of time. The failure rate of semiconductors in general, when plotted versus a long period of time, exhibit what has been called the "bath tub curve".

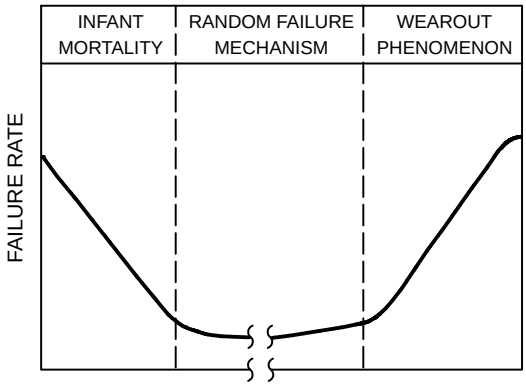

Figure 3. Failure Rate of Semiconductor

Reliability Mechanics

Since reliability evaluations usually involve only samples of an entire population of devices, the concept of the central limit theorem applies and a failure rate is calculated using the λ^2 distribution through the equation:

$$\lambda 3 \frac{\lambda 2(\alpha, 2r + 2)}{2nt} \qquad \text{(eq. 5)}$$

where

$$\alpha = \frac{100 - cl}{100} \qquad \text{(eq. 6)}$$

The confidence limit is the degree of conservatism desired in the calculation. The central limit theorem states that the values of any sample of units out of a large population will produce a normal distribution. A 50% confidence limit is termed the best estimate, and is the mean of this distribution. A 90% confidence limit is a very conservative value and results in a higher λ which represents the point at which 90% of the area of the distribution is to the left of that value.

The term (2r + 2) is called the degrees of freedom and is an expression of the number of rejects in a form suitable to λ^2 tables. The number of rejects is a critical factor since the definition of rejects often differs between manufacturers. Due to the increasing chance of a test not being representative of the entire population as sample size and test time are decreased, the λ^2 calculation produces surprisingly high values of λ for short test durations even though the true long term failure rate may be quite low. For this reason relatively large amounts of data must be gathered to demonstrate the real long term failure rate. Since this would require years of testing on thousands of devices, methods of accelerated testing have been developed.

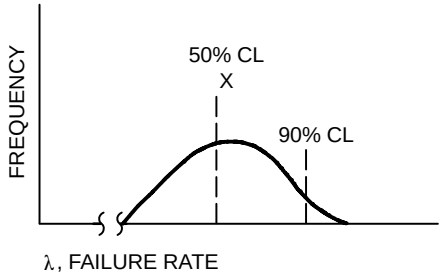

Figure 4. Confidence Limits and the Distribution of Sample Failure Rates

Years of semiconductor device testing has shown that temperature will accelerate failures and that this behavior fits the form of the Arrhenius equation:

$$R(t) = Ro(t)e^{-/KT} \qquad \text{(eq. 7)}$$

Where:

R(t) = Reaction rate as a function of time and temperature
R_o = A constant
t = Time
T = Absolute temperature, °Kelvin (°C + 273°)
= Activation energy in electron volts (ev)
K = Boltzman's constant = 8.62×10^{-5} ev/°K

This equation can also be put in the form:

AF = Acceleration factor
T2 = User temperature
T1 = Actual test temperature

The Arrhenius equation states that reaction rate increases exponentially with the temperature. This produces a straight line when plotted on log-linear paper with a slope physically interpreted as the energy threshold of a particular reaction or failure mechanism.

Reliability Qualifications/Evaluations Outline

Some of the functions of ON Semiconductor Reliability and Quality Assurance Engineering is to evaluate new products for introduction, process changes (whether minor or major), and product line updates to verify the integrity and reliability of conformance, thereby ensuring satisfactory performance in the field. The reliability evaluations may be subjected to a series of extensive reliability testing, such as those outlined in the "Tests Performed" section, or special tests, depending on the nature of the qualification requirement.

PUBLICATION ORDERING INFORMATION

LITERATURE FULFILLMENT:
Literature Distribution Center for ON Semiconductor
19521 E. 32nd Pkwy, Aurora, Colorado 80011 USA
Phone: 303−675−2175 or 800−344−3860 Toll Free USA/Canada
Fax: 303−675−2176 or 800−344−3867 Toll Free USA/Canada
Email: orderlit@onsemi.com

N. American Technical Support: 800−282−9855 Toll Free USA/Canada
Europe, Middle East and Africa Technical Support:
Phone: 421 33 790 2910
Japan Customer Focus Center
Phone: 81−3−5817−1050

ON Semiconductor Website: **www.onsemi.com**

Order Literature: http://www.onsemi.com/orderlit

For additional information, please contact your local Sales Representative