Precursor parameters identification for failure of IGBT devices

SRE Presentation

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Outline

Familiarization with Reliability

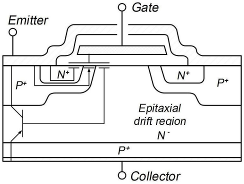
- Google's layman definition : The quality of being trustworthy or of performing consistently well.
- Reliability is the **probability** of an item to perform a required **function** under stated **conditions** for a specified period of **time**.

  -US DOD, Reliability Guide 2015
- Reliability of the device goes to 0.5 in 2 years will mean 50% of the devices would fail after 2 years statistically.
- Similarly failure is defined as the inability to deliver expected functionality under specified stressors and conditions under the specified time limit.

Introduction: IGBTs and their applications

What are IGBT's?

Insulated Gate Bippolar transistor: three-terminal power semiconductor device primarily used as an electronic switch.



- Conducts when Gate Voltage $> V_{th}$
- High frequency switching
- Blocks large voltage, high current handling
- Low on state power loss

Applications:

- High power consuming electronic devices
- Switching of automobile and train traction motors
- Switched Mode Power Supply (SMPS)

Motivation : About prognostic approach

The failure of these switches can reduce the efficiency of the system, or lead to system failure.

There are two methods for reliability estimation:

1. Post failure diagnosis
2. Prognosis : Pre-failure analysis

Prognostic Approach

- Predict future health of the product
- By measuring the deviation or degradation from expected behaviour
- Extrapolating the damage with appropriate physics of failure models
- Cost benefits by avoida of unscheduled maintenance.
- Taking measures to enhance reliability

Prognostic and Health Management method[3]

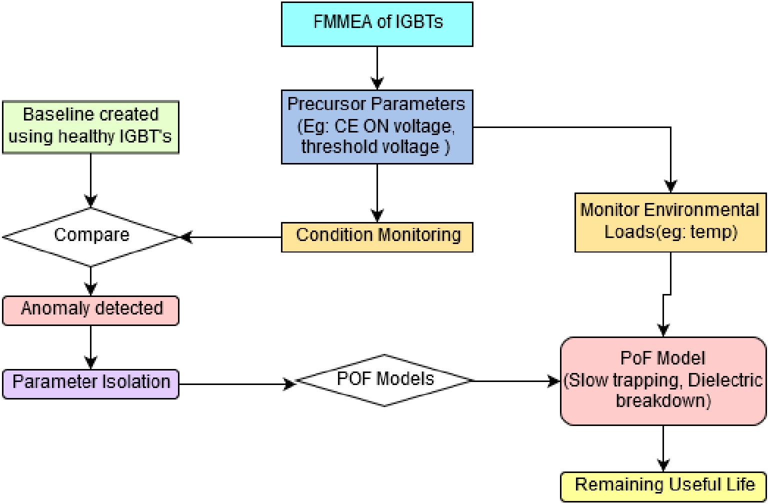


Figure: Flow chart of generic PHM method

Real Life Realization of prognostic approach

The idea is to apply PHM on students performances and derive the probable outcomes in future.

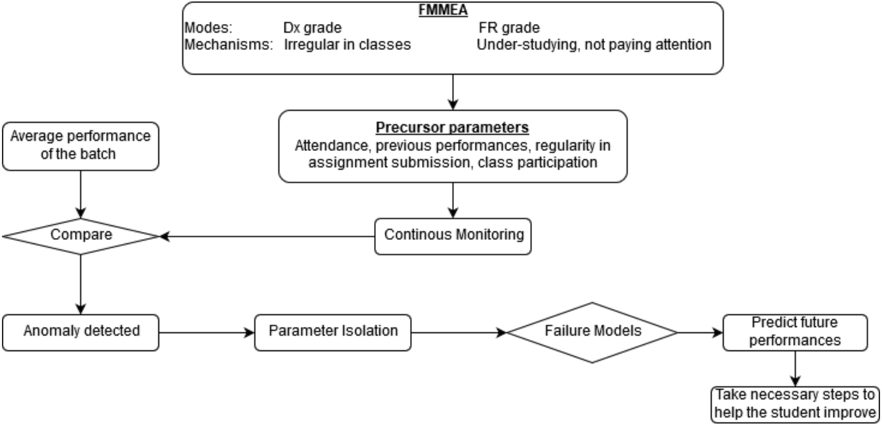


Figure: FMMEA

First step : FMMEA

Failure Modes for IGBT: [1]

- Lost Gate control
- Short circuit
- Increased leakage current

Potential causes :

- High temperature
- High Electric Field
- Overvoltage

Failure mechanisms for IGBT:

- Dielectric breakdown
- Latch up

Precursor parameters

- Failure precursor is an event or series of events indicative of an impending failure
- Precursor parameters are the device parameters to be monitored whose deviation from the baseline standard will be indicative of failure.

List of probable precursor parameters for IGBT failure:

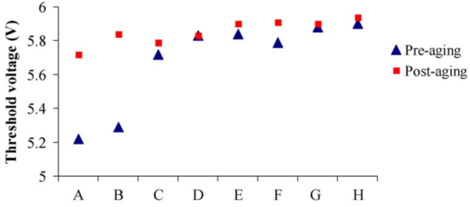
- Threshold voltage
- Emitter collector current
- Emitter-collector ON voltage drop
- Turn-off time of the transistor

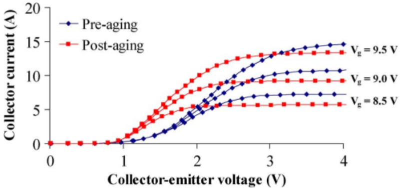
Aging Process

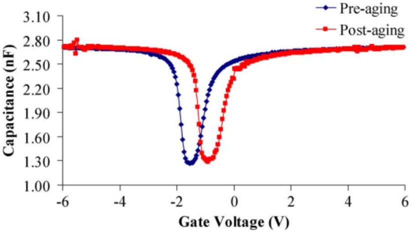
- Accelerated aging is done while monitoring of selected parameters
- Electrical and physical degradation analysis to correlate changes in monitored parameters to degradation in the devices under test
- The damage was realized by removing the heat sink, then switching the component such that it would heat itself
- For aging the IGBT, the gate voltage was chosen to be a square signal with amplitude of 8 V, a frequency of 1 kHz, and a duty cycle of 40%.
- Thermal cycling was done through switching ($T_{min} to T_{max}$) until latch up was seen
- On latch-up, the collector current is no longer controlled by the gate

Observations

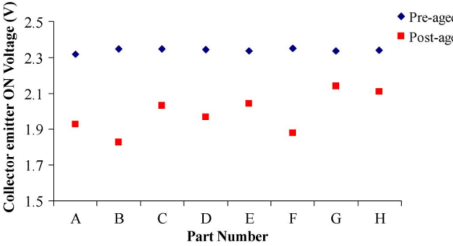
Following electrical observations were made:







[2]

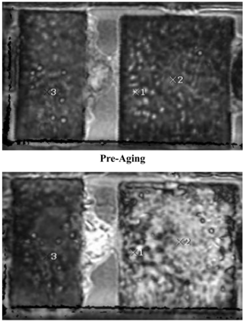


Observations

Physical degradation measurement via Scanning acoustic microscopy.

SAM(Scanning acoustic microscopy)[2]

- Used to detect delaminations and voids in microelectronic packages.



Pre-Aging

Post-Aging

[2]

- The C-scan image of the die attach of IGBT before, and after aging
- The brighter parts shows the degradation in the die attach of IGBT.
- It was found that the degradation was proportional to reduction in collector-emitter ON voltage after aging

Discussion

- The right shift in C-V plot indicates the degradation of gate oxide due to the electron trapped.
- The die attach is an integral part of the heat dissipation path, and its degradation is hypothesized to be the cause for drop in collector-emitter ON voltage.
- The degraded die attach leads to an increased temperature at the p-n junction above the collector which increases the number of intrinsic carrier concentration which eventually leads to the decrease in the voltage.[4]
- Increase in minority carriers also leads to the increase in turnoff time.

Acceleration Factor

- A general problem : For how long, the environmental test chamber is needed to simulate same degradation as in the field for a given period of time.
- Acceleration factor : Ratio of time taken in field to that of environmental chamber for same level of degradation with same mechanism of degradation.
- The lifetime of many devices are found to follow Arrhenius equation when it comes to thermal degradation.
- Characteristic Lifetime $= A_0 exp(\frac{E_a}{kT})$ -Arrhenius equation
  where $A_0 =$ constant,
  $E_a =$ Activation energy,
  T $=$ Temperature

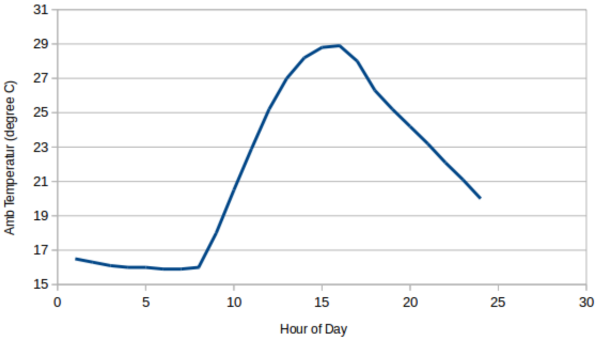
Acceleration factor

- If we know the activation energy for the degradation mechanism, we can calculate the equivalent time to simulate the damage in the environmental test chamber.
- Given field temperature $= T_{field}$
  Chamber Temperature $= T_{chamber}$

$$Accelerationfactor = exp\left[\frac{E_a}{k}\left(\frac{1}{T_{field}} - \frac{1}{T_{chamber}}\right)\right]$$

Variation of Temperature in Field

- Their wouldn't be any specific field temperature which the device will be facing.
- Environmental temperature will vary and that will be changing the device's temperature.
- This is the plot of hourly temperature variation in Jodhpur.

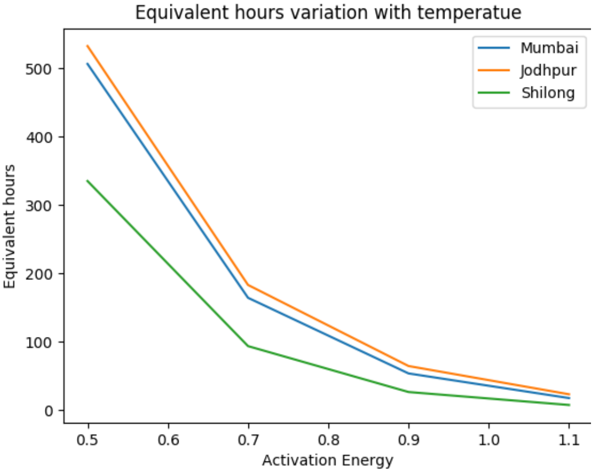


Equivalent Hour approach

- We can calculate equivalent chamber hours by considering the feild temperature for that hour as constant.
- We got the data(1 year) for hourly Temperature variation in three cities : Jodhpur, Mumbai and Shilong
- For each hour, equivalent chamber hour will be calculated by Arrhenius model.
- Summing up all the values will give us equivalent time(hrs) in chamber as that of 1 year in field.
- For an activation energy of 0.7eV and chamber temperature of 80C,
  Jodhpur : 183 hrs
  Mumbai : 164 hrs
  Shilong : 93 hrs

Variation with Activation energy

- Inverse dependence with Activation energy



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