Physics of Failure Based Quality and Reliability Investigation

Kristian Bonderup Pedersen

Aalborg University
Department of Physics and Nanotechnology

Supervisor
Kjeld Pedersen

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Degradation based Lifetime Assessment

- Modified Coffin-Manson:

  **Idea:**

  *Degradation as a function of load instead of load amplitude in lifetime assessment*

  **CM:**

  $N_f = a(\Delta T)^{\beta} \exp\left(\frac{E_a}{k_B T_m}\right)$

  Peak plasticity $\varepsilon_p^m$ instead of $\Delta T$? $N_f = a(\varepsilon_p^m)^{\beta} \exp\left(\frac{E_a}{k_B T_m}\right)$ *1

  Or plasticity density? $N_f = a(D[\Delta T, T(x, y, z, t), ...])^{\beta}$ *2

  A better understanding of the degradation process (fracturing, creep, etc.) is needed! But also the degradation distribution.

*1) Exponential term is not needed with plastic calculations
*2) More well shaped curve through plastic density function
Overview

1. **Enhanced physics-of-failure knowledge**
   i. Four point probing
   ii. SEM/FIB, EBSD, EDX, and micro-sectioning

2. **Detailed thermal, moisture, mechanical modelling**
   i. Commonly used (thermal network, etc)
   ii. FEM or MD

3. **Degradation calculation**
Four-point probing

- Identify the weakest interface
- Electrical parameter as degree of degradation
- Degradation distribution
Four-Point Approach

Sample: $T_I \rightarrow T_{out}$

A - New Module

Chip: $T_{out} \rightarrow D_{1,2}$

Close to failure (1.2M cycles)

B - 0.8M cycles $D_{1,2}$

Wires:

$I_1 \rightarrow w_{1-6}$

$I_2 \rightarrow w_{7-12}$

$D_1 \rightarrow w_{1-8}$

$D_2 \rightarrow w_{1-8}$

Etc.
Sections

- All interconnects degrading
- Ohmic change
- IGBT connections dominant
- Section spread increasing
Wire current distribution

- Clear current distribution across IGBT wires
- More uniform distribution across diode wires
Wire resistance
Metallization

SEM images of metallization surface

a) IGBT module A
b) IGBT module C (I2)
c) Diode module A
d) Diode module C
FIB – IGBT metallization

FIB milling

[Images of FIB milling results]

Center of Reliable Power Electronics
Fracturing
**Micro-Sectioning**

- Separation of section
  - 2xIGBT and 2xDiode
- Embedding in epoxy and polishing of DCB and chip solder
- Embedding in epoxy for wire interface
- Electrochemical etching
- 2min, 30V, 1% Hydrofluoric acid
- Microscopi
Large Scale "Micro-Investigation"
Electro-Thermo-Mechanical Simulations

Time=0.333333  Surface: Temperature (degC)
Time Domain Modelling of Bond Wire Lift-off

- Fracture mechanics modelling: (time-domain based)
  \[ \partial D = f(D, \epsilon, T) \partial T - \alpha(D, T) \partial t \]

  Damage parameter  Damage accumulation  Recovery

At high temperatures annealing effects are observed in the bond interfaces.

When the damage parameter reaches a given value in a region a fracture is assumed to propagate. The fracture occurrence is derived from four-point probing.

Possibilities: \( N_f \propto \Delta T, t_{out} \) or full FEM model