Characterization of Materials and their Interfaces in a DBC Substrate for Power Electronics Applications ECPE Workshop "Future of Simulation"

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21/11/18



# Introduction

Characterization of the copper layers

Characterization of the Ceramic Layer

Characterization of the Metal-Ceramic Interface

Conclusion



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# Introduction – Power Electronic Module





# Introduction – Power Electronic Module

### **Ceramic substrate Ensures**

- Electrical insulation
- Heat conduction

### **Direct Bonded Copper**

- ► Ceramic:
  - Heat conduction
  - Electrical insulation
- Patterned Metal:
  - Forms circuit
  - Bonding to module



# Introduction – Manufacturing of a DBC substrate



Standard: Al<sub>2</sub>O<sub>3</sub>/Cu (AIN also possible, with separate oxidation)

Bonding temperature very close to Cu melting point

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Bonding temperature very close to Cu melting point
Objective: modelling of the DBC for thermo-mechanical simulations

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Note: the content of this presentation is detailed in [2] and [3]



cu 1

### Tests on 3 Copper states:

### Cu3: Cu sheet prior to any process

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- temperature history
- no external mechanical stress

# 11: Full DBC process, followed by etching of the ceramic

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611

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- Cu3: Cu sheet prior to any process Cu2: The same after DBC annealing (but not bonded to ceramic)
  - temperature history
  - no external mechanical stress
- Cu1: Full DBC process, followed by etching of the ceramic
  - ► temp. and mech. history

### Preparation and test:

- Copper sheets supplied by Curamik
- samples formed by electro-erosion
- Uniaxial and cycling tensile tests

### Copper – Tensile test



- Dramatic change caused by annealing (yield stress)
- Also, effect of mechanical stress on yield
- ➔ Further characterization on Cu1, more representative

# Copper – Cycling test



Tests on Cu1, repetitive stress 0–120 MPa

No compressive stress to prevent sample from buckling Databat effect equad by kinematic bardening of econor

- Ratchet effect caused by kinematic hardening of copper
- → Need for a suitable model (Armstrong-Fredericks [4])

# Copper – Modelling





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### Ceramic - Preparation of the samples

### 2 grades of Al<sub>2</sub>O<sub>3</sub> tested:

- ► standard, thickness=635 µm
- "HPS" (Zr-reinforced), thickness=250 μm
- Material supplied by Curamik
- Samples cut using a wafer saw
- Sample size: 4 mm×40 mm
- 3-point bending test.





### Ceramic – Bending Tests



# Ceramic – Bending Tests (2)

### Weibull Analysis

- Considers the sample as a series of elementary volumes
- Each volume has a statistical defect probability



•  $\sigma_w$ : Weibull stress



### Model used

- Purely elastic behavior
- Considers rupture

### Identification of model parameters:

- E: from bending test
- ν: from literature [5]
- $m, \sigma_0$  and  $V_{eff}$ : from Weibull analysis.

	E	$\nu$	m	$\sigma_0$	V <sub>eff</sub>
Al <sub>2</sub> O <sub>3</sub>	403 GPa	0,22	16.03	322 MPa	0.103 mm <sup>3</sup>
$Zr-Al_2O_3$	330 GPa	0.22	18.95	590 MPa	0.501 mm <sup>3</sup>



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### Interface - Test Principle





- DBC sample with a notch in top Cu
- 4-point bending test
- Monitoring of fracture propagation
- Parameter identification with FE simulation



### Interface - Preparation of the samples



- **b** DBC configuration: 500  $\mu$ m Cu / 250  $\mu$ m Zr-Al<sub>2</sub>O<sub>3</sub> / 500  $\mu$  Cu
- Chemical etching of copper patterns
- Ceramic cutting with a wafer saw
- Sample size: 10 × 80 mm<sup>2</sup>











### Interface - Fracture Observation



### Cross section (SEM)

- Crack length measurement accuracy: ±50µm
- Crack occurs at interface
- No Al<sub>2</sub>O<sub>3</sub> remaining on Cu
- $\approx$  20 $\mu$ m bonding defects
- To be considered in simulation



### Interface - Fracture Observation



Delaminated copper surface (SEM)

- Crack length measurement accuracy: ±50µm
- Crack occurs at interface
- ► No Al<sub>2</sub>O<sub>3</sub> remaining on Cu
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# Interface – Cohesive model

### **Cohesive model**

- ► Once *T<sub>Max</sub>* has been reached, degradation occurs
- Gradual reduction in stiffness
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### **Implementation** [6]

- Simulation of the 4-point test
- Cohesive zone between Al<sub>2</sub>O<sub>3</sub> and bottom Cu
- Two parameters:  $T_{Max}$  and  $\Phi_{Sep}$



















23/29







Simulation for various:

- $\Phi_{Sep}$  (separation energy)
- *T<sub>Max</sub>* (crack initiation stress)
- With or without defects
- A suitable parameter set fits
  - "Macro" measurements (Force/Displacement)
  - "Micro" measurements (Crack length)



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# Example of simulation results





- Simulation predicts a strong effect of dimples
- Weakest configuration expected to be t<sub>Cu</sub> = t<sub>Cera</sub>
- → Results compatible with existing data, especially for  $t_{Cu} >> t_{Cera}$

# Simulation of the behaviour of a DBC structure

### We identified models for

- Copper: behaviour very specific because of bonding process
- Ceramic: must take into account material grades
- Interface: innovative approach with identifications at macro and micro scales

### Theses models have been used for

- Evaluation of impact of stress-relaxation effects
- Identification of robust Cu/Al<sub>2</sub>O<sub>3</sub>/Cu configurations
- Evaluation of robustness to thermal cycling
- These simulations must be validated against measurements



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# Thank you for your attention.





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