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PhD proposal M/F

Exploring self-healing solutions for Al source layers in Power Devices
Ref JCB_PhD_201902

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Type of contrat: 3 years contract, from October 2020

Reference: JCB_PhD_201902

Research topic: Reliability of power devices

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Context:

Power electronics applications have expanded in many fields such as domotics or energy conversion, but their reliability is mostly critical in the transportation field and off-shore applications. Power devices, as MOSFETs and IGBTs, are controlling many applications driving the electrical motors (in manufacturing process, electrical vehicles including trains and electrical cars) and converting the electrical energy in the case of the wind generation and HVDC transmission. Anticipating or even preventing their failure is a key technical issue.

In recent years, several weak spots have been identified in the structure of modern Si-based power MOSFETs and IGBTs, and some solutions have been found to increase their resistance to disruption (solder, packaging…). However, the aging of the top metal source, mainly made of Al or Al alloy has persisted as an intrinsic phenomenon, which degrades the electrical performance of the device over time. The deterioration of the Al layer occurs through mechanisms that involve grain boundary diffusion, crack formation and surface oxidation, also driven by stresses arising from thermal mismatch between the metal and the silicon, as described in Fig. 1.

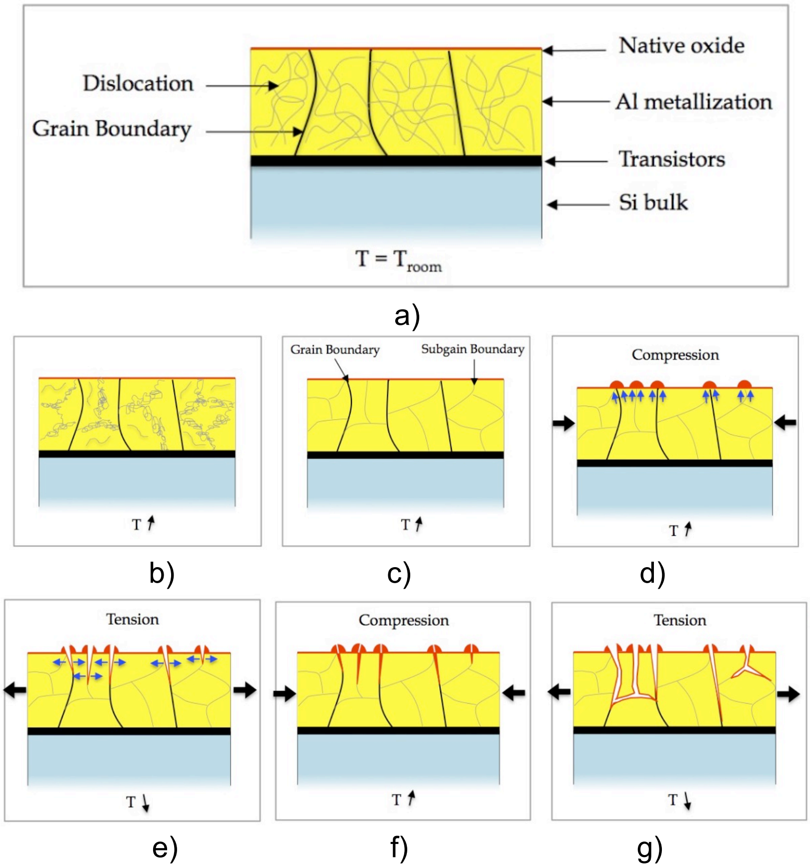

Figure 1. *Gao's model extended to Al layers undergoing tension and compression stresses during thermal cycles [2]. (a-c) The dislocation density decreases by recombination in sub grain boundaries and absorption at GB interfaces. (d-g) Al diffusion along grain boundaries, and subsequent oxidation causing crack propagation through the Al layer. ref. [1]*

Similar oxidizing cracks develop between the metallization and the wire bondings, leading to local failure of the device [2].

The goal of this thesis is to find processes favoring the self-healing of these cracks. Self-healing materials such as polymers, fiber-reinforced composites, asphalt and cement are already used in coating or structural applications. However, functional materials (electrical or thermal conductors) with self-healing properties are not identified yet.

Objectives:

The study will focus on the aluminum layer of the power device that interfaces the silicon die and the electrical circuit. The objective of this thesis is to find technical ways to slow down the mechanisms that causes the deterioration of the Al layer, either by increasing the metallic contact between the wire bondings and the metal in the initial state and/or to restore this electrical contact during operation. Possible ways (electrical, thermal, multi-material) to close the GB cracks in the Al metallization during the device operation will also be explored. Thermal excursions applied locally may help such restoration that will be monitored using the metal characterization tools of the CEMES (TEM, FIB,…). Circuitry modification or changes in fresh devices processing (focusing on wire bonding) will be carried out at Mistubishi Electrics, Rennes.

In a first step, the bonding conditions of Al wires will be modified, with temperature injection during or after bonding and under reducing atmosphere. The hopefully increased electrical and structural continuity at the bonding interface will be characterized at MERCE and CEMES.

In a second step, possible additional metallic layers, susceptible to fill opening cracks in the Al top layer will be deposited before thermal / electrical cycling. Again, electrical and structural characterization of the aged component will be performed at MERCE and CEMES.

Références bibliographiques:

1. D. Martineau, C. Levade, M. Legros, P. Dupuy, and T. Mazeaud. “Universal mechanisms of Al metallization ageing in power MOSFET devices.” In: Microelectronics Reliability 54.11 (2014), pp. 2432–2439.

2. R. Ruffilli *et al.*, Mechanisms of power module source metal degradation during electro-thermal aging. *Microelectronics Reliability* (2017),

Thesis conditions and development:

Thesis starts:

From June 2019 – monthly reports (1 page) and quarterly meetings (alternately in Toulouse and Rennes) not included below.

Presence:

Mainly at the CEMES in Toulouse (85% time).
Regular visits are planned to MERCE, Rennes.

Planning

The work program is divided as follows:
T1: Increase the metallic contact:

1. Definition of the test vehicle (IGBT)
2. Training on CEMES tools (sample prep,FIB, EBSD, EDX, TEM)
3. Test of solutions to increase the metallic contact: e.g. hot bonding, chemical attack before bonding, reducing atmosphere
4. Change the wire-bonding process in fresh devices
5. Thermal/electrical cycling and verification (electrical/structural)

T2: Restore the electrical connection:

1. Definition of the healing layer, deposition on naked dies
2. Potential MERCE circuitry modification to apply during operation (self-healing gate driver).
3. Thermo excursions definitions by CEMES.
4. Thermo excursion application and local thermal heat application through modified circuitry
5. Analysis with CEMES tools (included heat generation and characterization).

R: Thesis writing

	Y1				Y2				Y3			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
T1	1, 2	2,3	5	4,5	4,5	5						
T2		1		1,2,3	1,2	3	4	4,5	4,5	5	5	
R												

Education and experience required:

- Engineer's degree or Master's degree with a focus in Materials Science
- Simulation and programming softwares (COMSOL Multiphysics, Python)
- Competence in materials characterization tools (TEM, FIB)

- Strong general scientific knowledge and multidisciplinary opening (materials science, electrical, mechanical, thermal, chemical, mathematical)
- Power electronics skills would be a plus
- Communication and writing skills in English
- Motivation and dynamism to work in a research environment
- Ability to work in a multicultural and international environment

Merci d'adresser CV et lettre de motivation en format pdf par mail (en précisant en objet : votre nom et la référence JCB_PhD_201902) au contact suivant:

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