Abstract

Reliability is the key to match automotive sector needs. Innovation is exploded providing new opportunities and introducing new challenges, but robustness is still the most important feature above the others.

For this reason, power devices need to match AEC-Q101 global standards, and in some cases go beyond.

In parallel, higher device reliability is becoming a common requirement in industrial and consumer applications. Humidity robustness reached strong attention since power modules, commonly adopted for these purposes, are required to be operating outdoor as indoor.

When humidity diffuses through the package, a variety of deteriorating mechanisms initiates and a progressive reduction of the electrical performance lead to a failure.

The ability to combine optimal design and most efficient materials results in extended lifetime and improved resistance of devices in harsh working conditions.

This study is developed with a test-and-model systematic approach to obtain a full explanation of phenomena behind the principal failure modes and achieve the best structure.

Commonly, power semiconductor devices can be described with two main sections: active area and termination. Current capability and dynamic performances are determined by active area. On the other hand, termination plays a dominant role in controlling the rated blocking voltage value, combining ad-hoc design structure and multi-layer passivation schemes.

Both the regions influence the electrical field distribution, but its shape is significantly modulated by termination layout and composition. Furthermore, recent approaches consider design and passivation materials as an integrated ensemble that should be optimized simultaneously.

A typical passivation scheme includes a semi-resistive and dielectric layer framework made of inorganic and organic materials.

In this thesis work a high-voltage temperature humidity bias (HV-THB) test is adopted to investigate interaction and synergy between the various above-mentioned materials.

This test consists in three different simultaneous stressors applied to the devices:

- High voltage, corresponding to 80% of the nominal voltage Vnom
- High operating temperature (85°C)
- High relative humidity environment (RH 85%).

Their concurrent action can trigger specific device failures. These failure modes are successively examined in order to understand the different degradation mechanisms involved.

The principal effects observed are:

- aluminum erosion
- dendrite formation on silicon resistive layer
- bubble formation in organic film passivation.

Several studies report HV-THB tests on high-power silicon devices. These investigations highlight direct connection between passivation layer degradation and high electric field presence in specific regions of the device. Moreover, the presence of humidity acts as catalyst for chemical–physical deterioration processes.

Principal degradation reactions affect:

- solder and contact metals
- amorphous silicon resistive layer
- dielectric layers such as silicon oxide and silicon nitride.

A model for each of them is proposed in this thesis and a complete description of the context is fulfilled.

Summarizing the results and conclusions of this study, the interactions between different materials constituting the termination structure of power diodes devices have been investigated, while a process optimization and layout improvement have been accomplished.

The combination of high voltage, temperature and relative humidity has appeared to be the most stressful one for the devices, and HV-THB's capability to trigger failure modes has been employed to analyze the principal degradation phenomena. Furthermore, a full description of the involved chemical physical mechanisms has been proposed.

Eventually, thanks to the integration of TCAD simulations, this research contributed to validate new device designs with optimized passivation structure and superior reliability performances.