Top and Tail Transformation

A Grand Challenge in Energy Networks

Data-Model Fusion for Health Monitoring of IGBT Power Modules

BACKGROUND

IGBT power modules have been reported as one of the most delicate components in reliability-critical power applications. Unpredictable failures of power modules reduce the availability of power converters which can result in large economic implications. Predictive maintenance is one way to improve power converters availability. However, that requires an efficient prognostics and health monitoring of power modules. Failures of power modules evolve as a result of their multi-layer structure due to the thermo-mechanical stressing which causes wire-bond lift-off and solder fatigue. Wire-bond lift-off increases the electrical resistance of the power module due to the loss of electrical contact. Solder fatigue increases the thermal resistance due to the degradation of the thermal conduction path. Sources of health information can be model-based estimates or failure precursors measurements.

AIMS AND OBJECTIVES

- In-service real-time monitoring of the health state of IGBT power modules
- Combine model estimates with online measurements of failure precursors for more accurate lifetime predictions
- Discriminate between simultaneous ongoing wire-bond lift-off and solder fatigue mechanisms
- Improve power converters availability by enabling predictive maintenance

RESEARCHERS

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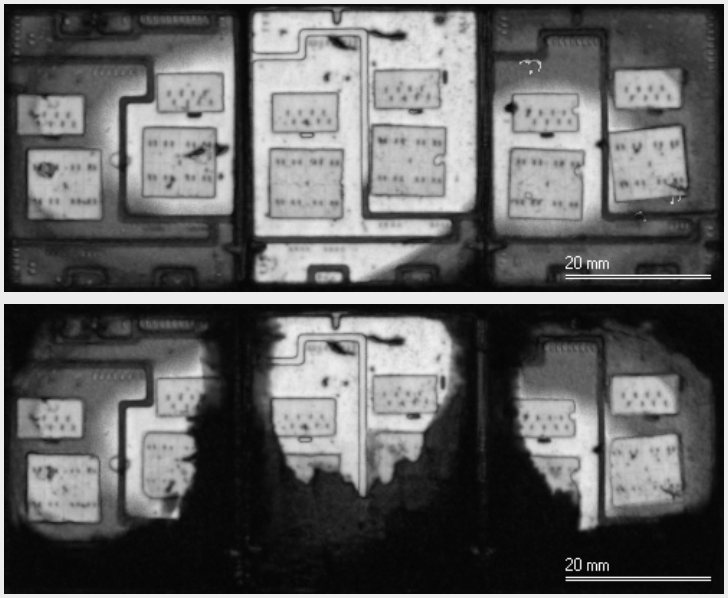
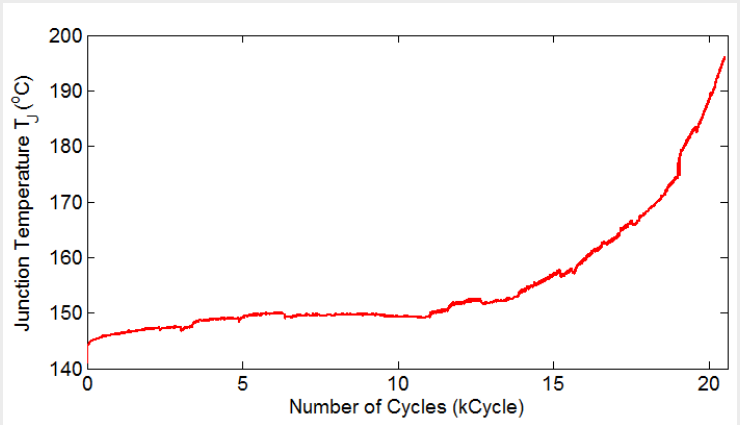
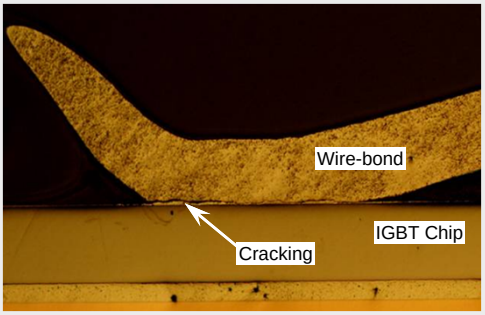


Scanning Acoustic Microscopy (SAM) of an IGBT power module. Top image shows the module in as received pristine conditions where the substrate copper and semiconductor devices can be seen. Bottom image shows the same module after 17500 cycles of power cycling test. The black shadow indicates a delamination in the substrate solder layer due to solder fatigue mechanism.



The junction temperature measured from an IGBT module during a power cycling test. Solder fatigue degrades the thermal conduction path within the module causing the thermal resistance of the IGBT power module to increase. This consequently results in an elevated junction temperature and semiconductor chip burn-out.



A metallurgical cross-sectioning of an IGBT power module shows the cracking at the wire-bond pad. This cracking causes a wire-bond lift-off which results in a loss of the electrical contact and an increment in the electrical resistance.

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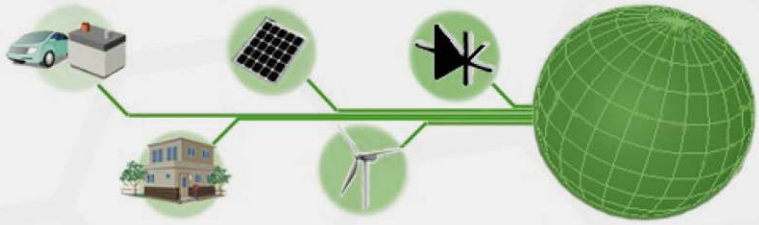

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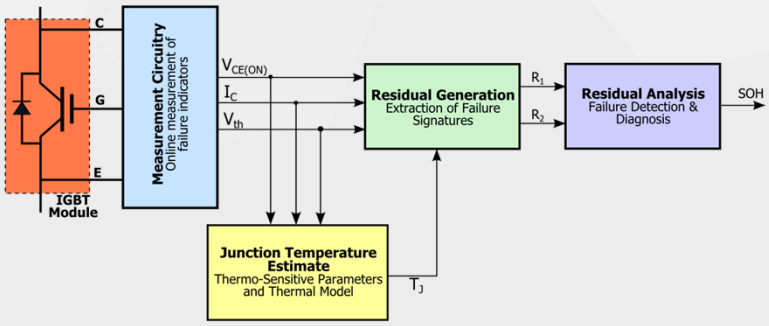
ACHIEVEMENTS

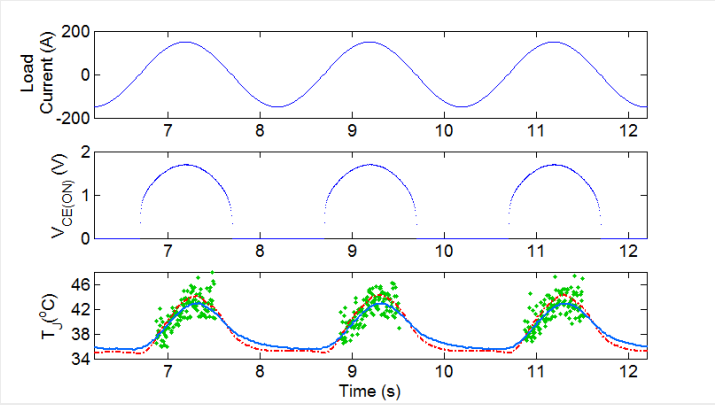
The behaviour of failure precursors with temperature, wear-out mechanisms and operating conditions is understood. Online measurement circuits are developed to obtain measurements of the on-state voltage $V_{CE(ON)}$ and gate threshold voltage $V_{GE(th)}$ during the normal operation of power converters. Real-time junction temperature estimation T_J for health monitoring is implemented utilizing the algorithm of Kalman filter which combines a thermal model with the measurement of $V_{GE(th)}$ which is a thermo-sensitive electrical parameter. The data of $V_{CE(ON)}$, $V_{GE(th)}$ and T_J are combined in a residual-based health monitoring framework. The discrimination between the wire-bond lift-off and solder fatigue failure mechanisms are achieved using two residuals. Each residual is sensitive to a single failure mechanisms.

IMPACTS

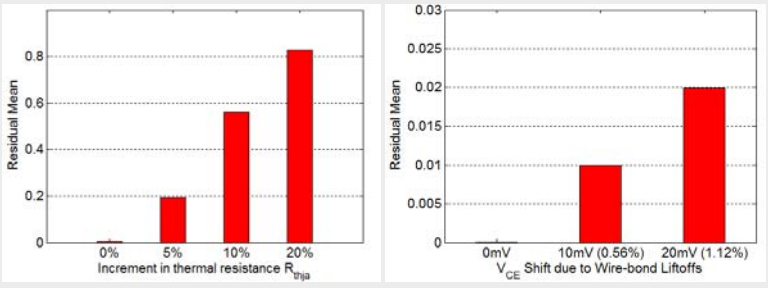
'Application of Kalman Filter to Estimate Junction Temperature in IGBT Power Modules', Eleffendi, A. Johnson, C. M., IEEE Transactions on Power Electronics, Vol. PP, pp. 1-1 (2015)



The proposed in-service health monitoring framework for IGBT power modules. Measurement data is combined with model-based estimates for improved accuracy and better detection and discrimination of ongoing failures.



Real-time measurements of load current, the on-state voltage $V_{CE(ON)}$ and junction temperature T_J. The proposed method to estimate junction temperature utilizing Kalman filter shows an improved accuracy over the estimate given by threshold voltage $V_{GE(th)}$ compared to the measurement of an infrared camera.



Two different residuals give health indications of the IGBT module. The residual on the left is sensitive to the change in thermal resistance due to solder fatigue. The residual on the right is sensitive to the change in V_{CE} due to wire-bond lift-offs.

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Transformation of the Top and Tail is a collaboration of 8 universities which began in 2011. The project focuses on the infrastructure change required in energy networks to move to a low carbon economy and achieve the Government's 2050 CO2 emissions target. The Top & Tail Transformation Program Grant, EP/1031707/1 was funded by RCUK's Energy Program.