Effect of Moisture on the Field-Grading of a Polymer Nano-composite Coating in Medium-Voltage Power Modules

One of the key challenges for packaging medium-voltage (MV) wide-bandgap (WBG) power devices is electrical insulation. This issue is especially prominent at triple points (TPs), where three different types of materials meet in the module. Nonlinear conductive field-grading materials are materials that have been shown to improve module insulation. Field-grading materials have been shown to be capable of improving the partial discharge inception voltage (PDIV) by nearly 100% via a polymer-nanoparticle composite (PNC). This electrical insulation improvement via the PNC material enables the use of thinner substrates to improve thermal performance.

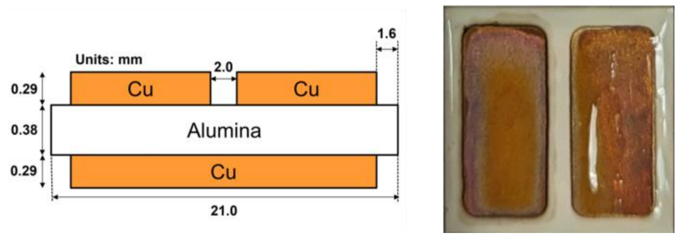

Fig.1. Schematic of alumina DBC test coupon and photo of a coated DBC substrate with silicone encapsulation

Power electronics converters are often used in applications under harsh, humid environments, such as in offshore wind turbines, electric vehicles, and railway systems. Silicone gels, which are used to encapsulate power modules, can absorb humidity, but reported decreases in their electrical resistivities and breakdown strengths after aging under humid conditions. In this work, we investigated the effectiveness and reliability of the PNC coating for enhancing the insulation capability of two types of encapsulant, a silicone gel and a silicone elastomer, under humid conditions.

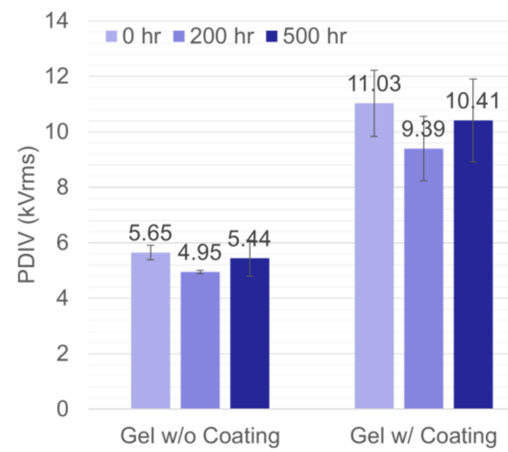

Fig. 2. Average PDIV for gel encapsulated gel DBC samples for 200/500 hr aging times.

The field-grading effectiveness and reliability of a polymer nanocomposite coating were studied under humid conditions for improving the electrical insulation of a silicone gel or a silicone elastomer encapsulated medium-voltage power modules. The results show that the PNC remains effective in improving the partial discharge inception voltage of medium-voltage power modules, even after prolonged exposure to a 70°C/70% RH environment. The mass change results confirm that moisture intrusion occurred within the silicone encapsulants, leading to small mass losses over time due to hydrothermal degradation. However, despite the moisture uptake, the PNC coating consistently enhanced the PDIV of silicone gel-encapsulated modules, with minimal reduction in performance after 500 hours of aging. For the silicone elastomer-encapsulated samples, the performance of the PNC degraded more over time, likely due to the formation of microcracks caused by the hydrothermal reaction and the elastomer's higher elastic modulus. Overall, the PNC showed its promise for improving electrical insulation of MV power modules under humid conditions. Further research is needed to explore the PNC's robustness in other extreme conditions such as in a low-pressure environment for aerospace applications.