Predicting LED System Failure through Real-time Changes

One question of recent interest has been how to predict catastrophic failure of LED lighting systems, especially for critical applications where failures could have safety consequences, such as in aviation or traffic control. Failure prediction involves real-time estimation of remaining useful life, which requires an in-depth understanding of failure mechanisms. This study sought to identify electrical and thermal parameters in a single-die InGaN LED package that could give real-time signals of impending failure while in use.

Electrical Experiments

Nearly all system electrical failures cause a change in the LED package's series resistance. While past studies have shown an increase in series resistance when LEDs age under current and temperature stresses, none have monitored it up to the point of catastrophic failure. Experiments were designed to study series resistance under different temperature and current stresses up to the point of catastrophic failure to develop a failure prediction model for electrical contact failure.

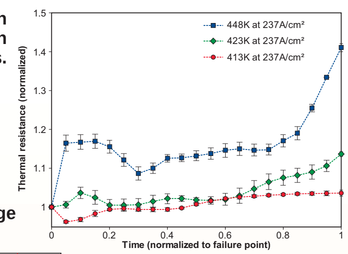
Two types of catastrophic failure took place: open circuit and short circuit. The results indicated that series electrical resistance goes through four phases of change, including periods of latency, rapid increase, saturation, and finally a sharp decline just before failure. Voids in the contact metallization were identified as the underlying mechanism for series resistance increase. Short circuit failures occurred due to electromigration-induced metal diffusion along dislocations in the semiconductor.

Thermal Experiments

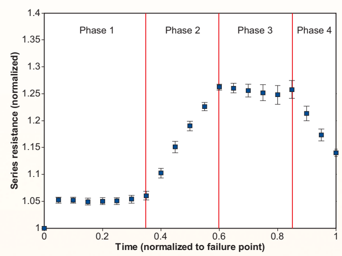
LED failure also can occur through a thermal path breakdown. The thermal resistance of an LED package increases with delamination and void formation in the die-attach layer, which is the primary thermal interface layer. Experiments were designed to study thermal resistance under different temperature and current stresses.

The results showed that thermal resistance increased with aging time, indicating a relationship between thermal resistance change rate and temperature. Dislocation creep was responsible for creep-induced plastic deformation in the die-attach solder. The temperatures inside the LED package reached the melting point of die-attach solder due to delamination just before catastrophic open-circuit failure.

Thermal resistance with time at different junction temperatures.



Series resistance change with time for an LED package at 423K and 296A/cm².



LED package failures can lead to safety problems.

Prediction Model

Under the conditions used in this study, the dominant failure mechanisms were die failure due to electromigration-induced metal diffusion, and die-attach interface failure. Given these results, a prediction model was developed to estimate the life of LED packages based on catastrophic failure of thermal and electrical contacts. This model can be used to make real-time estimations of LED package life based on catastrophic failure. Further research is needed to validate whether this model can be used at stress conditions lower than those used in this study.

Publication

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