Addressing Junction Temperature Instabilities in Optoelectronic Semiconductors: A Novel Adaptive Die-Bonding Process to Optimize Thermal Diffusion

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Optoelectronic semiconductors are a critical part of modern technologies, yet 50% of failures are linked to thermal overload. Conventional semiconductor packaging processes employ a single epoxy formulation applied uniformly to all dies, failing to accommodate die-specific thermal heterogeneity during the die-bonding process. To address this gap, my research aims to develop a novel targeted thermal optimization framework that evaluates individual die thermal profiles to assign an optimal epoxy formulation. A virtual metrology (VM) ensemble regressor model was developed to analyze thermal resistance (TR) in individual dies, which demonstrated strong correlation with a physics-based model and a high predictive accuracy (R^2=0.998). The model was trained on data of bisphenol F epoxies with varying boron nitride filler concentrations, with a novel integration of freeze-cast curing into the packaging process, to characterize interfacial heat transfer efficiency behaviors of the epoxies. Experimentally, freeze-cast samples demonstrated lower heat retention (up to 75% AUC reduction, $p < 0.001$), indicating a reduction in localized heat accumulation to improve interfacial heat transfer. The integrated model creates die thermal profiles to assign the best-fit epoxy based on its thermal behavior to enable adaptive epoxy application, resulting in a 12% statistically significant reduction in TR and a 48% recovery rate for previous thermally defective dies. My innovation constitutes a novel targeted die-bonding thermal optimization system for optoelectronic semiconductors. Ultimately, this scalable, reliable, and cost-efficient innovation aims to enhance manufacturing yield while reducing energy loss during optoelectronic semiconductor production.

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