Thermal and Thermo-Mechanical Analyses of Wire Bond vs. Three-dimensionally Packaged Power Electronics Modules

Sihua Wen

Thesis submitted to the faculty of
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

Master of Science
in
Materials Science & Engineering

Guo-Quan Lu, Chair
William T. Reynolds
Douglas J. Nelson
Burhan Ozmat

December 16, 1999
Blacksburg, Virginia

Keywords: 3D packaging, thermal, thermo-mechanical, finite element modeling, power electronics

To mom, dad and brother

Acknowledgements

I wish to express my deep sense of gratitude and thanks to my advisor Dr. Guo-Quan Lu, for his encouragement, support and guidance in the development of this thesis. I thank Dr. Douglas J. Nelson, Dr. William T. Reynolds, and Dr. Burhan Ozmat for their invaluable suggestions.

My thanks are due to my parents and brother, for their fond love and care through all the years I pursued a dream in the land across the sea.

I thank Shu Guo and Shuangyan Xu for their generous help with the analytical software when I most needed it. My thanks go to my colleagues in the power packaging group: Jess Calata, Shatil Haque, Bob Fielder, Xingsheng Liu, Jinggang Wang, Dr. Zhenxian Liang and our senior packaging engineer Dan Huff, for their understanding, companionship and encouragement.

Finally, I would like to thank my girlfriend Rui Hong, for her support and help on the completion of my master's degree.

Thermal and Thermo-Mechanical Analyses of Wire Bond vs. Three-dimensionally Packaged Power Electronics Modules

Sihua Wen

Abstract

The goal of more efficiently and more reliably realizing energy conversion in the power electronics industry is pushing the limits of current wire bonding packaging technology. Emerging three-dimensional power packaging techniques have shown their potential to replace wire bonding technology down the road. However, these innovative technologies have not yet been fully understood in terms of thermal and thermo-mechanical performance. Therefore, a comparative evaluation between the thermally induced response in conventional wire bonding (a 2-Dimensional technology) and 3-Dimensional packaging technologies is essential.

Thermal and thermo-mechanical analysis using the Finite Element Method (FEM) has been performed to evaluate a three-dimensional power module packaged in a Metal Post Interconnected-Parallel Plate Structure (the MPIPPS), and the result is compared with that of a wire bond module.

Under the same single-sided cooling conditions, thermal modeling results show a significantly lower junction temperature of 17^{o}C in the MPIPPS module than that in the wire bond module, due to the more uniform heat flow distribution in the MPIPPS module. The top DBC (direct bonded copper) substrate in the MPIPPS module helps direct the excessive heat generated from IGBT (Insulated Gate Bipolar Transistor) chips to diode chips (which dissipates less heat). The maximum junction temperature is reduced to 108 ^{o}C in the MPIPPS module by the implementation of double-sided cooling, which the wire bonding technique can not achieve. Subsequent thermo-mechanical analysis reveals the weak points in both modules during temperature cycling and power cycling. In the wire bond module, temperature cycle results have shown more severe stress and strain than that those of the power cycling conditions in the regions where the wires attach the device emitter pads. In the MPIPPS module, the solder joints exhibit high plastic and creep deformation. Power cycling produces more inelastic deformation at the solder joints between the posts and device, due to local over-heating, which causes more severe high-temperature creep deformation. Using a deformation-based thermal fatigue theory, the solder joint fatigue lives are predicted. Compared with the commercial wire bond module temperature cycle test, the fatigue life of MPIPPS is limited.

We conclude that the MPIPPS module is better in thermal managementb but is thermo-mechanically less reliable than the wire bond module.

Table of Contents

Table of Figures

List of Tables