QPTECHNOLOGIES
A DIVISION OF PROMEX INDUSTRIES

TECHNOLOGY BACKGROUNDER

Optimizing New Power Switch Technology Using Compound Semiconductors

Packaging development process yields first working double-sided parts

Abstract

Package technology plays an important role in reducing power loss and improving system efficiency in clean energy applications. Package inductance and electrical resistance directly contribute to the switching loss and conduction loss of power switches. Lowering package thermal resistance will improve energy conversion system efficiency. QP Technologies and Ideal Power have successfully developed a double-sided cooling bidirectional package. This paper studies the packaging challenges and the maturity cycle incurred for the B-TRAN™ double-sided power switch developed by Ideal Power, Inc., and provides the results achieved through the joint effort between Ideal Power and QP Technologies.

Introduction

Power switches are critical components in power conversion for a wide variety of applications, including DC-AC inverters for electric vehicles (EVs), solid state breakers, power converters for renewable energy such as solar and wind, and energy storage systems and power protection devices such uninterruptible power supplies (UPS) and static switches for data centers. Improving the efficiency and performance of semiconductor power switch components can have wide benefits, improving the efficiency and accelerating deployment of these applications.

Packaging technology plays an important role in reducing power loss and improving system efficiency, thereby improving end-user economics in clean energy applications. Package inductance and electrical resistance directly contribute to the switching loss and conduction loss of power switches. Lowering the thermal resistance of the package will improve energy conversion system efficiency.

Compared to conventional power switches, such as insulated-gate bipolar transistors (IGBTs), the B-TRAN™ bidirectional power switch from Ideal Power offers significant improvements in efficiency, reducing power losses by more than 50%.

Ideal Power teamed with QP Technologies to develop B-TRAN switches in various transistor outline (TO) packages. A leading provider of microelectronic packaging and assembly services, QP Technologies' expertise is well-matched to that of Ideal Power. Together, the companies successfully developed a bidirectional double side cooling package with ultra-low power losses. The development work started with TO-247 packages, advanced to a TO-264 package and finally, transitioned to a custom direct-bonded copper (DBC) solution.

This white paper investigates the challenges, solutions and finally the fabrication of **the first fully functional double-sided B-TRAN device.** To achieve a high-reliability design, the parties focused on developing die and packaging designs based on flip-chip technology in lieu of wirebonding to maximize the life cycle of the product.

B-TRAN Architecture

Ideal Power began focusing on commercializing its patented bi-directional, bipolar junction transistor (B-TRAN) solid state switch technology in 2019. The B-TRAN architecture was developed to extend the performance level of silicon-based power semiconductor switches. B-TRAN's unique performance characteristics compared to conventional silicon devices such as insulated gate bipolar transistors are: 1) high efficiency – offering a 50-90% reduction in switching and conduction losses; 2) bi-directional – enabling the control of power in both directions; and 3) switching speed – potentially up to 2.4 times as fast.

With its higher efficiency, B-TRAN results in less heat being generated and thus has significantly lower thermal management requirements. In addition, a single B-TRAN replaces multiple conventional power switches for bidirectional applications.

Its performance improvement is potentially an enabling technology with wide applicability in such fast-growing applications such as electric and hybrid vehicle electronic controls, industrial motor drives, electric distribution and transmission system switches and controls, renewable energy and energy storage system power converters and solid-state circuit breakers.

To enable commercialization, Ideal Power sought a packaging partner to help devise a manufacturable solution to accommodate the B-TRAN technology's double-sided device design, enabling ease of connectivity and heat dissipation in a range of high-reliability, high-temp environments.

Ideal Power contacted QP Technologies to seek its packaging and assembly expertise in early 2020. The primary driver for the engagement was Ideal Power. In collaboration with Diversified Technologies Inc., Ideal Power secured a contract for the design and demonstration of a 12kV medium voltage low-loss solid state circuit breaker for the U.S. Navy utilizing B-TRAN™. To meet this demand, the company sought a partner that could collaborate with them to co-develop packaging from concept to manufacture.

Phase I: Initial Engagement (Pathfinder)

Working closely with the customer, QP Technologies developed a concept for the package solution. Various requirements were defined including mechanical, electrical, thermal, test, bill of materials (BOM) and cost models.

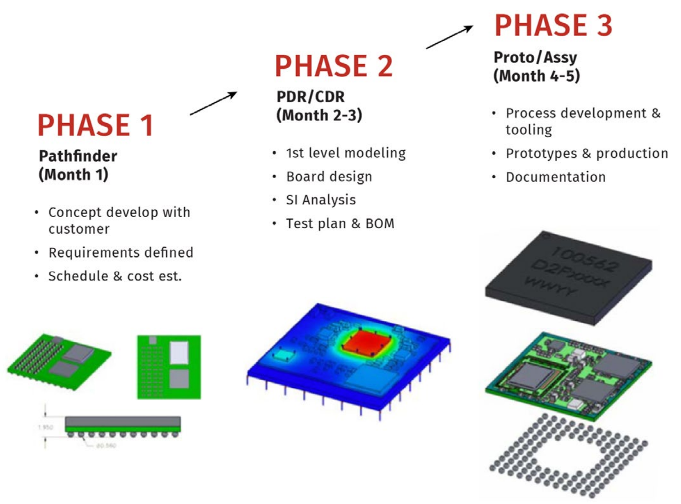

Figure 1

With a typical power transistor, the approach would be to stack the device on two sides (top and bottom) of a substrate (e.g., DBC) and enable heat dissipation from both sides. B-TRAN's two-sided structure required a different methodology. Unlike most power packages, B-TRAN is made of four separate layers mated together with the double-sided die sandwiched in between. With this in mind, QP Technologies began exploring a series of R&D and design options to create the optimal packaging solution.

Phase II: Preliminary/Critical Design Reviews

The second phase of the joint development effort began with QP Technologies meeting with Ideal Power to understand the needs and challenges associated with the B-TRAN structure. A plan was then formulated to address the following areas:

- First-level modeling and simulation
- Leadframe design and release to fabrication
- Scheduling and cost estimates
- Test plan development
- Signal integrity (as required)

Next, QP Technologies engaged with a leadframe house to create potential leadframe options. An initial approach investigated was unsuccessful because, while the copper side of the B-TRAN device could be soldered to the leadframe, the other side wouldn't take the solder.

QP Technologies came up with a stacked-leadframe scenario to explore/investigate. Some options turned out not to be viable due to cost considerations. One of the major challenges to overcome was attaching the stacked leadframes. Creating a test vehicle for the chips was necessary at this point to ensure the package could be built that meets the performance, cost and reliability requirements for the product. To do this, a simple custom test fixture was fabricated using gold ribbons to make contact with the chip I/Os (Figure 2).

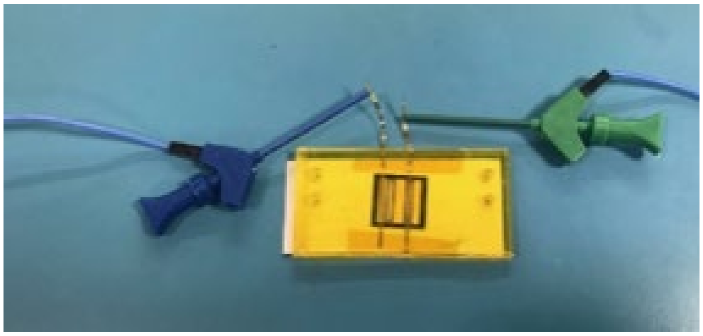

Figure 2

Phase III: Assembly Phase

Having been supplied with an initial quantity of double-sided B-TRAN™ parts, with top and bottom content, QP Tech began packaging products, working with Ideal Power's wafer fabrication partner.

- Develop the BOM (parts list)
- Leadframe fabrication
- Process development and tooling
- Documentation (process flowchart, part outline drawing, assembly drawing)

The result of these efforts was the development of the first fully functional double-sided B-TRAN. This was significant, as the test vehicle had only been able to accommodate single-side functionality.

At this point, a process flowchart was developed and optimized for future assemblies (Figure 3).

The project initially utilized several industry-standard TO packages – a wide range of small-pin-count packages often used for discrete parts such as transistors or diodes – before moving to DBC. The development work started with TO-247 packages, which offer a number of desirable features for power applications but have package inductances that can hinder fast device-switching.

This was followed by TO-264 packages, which are typically used for housing power transistors, thyristors, and ICs with low lead counts. The aesthetics are improved compared to TO-247, but the package has

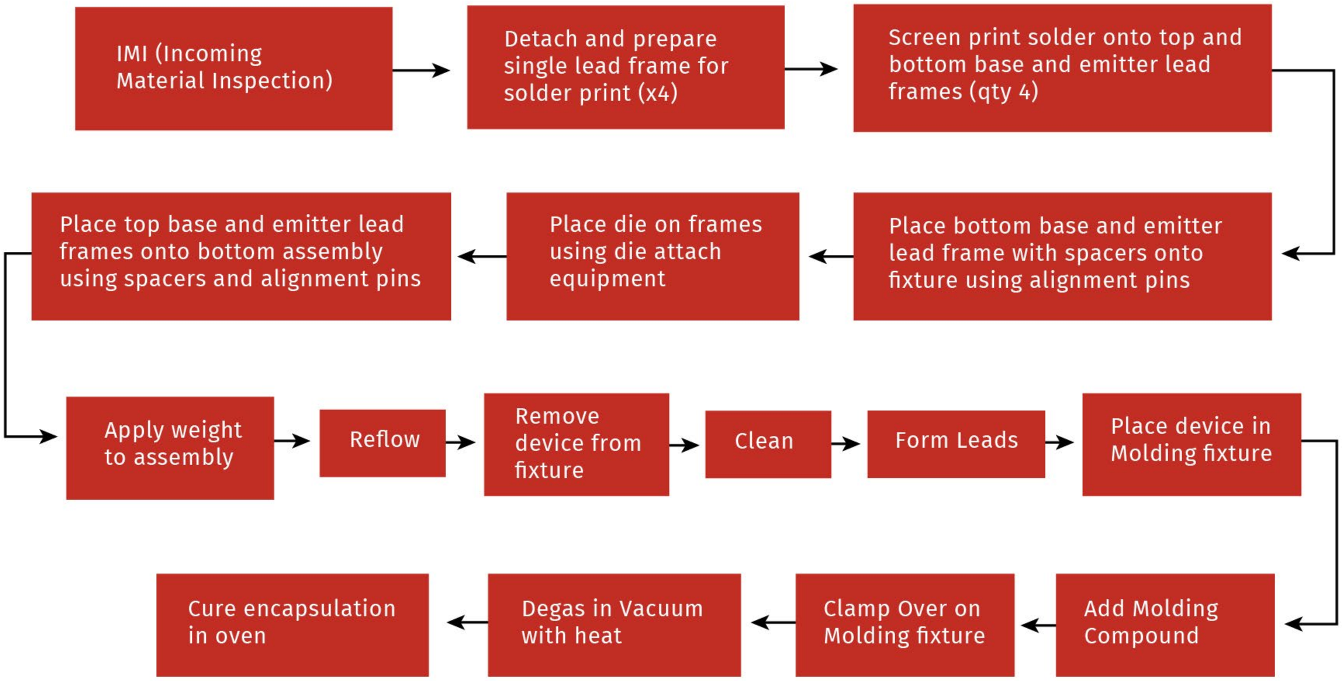

Figure 3

issues with respect to the heatsink as proper insulation can be difficult to achieve, especially for a more complex device such as B-TRAN™.

Upon receipt and testing of B-TRANs in a TO-264 configuration, Ideal Power developed a **technical datasheet**. Figure 4, from the datasheet, shows that an ultra-low Vce(on) was achieved: 0.61V at 30A with bidirectional blocking voltage >1300V.

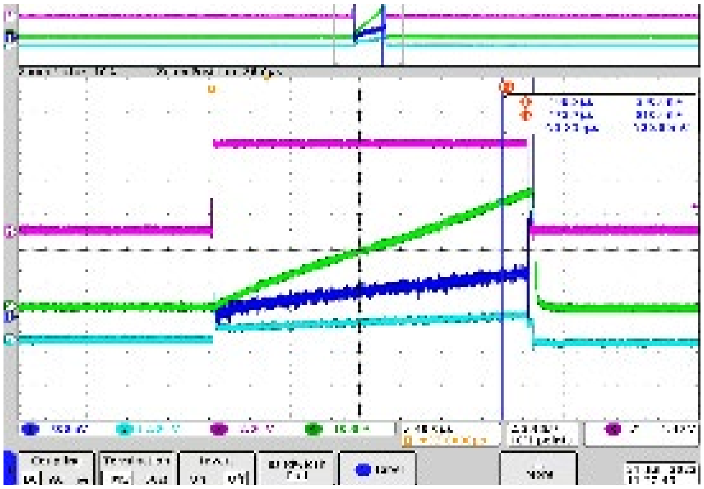

Figure 4

Figure 5, also from the datasheet, demonstrates good switching performance, 800V 15A without the use of a copack fast recovery diode or snubber damping circuit.

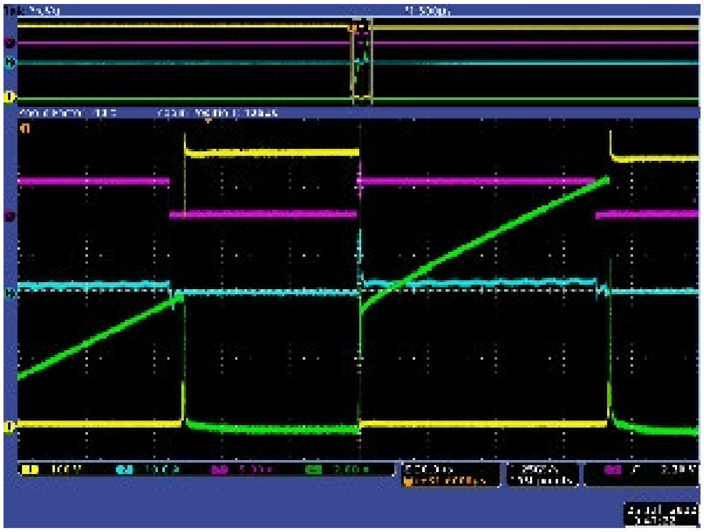

Figure 5

Phase III: Assembly Phase

Having been supplied with an initial quantity of double-sided B-TRAN™ parts, with top and bottom content, QP Tech began packaging products, working with Ideal Power's wafer fabrication partner.

The next step will be to explore over-molded DBC B-TRAN devices. Over-molding will provide myriad benefits, including enhanced adhesion between components, even more compact design, reductions in noise and vibration, waterproofing, insulation, and protection from UV and corrosive chemicals.

Further collaboration between Ideal Power and QP Technologies yielded a plan to move to a DBC lead-free approach. DBC denotes a process in which copper and a ceramic material are directly bonded. Normally, DBC has two layers of copper that are directly bonded onto a compound semiconductor – in this case, aluminum-nitride (AlN) – ceramic base. The DBC process yields a super-thin base and eliminates the need for the thick, heavy copper bases that were used prior to this process. Because power modules with DBC bases have fewer layers, they have much lower thermal resistance values and because the coefficient of thermal expansion (CTE) closely matches that of silicon, they have much better power cycling capabilities (up to 50,000 cycles). This approach is currently in development, with further details and updates to be provided by QP Technologies and Ideal Power when full-function parts are available.

The B-TRAN joint packaging and assembly development effort leverages the two companies' complementary expertise and core capabilities to yield a high-functioning, commercially viable approach to bringing B-TRAN to market in high volumes.

About QP Technologies

Escondido, Calif.-based QP Technologies (formerly Quik-Pak), a division of **Promex Industries**, provides wafer preparation, IC packaging and assembly, and substrate design and fabrication services in its 20,000-square-foot ISO 9001:2015/ISO-13485:2016-certified, ITAR-registered facility. The company's over-molded QFN/DFN packages and pre-molded air-cavity QFN packages offer a fast, convenient solution for customer needs ranging from prototype to small-volume production. Same-day assembly services reduce customers' time to market, while advanced assembly services can accommodate such structures as flip-chip, stacked die, SiP, chiplets, MCM and CoB. For more information, visit **www.qptechnologies.com**, or call 858-674-4676.

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