QP TECHNOLOGIES
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Optimizing New Power Switch Technology

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Overview

- Power switches are critical to power conversion in a wide variety of applications
- Package technology is key to reducing power loss and improving system efficiency in power switches
- Package inductance and electrical resistance directly contribute to power switches’ conduction and switching losses
- Lowering package thermal resistance improves energy conversion system efficiency
- QP Technologies and Ideal Power successfully developed a unique, double-sided cooling bidirectional package optimized for volume implementation
Introduction

BACKGROUND

- February 26, 2021: Receipt of RFQ to house a double-sided transistor in a TO-247 (transistor outline) configuration

**TO-247 BJT Terminals:** Lead 1, Base; Lead 2, Collector; Lead 3, Emitter

**TO-247 FET Terminals:** Lead 1, Gate; Lead 2, Drain; Lead 3, Source; Lead 4, Drain

**TO-247 SCR Terminals:** Lead 1, Cathode; Lead 2, Anode; Lead 3, Gate

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Different Switch Types

- Diode
- Bipolar transistors: Current driven
- FET: Field-effect transistors (FETs): Voltage driven
- IGBT (Insulated-gate bipolar transistor): Ruggedness of FETs plus switching speed of bipolar transistors
- B-TRAN™ (Bidirectional Bipolar Junction Transistor): The same 3-layer structure as the IGBT, with a control switch on each side

B-TRAN™ Operating Modes:
1) Turn on B-TRAN™:
   Off-Mode $\rightarrow$ On-Mode.
2) Turn off B-TRAN™:
   On-Mode $\rightarrow$ Pre-Turn Off $\rightarrow$ Off-Mode.
B-TRAN™ Benefits

◆ B-TRAN is a proprietary semiconductor power switch developed by Ideal Power, Inc.

◆ B-Tran architecture has three compelling advantages
  1. Bidirectional switching
  2. Lower losses = lower user cost
  3. Smaller form factor

◆ The first generation is being fabricated using mature silicon wafer processing equipment. Silicon carbide (SiC) is planned next!

◆ What’s new?
  ◆ The design (architecture) and fabrication of both sides of wafers
Device Description

- Device structure: NPN or PNP 4-terminal
- Bidirectional switch
- >1200 V breakdown
- Switching losses: Better than equivalent IGBT
- B-TRAN replaces four conventional devices to provide a bidirectional switch
- Effective forward drop <0.65 V

Conduction losses ~ 4x better than IGBT + blocking diode
A Systematic Approach

- Concept development with customer
- Requirements defined
- Schedule & cost estimation

**Phase I**
Pathfinder (Month 1)

**Phase II**
PDR / CDR (Month 2-3)
- 1st level modeling
- Board design
- SI Analysis
- Test plan & BOM

**Phase III**
Proto / Assy (Month 4-5)
- Process development & tooling
- Prototypes & production
- Documentation

CASE STUDY
Challenges

◆ Finding the B-TRAN chip metallization scheme that can withstand multiple SAC reflow (above 220°C for 90-120 seconds with peak of 260°C for a few seconds)

◆ Assurance that we are working with known good die (KGD), using rudimentary die-level testing

◆ Initial testing (pulse) in TO-247 package configuration appeared promising, but at full duty cycle thermals were poor

◆ Moved to a larger heat spreader and developed B-TRAN in TO-264 configuration

◆ Control of solder splash and reduction of voids is the key

◆ Moved to TO-264 with B-TRAN sandwiched between two direct-bond copper (DBC) on aluminum nitride (AlN) substrates; thermal ongoing
Maturity Cycle

Pros:
- Size: Standard
- Weight: Cost
- Cost

Cons:
- Poor thermal
- Better thermal: Cost
- Leads not on the same plane
- Making overmold is challenging
Milestones

January 2022
◆ Issue with the die recognized and remedied

June 2022 (TO-264 leadframe)
◆ TO-264 packages with both sides functional at BV > 1300V

December 2022
◆ DBC configuration matching TO-264 configuration

February 2023
◆ Started development of the first 120A power module
B-TRAN: Demonstrated Excellent Performance on Silicon

- Symmetrical, sharp Vbd >1300V
- Vceon @ 30A : 0.61V
  - Significant improvement over other HV switches
  - Single direction: IGBT Gen7 Vceon 1.7V @ 15A
  - Bidirectional IGBT: IGBT Vceon + Diode Vf: ~3V at 15A
- TH’s DBC TO-264 discrete package excellent
- Ready to sample, qual, volume production

Power Loss Comparison:
- Bi-IGBT Conduction Loss: 3V (Vceon+Vf) * 30A = 90W
- Uni-IGBT Conduction Loss: 1.8V * 30A = 56W
- BTRAN Power Loss: Conduction + Driving=25.2W
  - Conduction Loss: 0.6V * 30A = 18W
  - BTRAN Driving Power: 1.2V * 6A = 7.2W
  - IGBT Driver Loss: ~10W
Package Examples
Current B-TRAN Status

- In prototype fabrication
- Key features:
  - Double side cooling
  - Bidirectional
  - Current sharing considerations: strict symmetrical design, Cascade feedback, Rg
  - Low impedance: AC 35kHz: Resistance: 0.485mΩ; Inductance: 16.97nH
  - Kelvin source to reduce stray inductance
  - Compact: 6.6cm x 5.2cm x 0.6cm
Key Takeaways

◆ Collaboration between QP Technologies and Ideal Power yielded a viable solution to a unique packaging challenge

◆ Taking a systematic approach to package development enabled us to identify near-term and longer-term approaches for productizing B-TRAN technology

◆ Opportunities for this technology span multiple industrial and automotive power conversion market segments and applications

◆ We look forward to sharing additional phases, including the current effort to develop the first B-TRAN 120A power module