QP TECHNOLOGIES

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000943

Optimizing New Power Switch Technology

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Overview

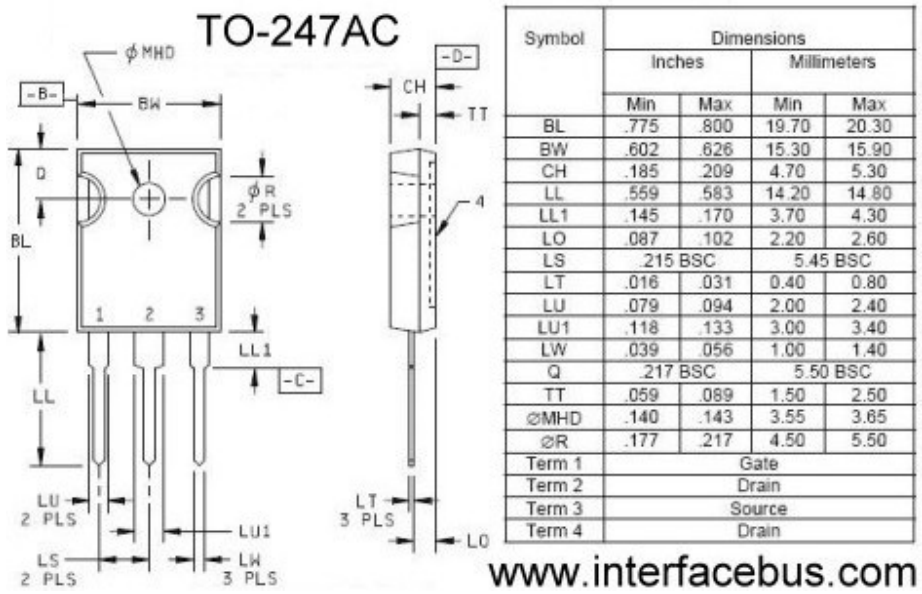
- Power switches are critical to power conversion in a wide variety of applications
- Package technology is key to reducing power loss and improving system efficiency in power switches
- Package inductance and electrical resistance directly contribute to power switches' conduction and switching losses
- 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

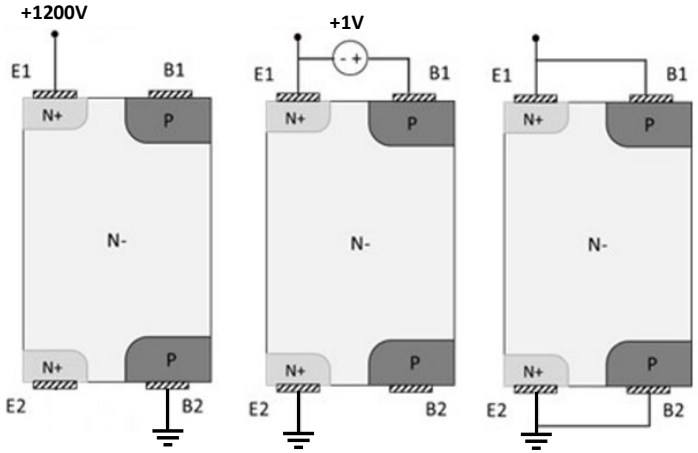
TO-247 BJT Terminals: Lead 1, Base. Lead 2, Collector. Lead 3, Emitter
TO-247 FET Terminals: Lead 1, Gate. Lead 2, Drain. Lead 3, Source. Lead 4, Drain
TO-247 SCR Terminals: Lead 1, Cathode. Lead 2, Anode. Lead 3, Gate



Symbol	Dimensions			
	Inches		Millimeters	
	Min	Max	Min	Max
BL	.775	.800	19.70	20.30
BW	.602	.626	15.30	15.90
CH	.185	.209	4.70	5.30
LL	.559	.583	14.20	14.80
LL1	.145	.170	3.70	4.30
LQ	.087	.102	2.20	2.60
LS	.215 BSC		5.45 BSC	
LT	.016	.031	0.40	0.80
LU	.079	.094	2.00	2.40
LU1	.118	.133	3.00	3.40
LW	.039	.056	1.00	1.40
Q	.217 BSC		5.50 BSC	
TT	.059	.089	1.50	2.50
∅MHD	.140	.143	3.55	3.65
∅R	.177	.217	4.50	5.50
Term 1	Gate			
Term 2	Drain			
Term 3	Source			
Term 4	Drain			

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

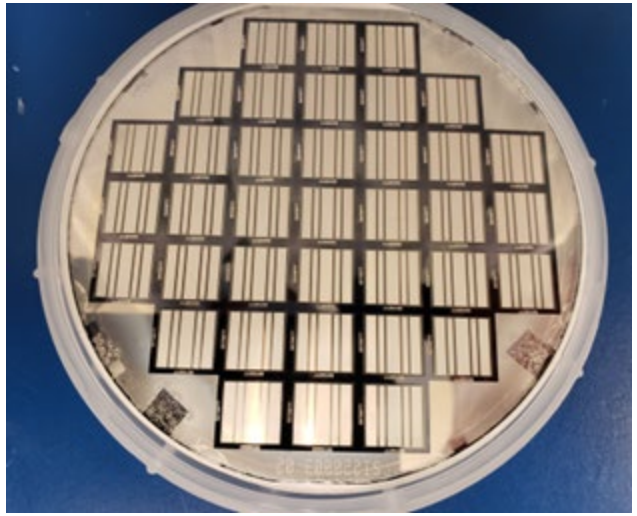


B-TRAN™ Operating Modes:

1) Turn on B-TRAN™:
   Off-Mode → On-Mode.
2) Turn off B-TRAN™:
   On-Mode → Pre-Turn Off → 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

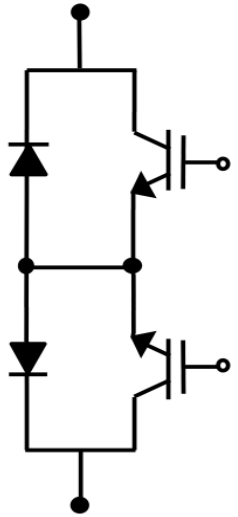


- The first generation is being fabricated using mature silicon wafer processing equipment. Silicon carbide (SiC) is planned next!
- What's new?
  - The design (architecture) and fabrication of both sides of wafers

Device Description

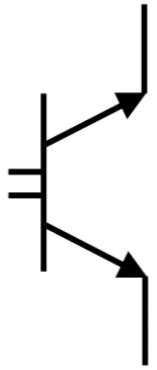
- Device structure: NPN or PNP 4-terminal
- Bidirectional switch
- >1200 V breakdown
- Switching losses: Better than equivalent IGBT
- B-TRAN replaces four conventional devices to provide a bidirectional switch
- Effective forward drop <0.65 V

Bidirectional IGBT 1200V



Vceon >2.5V @ 15A
1.50 V (IGBT) + 1.00 V (Diode)
Bidirectional with 4 chips

B-TRAN 1200V



Vceon 0.6V @ 30A
Bidirectional on 1 chip

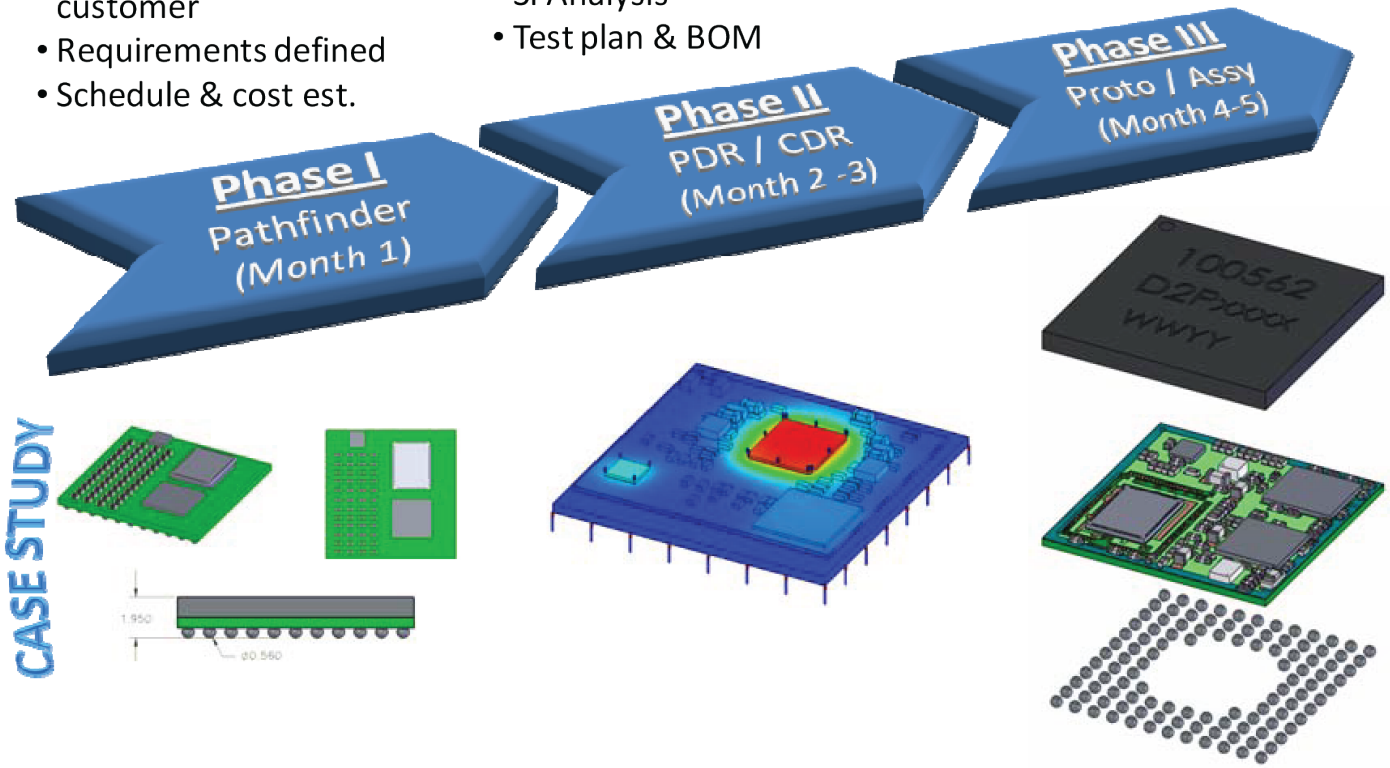
Conduction losses ~ 4x better than IGBT + blocking diode

A Systematic Approach

- Concept develop with customer
- Requirements defined
- Schedule & cost est.

- 1st level modeling
- Board design
- SI Analysis
- Test plan & BOM

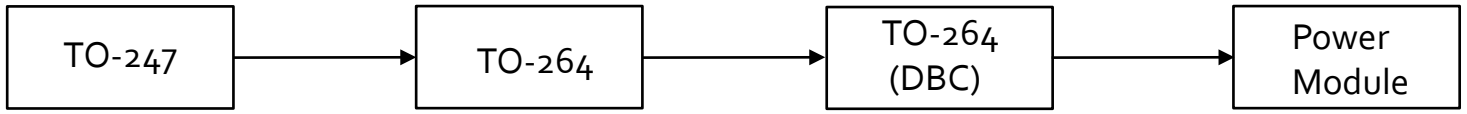
- Process development & tooling
- Prototypes & production
- Documentation

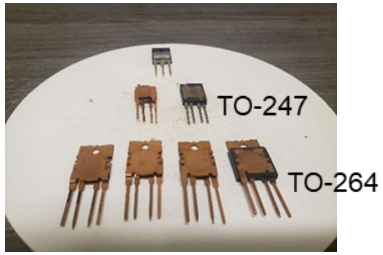


Challenges

- 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	Best thermal	TBD
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)

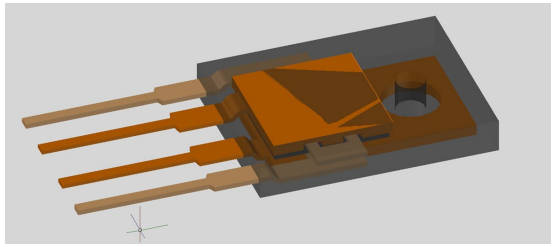
- TO-264 packages with both sides functional at BV>1300V

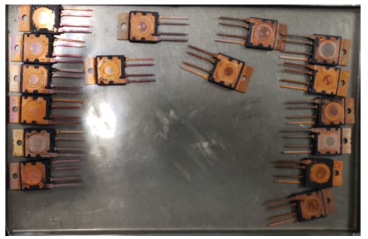
December 2022

- DBC configuration matching TO-264 configuration

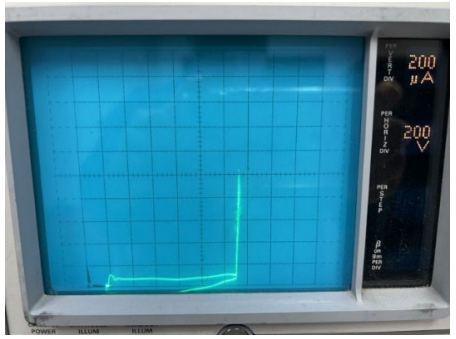
February 2023

- Started development of the first 120A power module

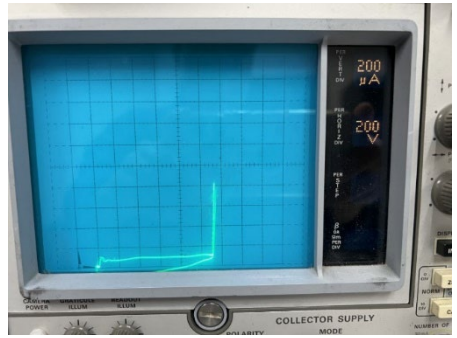




1st Prototypes



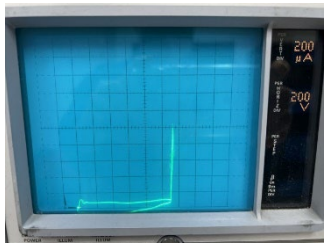
Symmetrical BV:
Front to Back



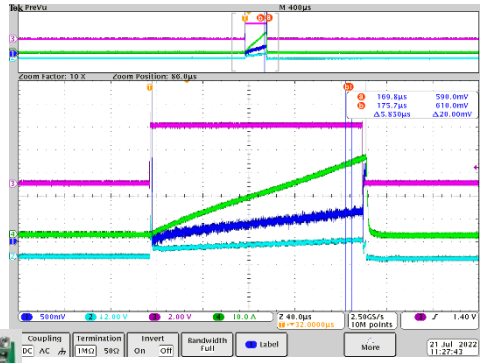
Symmetrical BV:
Back to Front

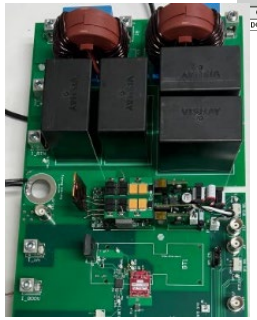
B-TRAN: Demonstrated Excellent Performance on Silicon

- 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



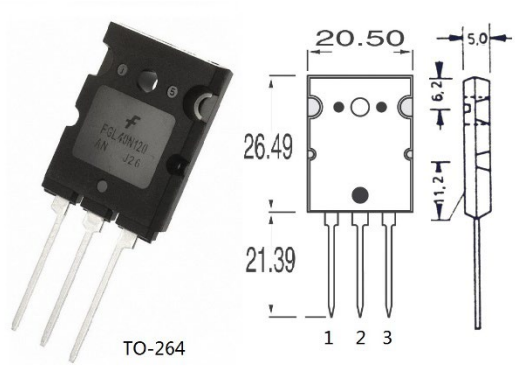
F-B HV	B-F HV
1360	1360
1300	1350
1320	1320

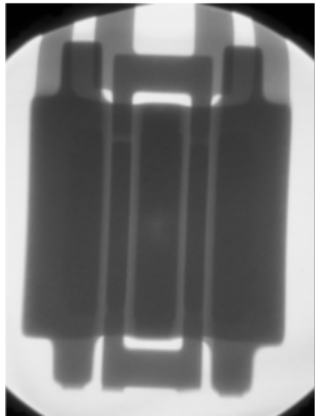


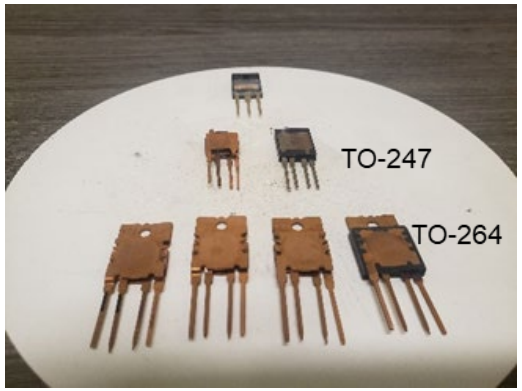


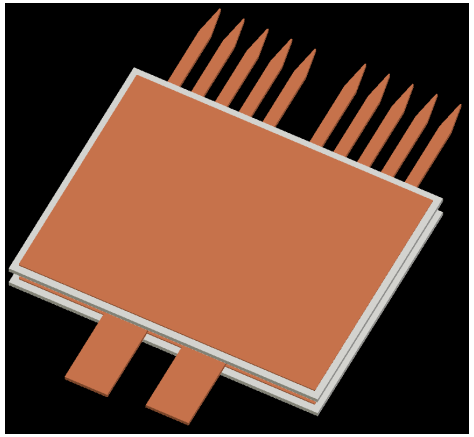
Power Loss Comparison:
Bi-IGBT Conduction Loss: 3V (Vceon+Vf) * 30A = 90W
Uni-IGBT Conduction Loss: 1.8V *30A = 56W
BTRAN Power Loss: Conduction + Driving=25.2W
Conduction Loss: 0.6V * 30A = 18W
BTRAN Driving Power: 1.2V * 6A = 7.2W
IGBT Driver Loss: ~10W

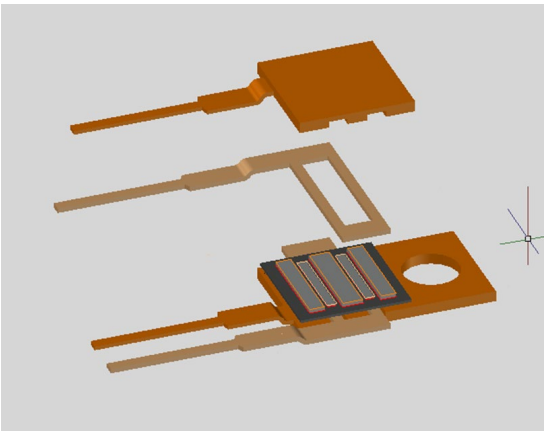
Package Examples





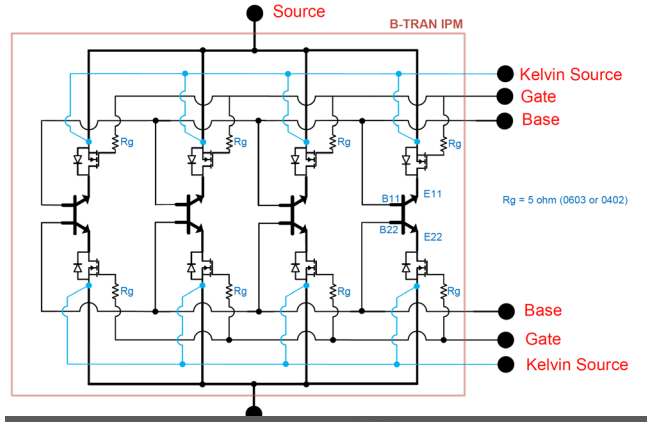


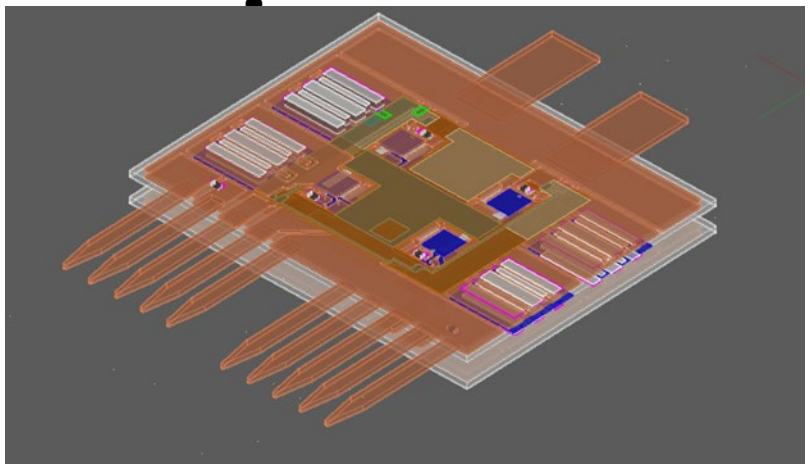




Current B-TRAN Status

- 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

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