IXYS UK Westcode Limited
Press-pack IGBT, towards the next generation of super switch
24th June 2014
PE Event Delft
First commercial products introduced by IXYS Uk (Westcode) in 1998
- 1.8kV High frequency aimed at induction heating
  - Single frame die carrier 47mm & 75mm electrode diameter rated up to 1200A

Following interest from Traction companies 2.5kV & 4.5kV devices launched in 2000
- Based on new single die sub-cell
  - Round package established as standard after square packages abandoned due to cost
- Combatable products available from Toshiba (round package) & Fuji (square package)

2nd & 3rd generation 4.5kV die introduced in 2004 & 2008 respectively

125mm electrode diameter package for 4.5kV introduced in 2006
- Developed with Industry partners for MV-Drives & traction

First 6.5kV device launched 2014
Press-pack IGBT - product status

- Press-pack IGBTs using the established mechanical designs are available up to 4.5KV
- Extension of voltage to 6.5kV in progress

<table>
<thead>
<tr>
<th>Electrode diameter (mm)</th>
<th>2.5kV IGBT/diode</th>
<th>4.5kV IGBT/diode</th>
<th>6.5kV IGBT/diode</th>
<th>2.5kV IGBT</th>
<th>4.5kV IGBT</th>
<th>6.5kV IGBT</th>
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<tbody>
<tr>
<td>47</td>
<td>360A</td>
<td>160A</td>
<td>500A</td>
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<tr>
<td>63</td>
<td>570A</td>
<td>340A</td>
<td>850A</td>
<td>510A</td>
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<td>66</td>
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<td>258A</td>
<td></td>
<td>385A</td>
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<tr>
<td>75</td>
<td>1200A</td>
<td>600A</td>
<td>1500A</td>
<td>800A</td>
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<tr>
<td>85</td>
<td></td>
<td>800A</td>
<td></td>
<td>1200A</td>
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<tr>
<td>90</td>
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<td>515A</td>
<td></td>
<td>775A</td>
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<tr>
<td>96</td>
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<td>2250A</td>
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<tr>
<td>110</td>
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<td>900A</td>
<td></td>
<td></td>
<td>1375A</td>
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<tr>
<td>125</td>
<td>1600A</td>
<td></td>
<td></td>
<td></td>
<td>2400A</td>
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<tr>
<td>132</td>
<td></td>
<td>1290A</td>
<td></td>
<td></td>
<td></td>
<td>1890A</td>
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</table>
Internal construction

- Mechanical design used in all 3rd generation products
- Fully bond free construction
- Common cell structure for each die rating
  - Allows versatility in ratings/package design
- Simple design with minimum component count
  - Limits number of interfaces
- Inter-location of carrier cells
  - Allows maximum die packing density
Internal construction of 125mm pole Press-pack IGBT
Mechanical construction - compared to module

- Common collector & emitter contacts
  - Identical R & L components to all die
  - Common thermal conditions
- Direct contact to die
  - Open circuit condition not possible
Parasitic Inductance

- Parasitic inductance in press-pack
  - Common value to all die
  - Parasitic inductance 40nH per die
  - In consequence each die will have identical over voltage due to di/dt

- Module Parasitic inductance
  - Higher due to emitter wires length of path to individual die
    - Typically 120nH per die
    - In consequence each die will have higher over voltage due to di/dt
  - Parasitic inductance is not common to all die
    - In consequence die will experience different over voltage due to di/dt

- The same principle applies to series resistance within the package and therefore distribution of current between die
Thermal resistance

- **Press-pack IGBT**
  - Die is cooled from both sides
  - As with L & R components, thermal resistance is common to all die
  - Die are ‘forced’ to common temperature
    - The large mass of the collector and emitter electrodes acts as a thermal capacitor
    - Reduces temperature effect variations from the cooling system

- **Module**
  - Thermal resistance to each die is unique
  - Influenced by the layout of the die
  - Lack of thermal mass allows lateral variations in temperature
  - Non uniformity in both base plate to sink thermal resistance and temperature of heat sink are translated directly to die
Press-pack IGBT Reliability

- Designed for high reliability
  - No solder or wire bonds
  - Enhanced shock & vibration resistance
  - Enhanced thermal cycling capability
    - Accelerated life test >10^5 cycles @ 135°C
  - Short circuit failure mode
    - 8000h short circuit stability test completed
    - Allows n+1 redundancy
    - Case rupture unlikely
  - Fully hermetic construction
    - Suitable for all cooling methods
      - Including oil immersion
  - Double side cooling
    - More uniform cooling of active area of die
    - Improved thermal impedance
  - Identical electrical/thermal path to each die
  - Minimal internal parasitic components
    - Insertion inductance 40nH per die

[Images: T2400TB45E under test, Drop test, Vibration]
Press-pack IGBT reliability – Thermal cycling

- For a press-pack IGBT $\Delta P_{\text{Cu}}$ is small compared to $\Delta r_1$ & $\Delta r_2$
  - For optimal thermal cycling performance $\Delta r_1 = \Delta r_2$
- For a Large single die device such as a GTO thyristor, all material expands relative to the centre
  - Movement at the edge of the silicon is at least five times greater than a similar rated PP-IGBT
Press-pack IGBT reliability – Thermal cycling

- Examples of completed thermal cycling tests
- Two criteria of test:
  - Test to ‘failure’ indicated by the red examples
  - Routine test followed by parts analysis, represented by the blue line
Press-pack IGBT reliability – Thermal cycling

- Thermal cycling of single die cells
  - 5.2kV die 1st Generation ABB die
- Standard power cycle test >80k, \( \Delta T_j \) of >80°C
  - Cycle 50Hz half-sine 330A (per 4 die)
  - Cycle time 60 Sec on, 30 sec off

![Thermal cycling diagram](image)
Press-pack IGBT reliability – Thermal cycling

- Post thermal cycling emitter side contact

Die emitter

Mo (die side)

Mo (Ag side)

Ag (Mo side)

Ag (Cu side)

Cu pillar
Press-pack IGBT reliability – Thermal cycling

- Thermal cycling of 3rd generation 4.5kV & 1st generation 6.5kV die
  - Device T2400GA45E, all IGBT x44 die
    - 30k cycles plus
    - 60 Sec on 60 Sec off, 1760A, ΔT 90°C
  - T0258HF65G, 6x IGBT & x3 Diode die
    - 30k Cycles plus,
    - 60 Sec on 60 Sec off, 468A, ΔT 95°C
Press-pack IGBT reliability – Thermal cycling

- Post thermal cycling internal views
Press-pack IGBT reliability – Thermal cycling

- Post thermal cycling internal views of example cell interfaces (ex. 4.5kV 2400A device)
Press-pack IGBT reliability – Thermal cycling

- Post thermal cycling die close up shows minimal evidence of aluminium abrasion
  - ex. 4.5kV 2400A device
Press-pack IGBT reliability – Short circuit & rupture

- Single diode failure (6.5kV 1390A PP IGBT)
  - Consequential discharge of 1400µF capacitor charged to 3880V
    - Discharge energy 10.54kJ
  - Failure is to a stable short circuit with no package rupture
    - Failed die forms an amalgam with moly
      - Which has been prised open for the photographs
    - Typically the device remains with volt drop similar to Vce(sat)
Press-pack IGBT reliability – Short circuit & rupture

• 1200A, 3.3kV module
  ➢ Consequential discharge of 1500µF capacitor charged to 1250V
    • Discharge energy 1.17kJ
    • Less than 10% of the energy of the PP device
  ➢ Failure sequence for module
    • Device failure initially to short circuit
    • Fusing of connections results in open circuit
    • Dielectric discharge through gel
    • High pressure gas release results in rupture
    • After brief secondary s/c final state is indeterminate
Press-pack IGBT reliability – Short circuit & rupture

- If you put in enough energy the package will rupture
  - Conditions and consequence is similar to a conventional thyristor
  - Plasma ejection is a possibility
  - Illustrated examples:
    - 1390A, 6.5kV Press-pack IGBT
    - 2360A, 6.5kV Medium voltage thyristor
  - Though ruptured, both devices remain as a stable short circuit
Press-pack IGBT reliability – Short circuit test

- Two IGBT die pre-failed by capacitive discharge
- Subject to repetitive pulses of >10kA
  - First & last pulse to right
- Device remains Short circuit under test

Example 1

Example 2
Example application: Medium voltage drive

- Medium voltage drives for steel mills, pumps etc.
  - Several applications 900A to 2400A 4.5kV devices
  - Example CKD Elektrotechnika
    - 7 level converter
    - 8.5kV, 700A, 800Hz using T2400GB45E
Press-pack IGBT - Marine drives

- Medium voltage drive for marine application
  - 3-level inverters single phase assemblies
  - 3.3kV (1.6kA)
    - Include snubbers and gate trigger circuits

3.3kV stack XA1600GV45WT

<table>
<thead>
<tr>
<th>Power Rating (MW)</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Line Current (Amps)</td>
<td>1600</td>
</tr>
<tr>
<td>No. of IGBT's</td>
<td>4</td>
</tr>
<tr>
<td>No. of Diodes</td>
<td>6</td>
</tr>
<tr>
<td>No. of Coolers</td>
<td>13</td>
</tr>
<tr>
<td>Required IGBT Type</td>
<td>T2400GB45E</td>
</tr>
<tr>
<td>Required Diode Type</td>
<td>E2400TC45C</td>
</tr>
</tbody>
</table>
Application: Wind generation

- Three level phase leg assembly
  - 6MW converter for connection to power grid
  - T1800GB45A & E2400TC45C
Application: Frequency converter

- 5MW Ship to shore frequency converter
- Phase leg assemblies
  - T0900EA45A
Example application: Electric vehicles

- Electric vehicles – several active projects & past projects
  - Electric drive mining trucks
    - Customer for now obsolete WTC140AAC18
    - Project revived with T1200TA25A & F1500NC250
  - Agricultural tractors & commercial vehicles
    - Devices in immersion oil cooled system
    - 1.7kV/2.5kV press-pack IGBTs, 47mm pole face housing – 600A rating
Example application: High speed train

- KTXII High speed train (South Korea) - main traction drive
  - New build design - 8MW four quadrant asynchronous traction drive
    - Switching frequency 540Hz, Fundamental frequency 0-60Hz
  - Device operating conditions
    - DC voltage 2.8kV, Peak current 1.8kA
      - T2400EA45E 125mm boss asymmetric blocking press-pack IGBT
      - E2400TC450 75mm boss HP Sonic FRD
Application: Traction refurbishment

- RSA rail Class 8E chopper refurbishment
  - 600A Chopper circuit, operating at 3kV DC
  - Replacement of reverse conducting thyristors
  - Oil immersed cooling system
- Polish 1.2MW Shunting locos
  - Re-engineering of fast thyristor chopper
- Street tram conversion
  - Inverter & chopper phase leg assemblies
  - Replacement of GTO thyristors with PP-IGBTs
  - 2.5kV asymmetric blocking PP IGBT
Example application: Pulsed-power

- Five terminal Pulsed power switch
  - 13 press-pack IGBTs in series
  - Ancillary circuits
    - Gate trigger circuits.
    - Snubbers & voltage sharing
Example application: Induction power supplies

- Induction Heating power supplies
  - Metal processing
    - 400kW, T0500NA25E
  - Induction melting
    - Various applications 300Hz to 1.5kHz
Press-pack IGBT: Introduction of 6.5kV

- **6.5kV products**
  - New larger die size
  - 30mm thick package for higher voltage rating
  - First introductions in 66mm & 110mm electrode diameter packages
    - 110mm device rated at 900A with integrated diode, 1375A all IGBT
  - Future product with 132mm electrode in development
    - All IGBT device with current rating of 1890A
  - Offers reduction in number of series devices for medium voltage applications
Press-pack IGBT: towards the next generation

- The current range of press-pack IGBT is a mature product.
- Higher power ratings for 6.5kV are possible with present design.
  - But limited to parts with similar dimensions.
- Extension of the power ratings is now limited by packaging technology.
  - SOAR does not scale beyond the current ratings.
    - For devices up to 85mm SOAR is twice nominal current rating.
    - For larger devices this reduces by 20% for a 125mm pole device.
  - Both thermal and electrical limits have been reached.
- How to improve the package design and extend ratings?
  - Two principle aspects are in consideration:
    - The cooling of the individual die.
    - The harmonisation of switching multiple die in parallel.
  - A next generation of packaging should realise devices to 150mm electrode diameter.
    - Potential current ratings of >4kA with >8kA SOAR (4.5kV die).
- Third generation package:
  - Ag bonded die.
  - Dual pin (emitter return).
Press-pack IGBT – Next generation packaging

- Third generation package – emitter return pin
  - Current design uses the emitter electrode as the gate return
  - Gates are connected via sprung pins to a symmetrical distribution board
  - The larger the device the greater the imbalance between the paths
    - Parasitic components in the gate are very uniform
    - Not so in the emitter
    - Only the gate is damped against inter chip oscillation by resistor embedded in the die
Press-pack IGBT – Next generation packaging

- Third generation package – emitter return pin
  - New design will incorporate a multilevel board
  - Close coupling of the gate and emitter paths to each die
    - Improved cancelling of parasitic components
  - Separate pin contact and path for each emitter
  - Addition of emitter resistors to dampen inter chip oscillation

- Better matching of the emitter gate path
  - Enhance parallel switching of die
Press-pack IGBT – Next generation packaging

- Third generation package – Ag sinter
  - Construction today is based on floating die
    - Fundamental of design was to eliminate unreliable solder joints
    - Limitation is the cooling of the junction termination
    - Dry face between collector side of die & backing moly
      - Same basic construction as alloy free thyristor
      - Proven technology, but increased thermal resistance between die & moly
    - Improved cooling can be achieved by bonding the die to moly
      - Solder or hot alloy not possible
      - New technology available in Ag sinter
        - Lower temperature does not damage die characteristics
        - Uniformity of bond to maintain consistent cell thickness

![Diagram of heat flow and bonding interfaces](image)
Press-pack IGBT Next generation packaging

- Third generation package
  - Based on 150mm electrode diameter package
Press-pack IGBT

- Thank you for your attention
- Questions?