Electromechanical characteristics of a bondless pressure contact IGBT.

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Abstract
The mechanical design of a completely bondless, pressure contact IGBT is discussed and its implications on the electrical characteristics are compared to those of a similarly rated module device. It is determined that the differences in the electrical characteristics of a pressure contact IGBT may offer certain advantages in some applications.

Introduction
It has been the conclusion of a number of independent studies [1-4 and others] that the long-term reliability of the module IGBT, in some applications, is still in question. Most of the identified failure mechanisms are associated with one of the many bonded joints, both wire and substrate, which occur in this type of construction. To overcome these potential failure modes a completely bond free pressure contact IGBT package has been developed, along with specially designed chips, which have been optimised for operation under pressure contact.

In addition to the potential for improved mechanical reliability in some applications, the package also offers some distinct differences in the electrical characteristics, which may also offer some additional advantages.

The paper considers the approach taken in the design of the pressure contact package and how this is reflected in the electromechanical properties of the device.

Mechanical design
The mechanical design of the pressure contact IGBT, had two principle objectives, firstly to allow for the pre-encapsulation testing of the constituent IGBT chips as a single unit and secondly to eliminate all bonded contacts.

To achieve optimum performance, in a bondless pressure contact encapsulation, a new IGBT chip was designed. Fig. 1a shows the typical design used in a wire bonded construction with the gate contact at the centre and eight emitter cell groups with centrally located bonding contacts to take the emitter bond wires. Fig. 1b shows the modified design with a corner gate contact, allowing maximum use of the remainder of the chip for a flat emitter pressure contact. The new chip design incorporates a metalisation process developed specifically for a pressure contact device, which ensures maximum thermal cycling capability.

The basic mechanical construction for a single IGBT chip is illustrated in fig. 2 and fig. 3, which respectively give exploded and compressed views of the constituent parts. The design allows for the pre-assembly of the chips in an integral carrier, which combines the required number of IGBT and diode chips into a single unit for pre-testing prior to encapsulation. This whole unit is then directly mounted into the pressure contact housing, for final assembly and test.
applied for. The basic concept of the wireless gate assembly is illustrated in Fig. 3 and Fig. 4. A spring loaded contact pin connects the gate of the chip to the planar distribution system, which in turn connects to the external gate terminal.

The planar gate distribution system ensures a very low inductance path to the gate contacts of each IGBT chip. The construction includes no discrete series gate resistors, these being integrated into the new chip design.

Fig. 4, Gate pin contact path.

To evaluate the electromechanical performance, a new device has been developed incorporating the design features described in the proceeding text. The experimental devices comprise five IGBT chips and two antiparallel diodes. The whole unit is assembled into a standard, 47mm boss diameter, outline pressure contact package as illustrated in Fig. 6. The evaluation device is nominally rated at 400 amperes.

The same concept can be applied to larger housings to obtain higher current ratings, 1400 amperes being achievable with a standard 75mm boss diameter package.

Electromechanical characteristics

The standard ceramic pressure contact housing offers compatibility with existing mechanical system designs and offers the possibility of introducing IGBT technology without the added cost of redesigning cooling systems. The ceramic package ensures the same level of hermetic integrity offered in other similarly encapsulated components in hostile environments.

It has been reported by others [9], that a pressure contact IGBT shows an improved thermal resistance performance when compared to the module. The design evaluation devices, described in this paper, have shown a similar improvement in thermal cycling performance, when compared to the published results of other technologies [10-11]. Experimental bondless pressure contact devices, of the type described in this paper, have endured greater than $10^5$ cycles, with a junction $\Delta T$ of $>85^\circ$C. Further work is being conducted which it is anticipated will show similar improvements in performance, over other technologies, at lower values of $\Delta T$. While not applicable in all cases, the increased thermal cycling performance is perceived to offer some advantages in some application areas. Fig. 7 shows the typical thermal cycling performance of a module compared to the recorded results for the experimental bondless pressure contact device at $\Delta T$ of $85^\circ$C, along with the predicted performance at low values of $\Delta T$.

Apart from the improvements in reliability, which come from the elimination of the bonded contacts, the mechanical design of the pressure contact device offers some interesting differences in electrical and thermal characteristics, when compared to a module.

Fig. 8 and fig. 9 offer a greatly simplified image of the typical IGBT module construction. Contact to the device is made through a network of busbars and contact wires, which introduce a complex arrangement of distributed series inductance with the chips. A simple equivalent circuit is represented by Fig. 10, where the $L_T$ is the terminal inductance, $L_E$ is the emitter bus bar inductance, $L_W$ the emitter bond wire inductance and $L_C$ is the collector bus bar inductance. The values of both $L_E$ and $L_W$ may be different, for each individual chip. In comparison, the pressure contact device, represented by the simplified image of Fig. 11, has a much simpler equivalent circuit. Fig. 12, $L_T$ is the emitter inductance and $L_C$, the collector inductance. It is possible to conclude from the equivalent circuits that, under high speed switching conditions the voltage distribution across the chips in a module could be uneven, where as in the pressure contact device all chips must have an equal potential.

With the aid of some simple calculations it is possible to determine the scale of the difference in voltages seen by the
chips in the two device constructions. It should be noted that the following assessment of the difference in voltage is included only to give an indication of what may be encountered, as the design of module devices varies quite considerably from manufacture to manufacture.

![Graph](image_url)

**Fig. 7.** Thermal cycling.

![Diagram](image_url)

**Fig. 8** Chip positions on module base plate.

![Diagram](image_url)

**Fig. 9.** Wire bonds and bus bars.

![Diagram](image_url)

**Fig. 10** Module equivalent circuit.

The five chip IGBT device described in this paper has been found to have a pole face to pole face inductance of < 8nH, which gives an inductance of 40nH per chip, if equal inductance is assumed. A similarly rated six chip module has a terminal to terminal inductance in the order of 20nH, which would give an individual chip inductance of 120nH if all paths were assumed to be equal. If these examples are taken, then for a typical fall time of 0.1µs, the device would see a rate of change of current (di/dt) of 4000A/µs at the rated switching current of 400A. This di/dt will give an effective single chip di/dt of 800A/µs in the capsule and 667A/µs in the module. It is simple to calculate from this that the module will see an over-voltage of 80V compared to only 32V in the capsule.

So far an equal distribution of inductance is assumed, however this is clearly not the case in modules examined by the authors. If a 30% difference highest to middle to lowest is assumed in the six chip module, with devices in pairs, then corresponding effective inductance is 89.5nH, 128nH and 166.5nH. This will give a corresponding chip over-voltage, under the same conditions as the previous examples of 60V, 85V and 111V. With this simple example, it can be seen that any difference in the path inductance to the individual chips can be quite significant. The degree of difference in inductive paths will probably increase with higher current rated module devices, which incorporate more chips, where as the capsule device will maintain the same effective path per chip and consequential over-voltage.

How significant these differences are, will ultimately depend on the specific application and no specific inferiority of the module design is implied. However, the inherent reduced overshoot voltage of the capsule design does allow for the optimisation of the chip design in terms of its voltage rating, with a smaller margin of safety being required in the design voltage.

The lower internal inductance of the pressure contact device gives greater control of the total circuit inductance to the
equipment designer, although it has to be acknowledged that this may be higher than in some designs incorporating modules. Overall system inductance is however, likely to be similar without detracting from the chip design optimisation described above.

The same issues of inductance also apply to the anti-parallel diodes, with the additional consideration of a very small inductive path between these and the IGBT chips. The absence of the relatively high inductance of wire bonds, ensures the anti-parallel diodes are able to very effectively clamp the IGBT chips in the reverse conduction cycle.

One other aspect of inductance in the new bondless pressure contact device also requires further consideration. As determined in the discussion of the mechanical design the planar bondless gate assembly offers a lower inductive path of both the equivalent module design and alternative capsule designs employing wire bonded gate assemblies. In combination with the very small difference in inductance between the external terminal and the individual chips, the optimised turn-on of the IGBT chips should be achieved, with minimal differences in transient voltages. A lower value of chip to gate inductance, also allows for a reduced value of series damping resistance in the individual chip gate circuits, which may offer some advantages in high frequency applications.

In the same way that the inductance was seen to be the same for each of the individual chips in the bondless pressure contact device, so is the thermal resistance from chip to pole face. Fig. 13 shows a simplified equivalent circuit, in which \( R_{\text{ThE}} \) represents the emitter thermal resistance and \( R_{\text{ThC}} \) the collector. The relatively high thermal mass of the copper pole pieces aids the equal distribution of heat between the chips, preventing any individual chip from running at a significantly higher temperature than its neighbour.

The example considered in the text above was for two similarly rated devices with nominal switching currents of 400A. If higher current devices are considered then a further aspect of temperature difference between individual chips may be worth consideration. The higher the device current the greater the number of parallel chips required and in the case of a module, the greater the total area of the base plate. A larger base plate requires a greater heat sink area and an increase in the possibility of temperature differentials occurring across its surface, which will be directly transferred to the individual chips. In the case of a larger current rated bondless device the same increase in chips is required but the larger thermal mass of the copper pole pieces will help to equalise any difference of temperature across the contacted heat sink area and in consequence between the individual chips.

As well as helping to equalise temperature between chips, the relatively large thermal mass of the pressure contact device has been shown in the development samples to have an improvement transient thermal resistance, when compared to an equivalently rated module.

A possible disadvantage of the relatively thick copper pole pieces of the pressure contact IGBT is the actual value of thermal resistance junction to sink. To fully optimise the device it is necessary to cool both sides, in which case the thermal resistance of the pressure contact device has a lower
thermal resistance than a similarly rated module. If only a single side is cooled then a comparable module may have a lower published value, however, when this is offset against the higher realisable junction temperature of the pressure contact device, this is unlikely to be a problem in most applications. Typical double side cooled thermal resistance of the development devices has been measured as 50 K/kW.

One other feature of the pressure contact device’s characteristics, which is directly attributable to the mechanical design and differs considerably from the module, is catastrophic failure. In the module the chips will initially fail to a short circuit but as the current builds the emitter wire bonds will fuse resulting in an open circuit. In extreme cases this is then followed by break down of the compound used to fill the module, which can result in the rupture of the package [12]. In contrast the pressure contact can only fail to a short circuit and the ceramic housing has a much higher rupture rating. This particular feature of the device has obvious implications where the devices are to be used in large series stacks, for example in medium voltage drives or power conditioning applications. With built in redundancy it is possible to maintain circuit operation in the same manner as is commonly employed with conventional thyristors and GTO thyristors.

Mounting the pressure contact device

One feature of the module, which is obviously lost with the pressure contact device, is the electrical isolation from the heat sink. This feature alone may make the pressure contact device seem unattractive in some low cost applications. However, this may be a worthwhile sacrifice in applications where some of the other features of the pressure contact device can be exploited to improve the overall system.

The more complex internal structure of the pressure contact IGBT does require a higher degree of care in selection of the clamping system, when compared to a conventional thyristor. However during the evaluation of the experimental devices, no significant problems have been encountered when specially designed clamps with added free movement in the pole piece contacts are used. Two clamps, one for single side cooling and a second for double side cooling have been developed for use with the experimental devices.

The use of a standard outline package in the pressure contact design allows for the use of standard water cooling systems and is here that the device is seen to have some advantages over the module in terms of overall system size. The pressure contact device should, in a well designed water cooled system and particularly if several devices are operated in series, offer a very compact solution.

Conclusion

The design of a bondless pressure contact IGBT, in a standard encapsulation outline has been introduced. It has been shown through discussion and the evaluation of experimental test devices, that the bondless pressure contact device offers different electromechanical characteristics from a similarly rated module device. The differences seen in the characteristics have been shown to offer possible advantages in some application areas.

The bondless pressure contact encapsulation allows for the optimisation of chip design. Improved distribution of voltage current and heat between chips reduces the need to over specify the chip design.

The industry standard outline permits the use of existing cooling technology and drop in substitution for existing thyristor technology. The pressure contact device has proven reliability and is particularly suited to the production of compact systems when devices are operated in series stacks.

In some applications it is clear that the advantages of the module IGBT cannot be surpassed, but it is also clear that the differences seen in the characteristics of the pressure contact device make this an attractive alternate.

Acknowledgement

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References