The application of pressure contact IGBTs in pulse power

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Abstract
The pressure contact IGBT is introduced as a suitable switch for pulse power applications. A comparison is made between the electromechanical characteristics of the pressure contact IGBT and a similarly rated substrate mounted device. Some significant differences, which may offer an advantage in some pulse power applications, are identified. Initial test results, under short pulse high d/dt conditions, are presented and some conclusions drawn as to the future expansion of these results to encompass additional pulse power operating conditions.

Introduction
The semiconductor switch is progressively becoming accepted as a realistic alternative to thermionic devices in pulse power applications. In particular the GTO thyristor has proved to be a satisfactory alternative to thyratrons in some high peak current applications [1-4]. It is the intention of this paper to introduce a new semiconductor switch, the pressure contact IGBT, which due to its electromechanical characteristics is highly suited to pulse power applications. The IGBT has much simpler gating requirements and a faster switching speed than the GTO thyristor, which may represent an advantage in some pulse power applications.

IGBT technology is now established in power electronics, however, the generally available packaging technology does not make it suitable for most pulse power applications. Many pulse applications require a higher operating voltage than that available in a single switch, necessitating series operation, which is difficult to implement using the traditional IGBT module. In contrast the pressure contact IGBT, introduced in [5-8], is housed in a conventional ceramic package, as illustrated in figs. 1 & 2, which is ideally suited to series operation. Also the pressure contact device has been shown to exhibit very good thermal characteristics and reliability, which are essential for many repetitive pulse applications.

Mechanical design.
The pressure contact device considered in this paper has no wire bonded or soldered joints, (i.e. totally pressure contacted) and has been described in detail in [5]. The individual chips are mounted into a common sub-assembly, fig. 3 shows the internal arrangement of a 400A device with the chips removed.
Gate contacts are achieved through spring loaded pins, which are then connected to the external gate terminal via a planar gate assembly, fig. 5. No discrete series gate resistors are included in the assembly, as these are integrated directly into the chips. The integral resistors have a low value and this in combination with the very low inductance path of the gate assembly, permits a very fast turn-on to be implemented.

Connections to gates of individual IGBT chips

**Fig. 5. Planar gate distribution system.**

**Electrical characteristics.**

A number of differences in the electromechanical characteristics of the pressure contact IGBT, when compared to an equivalent substrate mounted device have been identified [5]. Some of these are of particular interest when the devices are considered for pulse power applications. The internal structure of the pressure contact device is of an inherently lower inductance, than the equivalent substrate mounted device, >8nH pole face to pole face for the 400A device. The electrical path to each chip is identical ensuring an equal inductive path to each chip, fig 6. This ensures an equal rise in current for each chip under high di/dt conditions, which is unlikely to be the case in the more complex distribution of inductance in a substrate mounted device. Fig. 7 shows the equivalent circuit for a substrate mounted device, the intricate arrangement of bus bars and bonded wires used to connect the chips are represented by the inductors L_T (terminals), L_E (Emitter bus bar), L_W (Emitter bond wires) and L_C (Collector bus bars). The complex distribution of inductance results in both a higher terminal to terminal inductance (typically 40nH for a 400A module) and an unequal inductive path to the individual chips.

In addition to the reduced internal inductance of a discrete device, the ability to stack multiple devices for series operation, without the need of interconnecting bus bars, helps reduce total circuit inductance. When connected in series the pressure contact IGBT also has the advantage of failure to a stable and permanent short-circuit [9]. This offers the opportunity for device redundancy and avoids the possibility of a dangerous open circuit condition in a high voltage application.

Some preliminary testing of the pressure contact IGBT under short pulse, high di/dt conditions has been conducted with the circuit of fig 8. In the circuit C1=C2 & L1=L3, with C2 & L3 being adjusted to give the required peak current and pulse duration. The saturable reactor L2 can be shorted out by SW1 for hard turn-on. Diode D3 is the integral anti-parallel diode.

Examples of test results obtained with the test circuit of fig. 8, are given in figs. 9 to 12. The test device for all four example measurements is the 1800V/400A device illustrated in fig. 1. In each of the examples, voltage is 500V/div and current is 500A/div. The gate current is given at the top of the illustration, 5A/div. Time base is 2µs/div.

**Example test result (1).** Fig 9 illustrates a double pulse, with turn-off being initiated from the gate during the second pulse. The voltage on capacitor C2 at turn-on is 1000V and the saturable reactor is switched out of the circuit. The first current pulse has a peak of 1700A, with an initial di/dt of >2.5kA/µs. Total energy for the double pulse is 200mJ.

**Example test result (2).** Fig. 10 illustrates a series of pulses, with the device being allowed to naturally commutate off, i.e. no reverse voltage applied to the gate. The initial voltage on
capacitor C2 is 1000V and the saturable reactor is included in the circuit. The first current pulse has a peak of 1500A, with an initial di/dt of >2kA/µs. The total energy for the first current pulse is <65mJ.

Example test result (3). Fig 11 illustrates a single pulse with the device being turned off from the gate after the peak of current has been reached. The initial voltage on capacitor C2 is 1000V and the saturable reactor is included in the circuit. The current pulse has a peak of 750A, with an initial di/dt of >400A/µs. The total energy for the current pulse is 50mJ.

Example test result (4). Fig 12 illustrates a single pulse with the device being turned off from the gate after the peak of current has been reached. The initial voltage on capacitor C2 is 1000V and the saturable reactor is included in the circuit. The current pulse has a peak of 1300A, with an initial di/dt of >400A/µs. The total energy for the current pulse is 120mJ.

As can be seen from the test samples, it is possible to obtain very narrow current pulses, with either natural or gate commutated turn-off. Peak currents greater than three times the rated current are possible and the device can be safely turned off from the gate with a peak current equivalent to more than twice the nominal rating.

From these results it can be determined that the larger diameter device with a nominal current rating of 1400A, illustrated in fig. 2 could sustain a peak current of >4kA. A larger device, presently under development in a 100mm pole face package, would support a peak current of >7kA.

The tests carried out were all single shot measurements but the calculated energy per pulse indicate that, with suitable cooling, the devices are capable of being operated at considerable repetition rates. The energy recorded in the first example measurement suggests that a frequency in excess of 5kHz is achievable and that it may be possible to double this if a saturable reactor is included in the circuit.

Further work is being conducted, to both evaluate the higher current devices and determine the operation of the devices under higher di/dt conditions, with narrower pulses. In addition to this, an investigation will be conducted to determine performance of the devices in series operation under pulse conditions. The results of these investigations will be reported at a later date, when the work has been completed.

Reliability

A particular feature of the pressure contact IGBT is a high level of reliability, this is determined by both the thermal and mechanical characteristics of the device. As previously illustrated for the inductive path, the thermal path to each individual chip is also by nature identical. This ensures that the individual chips share a common junction temperature and therefore close matching of electrical characteristics and performance, under dynamic operating conditions.

Once mounted, the pressure contact IGBT maintains the same thermal contact conditions to the heat sink as seen in other pressure contact devices. The distortion of the base plate and migration of cooling compound associated with some substrate mounted technologies [10-11] is therefore not an issue.

The pressure contact device is less susceptible to wear out under the repetitive high thermal transient conditions seen in some pulse power applications. Extensive testing has indicated the devices to have exceptional thermal cycling capability [9], with test devices having achieved >100k cycles with a DTJ >135°C (accelerated life-test outside the normal operating range of the device).

Conclusion

The pressure contact IGBT offers several possible advantages over other semiconductor technologies in pulse power applications. In particular the simplicity of the gate trigger requirements and reduced external circuit component count offers a competitive alternative to a GTO thyristor. The reduced internal inductance and simplification of series connection can be seen as an advantage over substrate mounted IGBT technology.

Initial test results indicate that the pressure contact IGBT offers switching characteristics suitable for pulse applications and can be operated in both a natural and gate commutated mode. Projected results indicate the suitability of the devices to operate at high repetition rates above 5kHz, depending on required operating conditions.
The future expansion of the product range, in terms of both current and voltage, will expand the pulse power applications for which the pressure contact IGBT is an appropriate solution.

References


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