New Extra Fast Soft Recovery Diodes and their Applications

The advent of press-pack technology for IGBTs and GCTs highlighted the need for a discrete fast recovery diode capable of operating at high commutation rates with low reverse recovery current and soft recovery behaviour. A new range of 1.7, 2.5 and 4.5kV extra fast soft recovery diodes are outstanding in their dynamic characteristics, such as very soft recovery, reverse recovery di/dt >5000A/µs and low reverse peak current. **Gangru Li, Westcode Semiconductors, Chippenham, UK**

FRANÇAIS

L'avènement de la technologie compacte pour les transistors bipolaires à porte isolée et les thyristors à commande dure ont mis en évidence la nécessité d'une diode de récupération rapide discrète capable de fonctionner à des taux élevés de commutation, avec un courant de récupération inversé faible et un comportement doux de récupération. Une nouvelle gamme de diodes ultra rapides douces de 1,7, 2,5 et 4,5 kV offre des qualités dynamiques remarquables comme la récupération très douce, la récupération inversée di/dt >5000A/µs et un courant de crête inversé faible. **Gangru Li, Westcode Semiconductors, Chippenham, R.U.**

DEUTSCH

Das Aufkommen der Press Pack-Technologie für IGBTs und GCTs unterstreicht den Bedarf an einer diskreten Fast Recovery Diode, die bei hohen Kommutierungsraten mit geringem Rückwärtserholungsstrom und weichem Erholungsverhalten arbeiten kann. Eine neue Reihe von 1,7, 2,5 und 4,5 kV extra schneller Soft Recovery Dioden weisen hervorragende dynamische Charakteristika auf, wie sehr weiches Erholen, Rückwärtserholung di/dt >5000 A/µs sowie geringem Rückwärts-Spitzenstrom. **Gangru Li, Westcode Semiconductors, Chippenham, UK**

When press-pack IGBTs are used as switching components in an inverter, converter or chopper circuit, appropriate diodes are needed to sustain the current from the inductive load such as a motor, transformer or induction heater. To reduce the switching energy losses it is suggested to turn on the press-pack IGBT with rapid rate of change of current (di/dt), however this placed increased demands on the switching behaviour of the diode. A medium power press-pack IGBT is capable of switching on at an extremely high di/dt of up to 10000A/µs without causing damage to the device. However, a typical medium voltage, fast recovery diode is designed to operate at a reverse recovery rate of up to 500A/µs. To take the advantage of fast switching capability of the press-pack IGBT, the relevant freewheeling diode needed to meet the following requirements:

- Very high reverse recovery current change rate. (di/dt >2500A/µs).
- Very low reverse peak current I_{rm}, which is also relevant to the turn-on loss in IGBT.
- Soft reverse recovery. The soft factor $S = t_b/t_a$ should be more than 1.
- Clamp pressure compatible with associated press-pack IGBT or GCT.
- Low forward voltage drop and low leakage current.
- Robust against dynamic avalanche.

To achieve these design goals, many innovative ideas were tried and tested. Three 4.5kV rated voltage elements with 3 different lifetime controls ere selected as follows:

- Type A - gold diffused plus helium implantation lifetime control,
- Type B - platinum diffused plus helium implantation lifetime control, and
- Type C - electron irradiation plus helium implantation. Extensive test results were evaluated and demonstrated [1] that the aim of the design has been achieved.

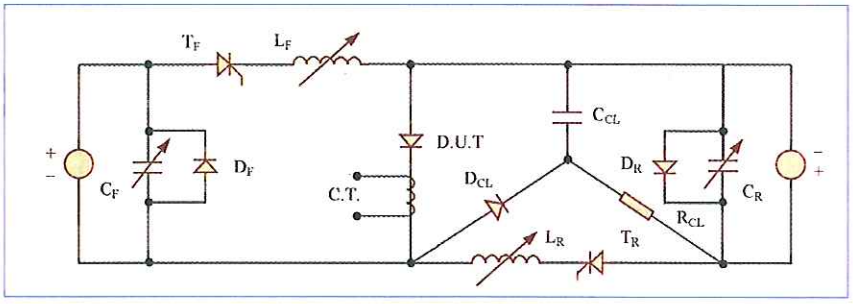


Figure 1 (above). Circuit for reverse recovery testing

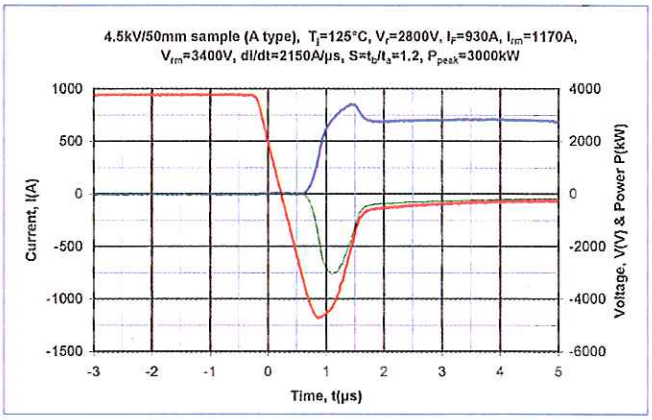


Figure 2 (left). Type A 4.5kV/50mm diode reverse recovery waveforms

DIODE MEASUREMENTS

A series of evaluation tests on the static and dynamic characteristics of the

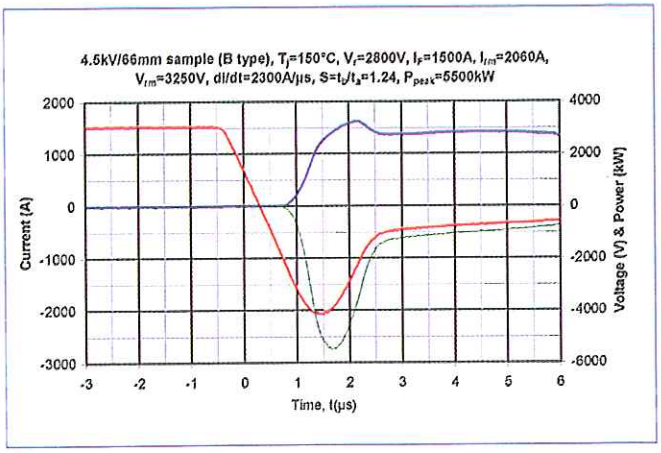


Figure 3 (left). Type B 4.5kV/66mm diode reverse recovery waveforms

new 4.5kV/50mm diode samples were conducted. Among the test results, Type B samples appear to be the lowest in both blocking leakage current and forward voltage drop, Type A appeared to be the highest in the both, and Type C in between. The 2.5kV/50mm samples, with three corresponding lifetime control techniques, show similar characteristics.

Initial dynamic tests were carried out using a tester, whose circuitry is shown in Figure 1. The forward current I_F was generated by C_F T_F L_F Loop, and the reverse current I_R by C_R T_R L_R Loop. The reverse recovery di/dt is predetermined by both variable inductor L_R and line voltage V_R according to the relationship $di/dt = V_R/L_R$.

A comparison between the three diodes showed that Type B had the best trade-off on both of its static and dynamic characteristics, as well as its high temperature operating capability. Thus, Type B was chosen as the product type, although Type A could also be applied in some cases when device junction temperature is not a main issue. As examples, two reverse recovery waveforms for Type A and Type B are illustrated in Figures 2 and 3.

When compared to a normal fast recovery diode, the peak power of a new extra fast soft recovery diode is much lower due to its low I_{rm} and very soft reverse recovery characteristics, which help significantly to reduce the recovery peak voltage V_{rm}. Test results showed that the instantaneous power limit was roughly proportional to the size of the element. The power limit drops when the junction temperature rises. For a 50mm element, the power limit is about 3000kW at 150°C. In practice, when such a diode type is used as a freewheeling diode in IGBT switch leg, its reverse recovery di/dt would be manipulated by the turn-on resistance of the IGBT gate driver. Thus, the recovery voltage over-shooting on the diode could be further dampened down by the turn-on voltage falling of the press-pack IGBT.

Following the encouraging results from the 4.5kV/50mm samples, more tests on new samples with voltage grade 1.7 and 2.5kV, and with different silicon wafer sizes, are proceeding. So far, a maximum reverse recovery di/dt of up to 4700 and 7000A/µs has been reached in Type B 2.5kV/50mm and 1.7kV/50mm samples respectively.

DIODE APPLICATIONS

With their outstanding reverse recovery characteristics, the new extra fast soft recovery diodes can be applied in many fields. One of their major applications is to function as freewheeling diodes in single- or three-phase press-pack IGBT inverters. Figure 4 demonstrates the new extra fast soft recovery diodes used as anti-parallel freewheeling diodes with press-pack IGBTs in a three-phase inverter stack working for induction heater, adjustable speed motor driving and voltage supply on the primary side of a transformer. A higher reverse recovery di/dt and a low I_{rm} on the freewheeling diodes will help reduce the commutation energy losses both on the diodes and the press-pack IGBTs, and enable an inverter to work at high operating frequency. The advantage of the new diodes appears to be more appreciable when used in PWM inverter, in which the current commutation frequency between the press-pack IGBT (or GTO thyristors) and the freewheeling diodes needs to be much higher than the inverter's operating frequency.

Figures 5 and 6 show the circuit schematic and the assembly of a press-pack IGBT chopper built for Spoornet, RSA. In the assembly, five diodes of Type B 1500A/2.5kV/50mm (E1500NC250) and four 1500A/2.5kV press-pack IGBTs (T1500TA25E) were connected in serial stacks to meet the high voltage requirement. The whole assembly stack was immersed in an oil tank.

Another application example of the new diode is to act as snubber and freewheeling diode in a McMurray inverter (Figure 7). D_p and D_n are main freewheeling diodes, each of which is across a GTO thyristor. A discharge resistor is

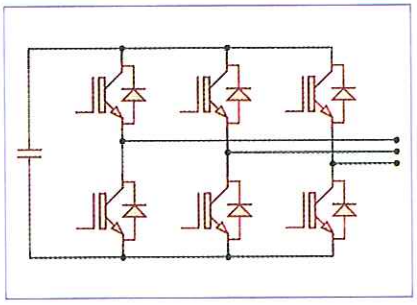
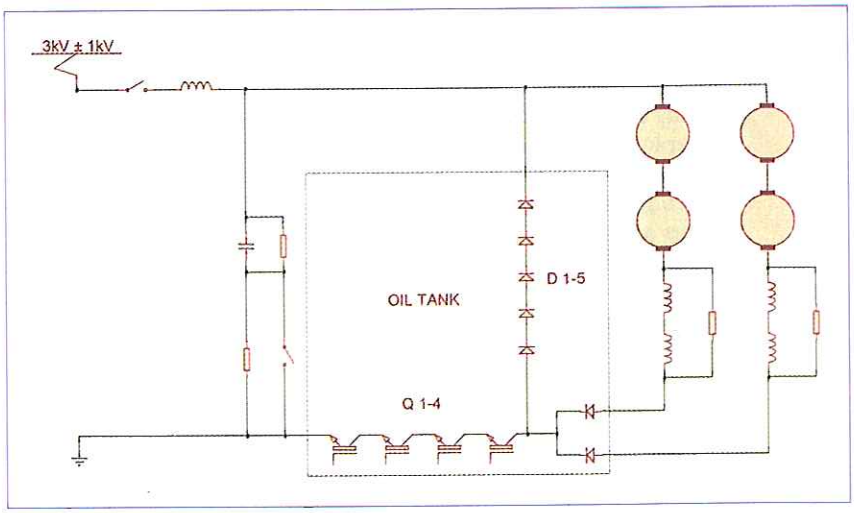


Figure 4 (left). New extra fast soft recovery diodes used as anti-parallel freewheeling diodes with press-pack IGBTs in a three-phase inverter stack

Figure 5 (below). New extra fast soft recovery diodes used as chopper diodes in anti-parallel configuration with press-pack IGBTs in chopper circuit



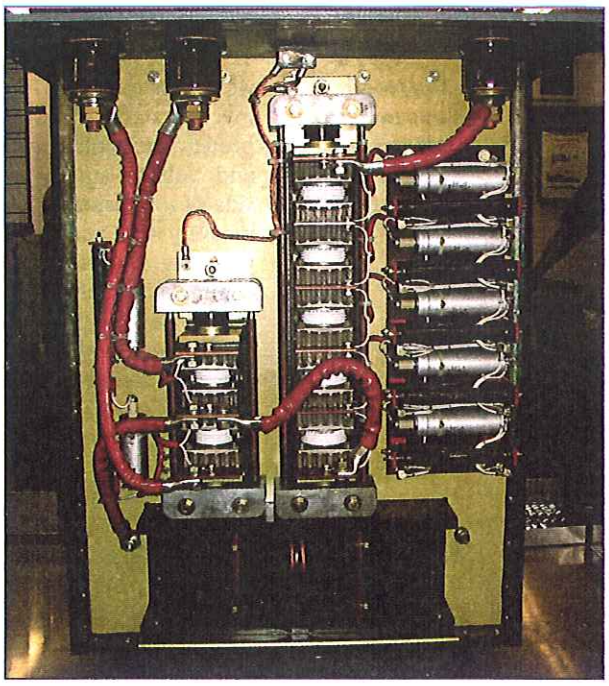


Figure 6 (left). Chopper assembly with new extra fast soft recovery diodes and press-pack IGBTs in series

terminated with the auxiliary diodes D_{sp} and D_{sn}. Two inductive snubbers, each with inductance of L_s, are connected in series with mutual couple coefficient k to give a total inductance of $L_S = 2L_s(1+k)$. This inductor acts to limit the di/dt through high or low GTO thyristor to a value of E_d/L_S. In particular, this di/dt limit applies to the discharge of the shunt snubber capacitors C_{sp} and C_{sn} due to the steering action of diodes D_{sp} and D_{sn}. The resistance of R_S can therefore be low, as determined by the need to limit the over-voltage $I_{off}R_S$ caused by turn-off current I_{off}. Since R_S is low, C_{sp} and C_{sn} would be able to mutually assist one another to limit the dv/dt at GTO thyristor turning-off, thus allowing a reduction in the capacitor size by a factor up to 2 and the associated losses could also be reduced by the same factor.

In this application, the commutation rate is limited by L_S and this aids both turn-on of the GTO thyristors and turn-off of the freewheeling diodes. The snubber diodes D_{sp} and D_{sn}, however, are subject to rapid commutation limited only by the self-inductance of the snubber loop. At lower current this can lead to snappy behavior of the diode resulting in high dv/dt applied to the GTO thyristors and consequential failure. The soft recovery behavior of these new diodes across a wide range of current and temperature offers a distinct advantage over conventional diodes.

To demonstrate the application feasibility and prove the benefit of the new diodes when used with IGBTs, several tests with the circuit illustrated in Figuure 8 were conducted. A 3kVDC voltage source was used as the line voltage E_d. The inductive load and inductance LS were replaced by a 500µH inductor and a saturable inductor made of ferrite toroid respectively. A press-pack IGBT (T0900TA52E) was triggered by a double pulse of the gate driver, in order to generate current commutation waveform similar to that in a real McMurray inverter. The test results show that the turn-on and turn-off energy losses of the diode and IGBT have been significantly reduced due to a much softer switching behaviour.

CONCLUSIONS

All three 4.5kV/50mm extra fast soft recovery diodes with different lifetime control techniques show excellent figures in both static and dynamic characteristics. Type A has an advantage in its low I_{rm} value while the Type B has a low forward voltage drop and high temperature performance. Compared with A and B, Type C appears to be less advantageous due to its higher forward voltage drop and higher reverse recovery peak current. Apparently, Type B diode is the best option for all the applications. Type A could, however, be used in some special case when the junction temperature is not a main issue in its operation. The new diode type is particularly suitable to be used as freewheeling diodes in the press-pack IGBT assembly stack. By using heavy metal diffusion and ion implantation for profiled lifetime control, an optimum trade-off in static and dynamic parameters has been achieved. Its development has expanded the application field for high voltage IGBTs.

REFERENCES

[1] G. Li, Z. Q. Liu, A. Golland, F. Wakeman, 'New Extra Fast Soft Recovery Diodes and their Applications', EPE 2005 - European Conference on Power Electronics and Applications.

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Figure 7 (right). Schematic of McMurray inverter

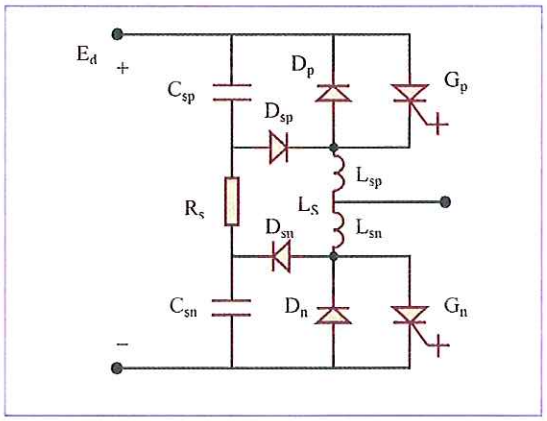

Figure 8 (right). Experimental circuit for proving the new extra fast diode application