Dependence of Diode's Behaviour on Conduction Time

1. Purpose:

In designing a power electronics system employing IGBT modules, the reverse recovery energy loss Err of a freewheeling diode is one of essential items which should be evaluated. The value of the energy loss increases with the diode conduction time and reaches a saturation state. Therefore, the value must be measured with a sufficiently long conduction time. The aforementioned saturation characteristics are also true of a stored charge (Qrr) and a reverse recovery current peak (Irm). In this application note the saturation characteristics of Err, Qrr and Irm are reviewed as is a proper conduction time for evaluating diode behaviour.

2. Definition of conduction time Tco:

In this section, the definition of the diode's conduction time is explained in connection with the operation waveforms of a half-bridge circuit. Fig. 1 shows the half-bridge circuit generally used for measuring the dynamic characteristics of power devices. The reverse recovery waveforms of a freewheeling diode are measured by operating the half-bridge circuit under the gate voltage pattern of Fig. 2(a). The voltage and current waveforms are schematically shown in Fig. 2(b) and (c) respectively. In accordance with the gate pattern, IGBT B_2, i.e. Module 2, is driven. From t = 0 to t_1 the state of B_2 is ON and current I_C flows through load L and IGBT B_2, as shown in Fig.3. In this case the load current I_L, which flows through an inductive load L, has the same value as the collector current I_C of B_2, where I_C increases with time. After t_1, B_2 shifts to OFF-state through a transient period. During the OFF-state of B_2, the current I_C is blocked but the load current I_L is maintained as a circulating current through diode D_1 as shown in Fig.4. After t_2, B_2 is turned on again during a transient period. Just after t_1 and t_2, a transient state occurs, where both I_C and I_L flow as shown in Fig.5. The reverse current I_R of D_1 is the difference between I_C and I_L, that is, $I_R = I_C - I_L$. The conduction time is defined as the period T_{CO} in Fig. 2(c) where the forward current, that is a negative value of I_R, flows through the diode.

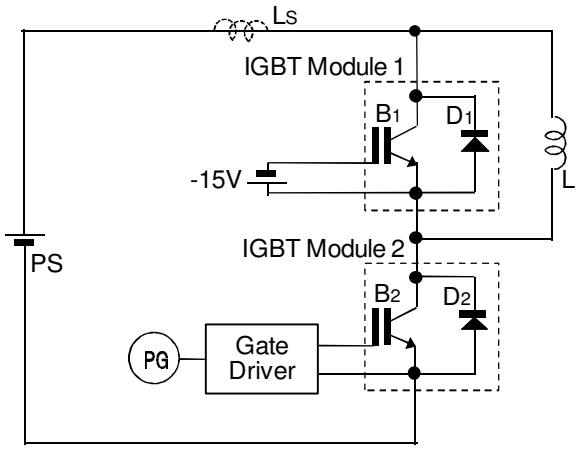

Fig.1 Half-bridge circuit

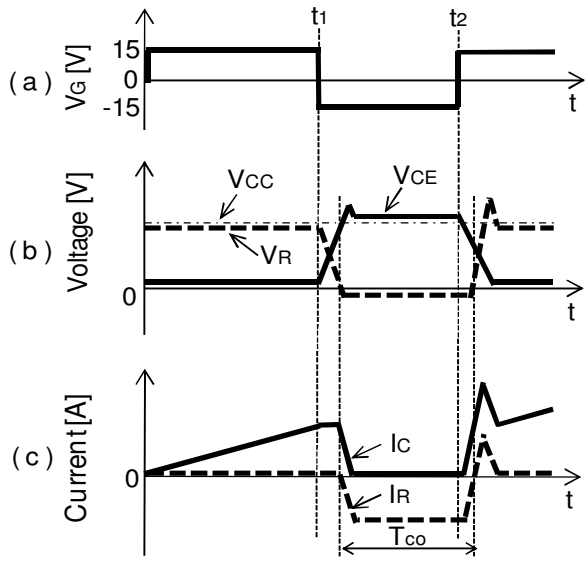

Fig.2 Operation pattern for B_2

(Solid line: Waveform of B2, Dashed line Waveform of D1)

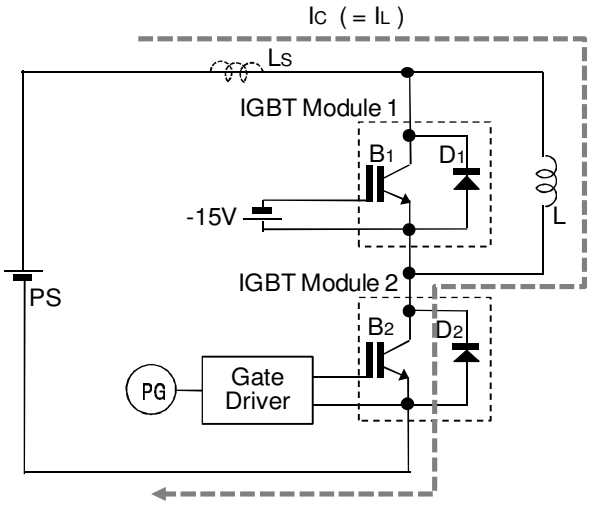

Fig.3 Current flow in ON-state of B2

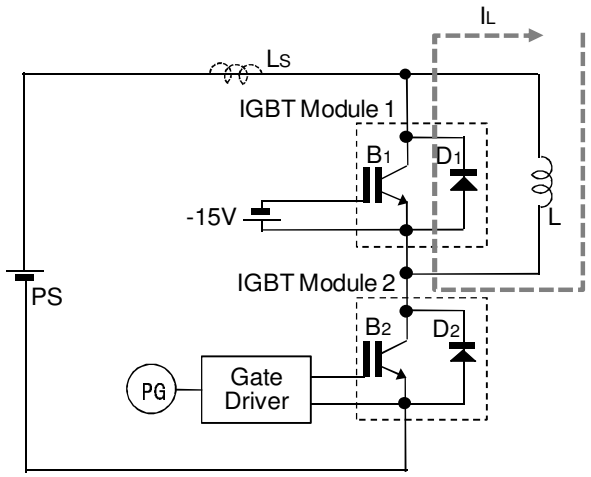

Fig.4 Current flow in OFF-state of B2

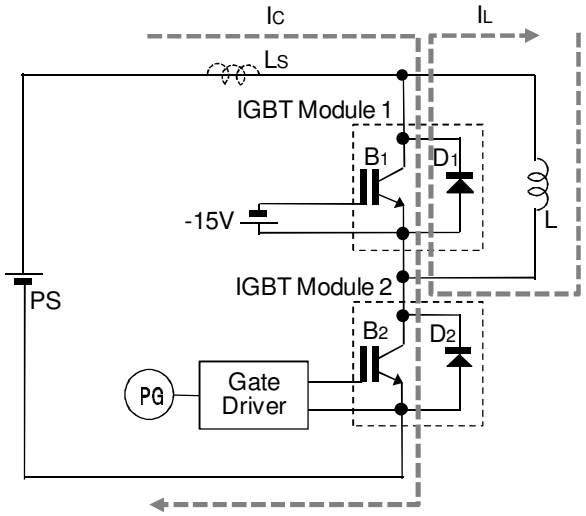

Fig.5 Current flow during transient period

3. Saturation characteristics of Err, Qrr and Irm:

The values of Err, Qrr and Irm rise with the increase of conduction time and reach a saturation state. The saturation characteristics of Err, Qrr and Irm can be experimentally verified using the half-bridge circuit. As a representative example, the diode's characteristics of the IGBT module MBN1200H45E2 are shown in Fig. 6, Fig. 7 and Fig. 8. The measuring conditions of the characteristics are as follows.

Measuring conditions:

- Supply voltage Vcc = 2600 V
- Forward current IF = 1200 A
- Junction temperature = 25℃ and 125℃
- Stray inductance Ls = 150nH
- Gate resistance = 3.3Ω

Fig. 6 shows the characteristics of the reverse recovery energy loss Err at diode junction temperature 25℃ and 125℃. In the case of the junction temperature 25℃, the characteristics curve is saturated in the domain where the conduction time is over 40μs. Where the junction temperature is 125℃; the curve reaches a saturation state after approximately 60μs conduction period. Figures 7 and 8 show the characteristics of Qrr and Irm respectively, where both characteristics curves of Qrr and Irm are saturated after the same conduction time of Err.

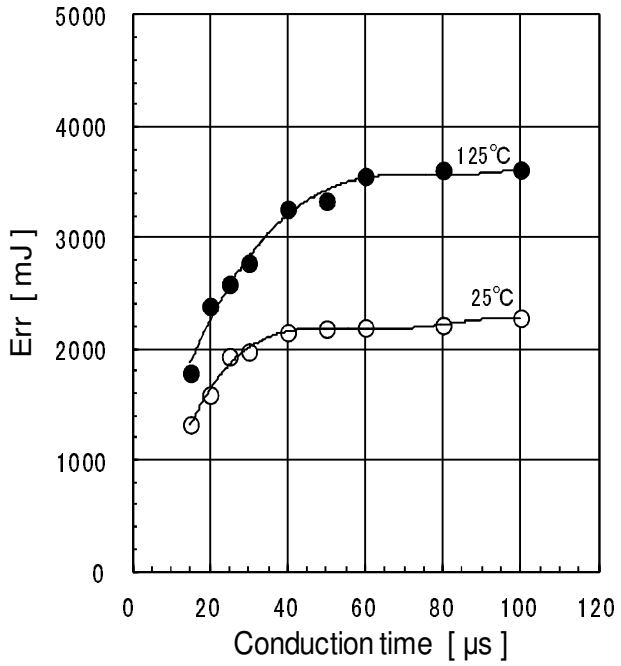

Fig. 6 Dependence of Err on conduction time

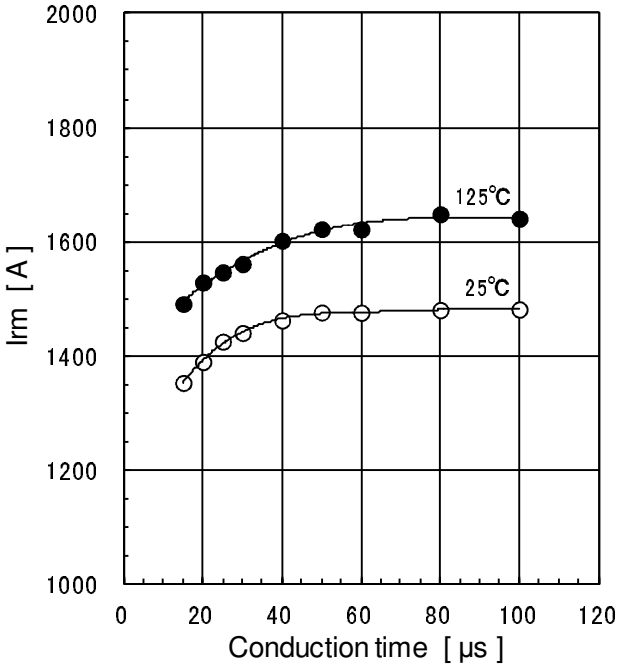

Fig. 8 Dependence of Irm on conduction time

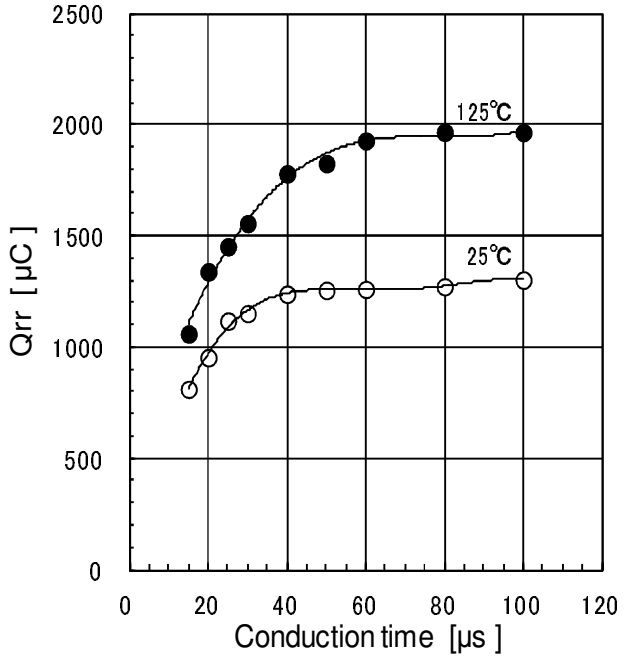

Fig. 7 Dependence of Qrr on conduction time

4. Proper conduction time:

As mentioned in the preceding section, Err, Qrr and Irm exhibit saturation characteristics with an increase of diode conduction time. Therefore, in evaluating a diode's behaviour, a sufficient conduction time must be ensured to avoid the influence of the diode's transient characteristics. In this document the behaviour of a diode was the focus, however an IGBT also exhibits a similar saturation tendency. Therefore, when evaluating the turn-on and turn-off power loss of an IGBT, a suitable value of conduction time must be considered.