Ringing Phenomenon during Recovery of Power Diodes

In this document diode ringing phenomenon is reviewed. The phenomenon has a tendency to appear under conditions where the forward current of the diode is small and the conduction period of the current is short. When reverse voltage is applied to the diode after forward current flow, reverse current flows for an instantaneous moment. This reverse current is called recovery current. Depending on conditions of use, the recovery current may demonstrate oscillations. This oscillation may also be referred to as ringing.

Ringing is caused by the interaction between intrinsic behaviour of the diode chip and the response characteristics of the external circuit. Fig. 1 shows an example of experimental waveforms to highlight the ringing phenomenon. In Fig. 1, the operation current and voltage waveforms of the diode during the recovery period where forward current flows for Δt = 1 are shown. Fig. 2 shows correlation between the peak value of reverse voltage, V_{RM}, and the time period of forward current, Δt. The results show the shorter the flowing period the larger the peak value of reverse voltage.

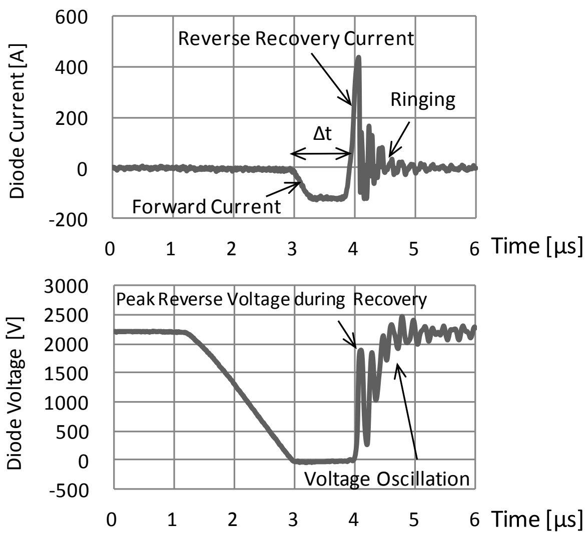

Fig.1 Experimental waveforms for recovery

The reason why there is correlation between V_{RM} and Δt can be explained using Fig. 3 and Fig. 4. During the period from t2 to t3 in Fig.3, holes are injected from the p region to n region as shown in Fig. 4(a), and the diode begins conduct. During the period from t4 to t5, diode current continues flowing in the reverse direction until holes stored in n region become extinct by returning to the p region or by recombining with electrons. Further reduction of holes forms a depleted layer in the p-n junction area as shown in Fig. 4(b), and reverse voltage appears at the terminals of diode. During the period from t5 to t6, as holes remaining behind are swept out, current continues flowing and the depleted layer expands while reverse voltage increases. The peak value of the reverse voltage is determined by the product

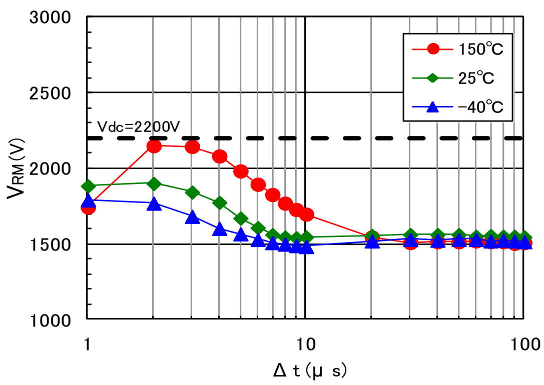

Fig.2 Peak value of reverse voltage

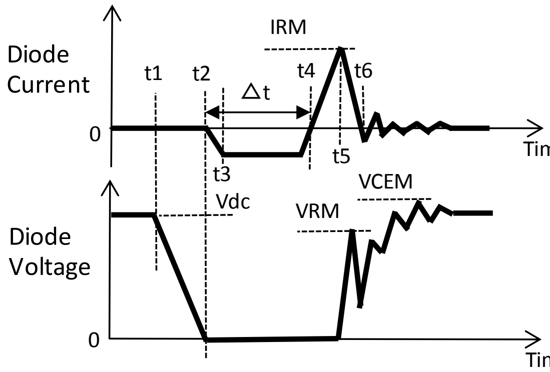

Fig.3 Recovery phenomenon of diode

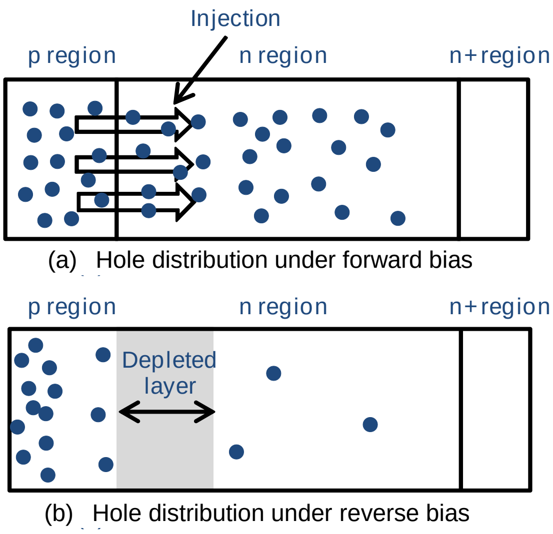

Fig.4 Distribution of holes

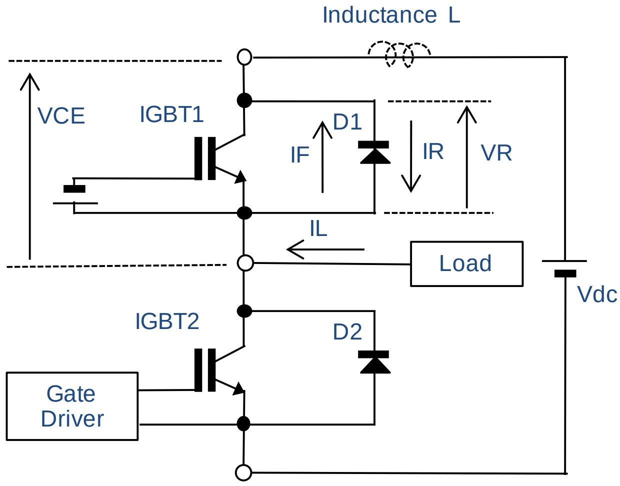

Fig.5 One phase circuit of inverter

of di/dt as the reverse current returns to zero and the inductance (L) of the external circuit. It is important to keep the inductance (L) small by laminating electric wiring. If forward current is small or Δt is short, the holes stored in the n region will be low. In that case the reverse current after t4 will becomes small allowing the depleted layer to expand rapidly. The subsequent di/dt in the period from t5 to t6 becomes large and a sudden voltage peak may occur.

Care should be taken during the evaluation and design cycles to observe if ringing occurs at the application level. An example of a one-phase leg of an inverter employing IGBTs is shown in Fig. 5. Supposing that forward-current I_F flows through upper-arm free-wheel diode and the lower-arm IGBT turns on, the free wheel diode begins reverse recovery and reverse current I_R will flow. Where the current I_F flows for a very short time, the diode recovery may be instantaneous. This short time recovery period may lead to the ringing phenomenon on the free wheel diode. If the load current is very small, close to zero Amperes (0A), the phenomenon has a tendency to occur.

During this ringing, the voltage between the collector and emitter of upper-side IGBT may not be stable causing the gate voltage to vary, potentially leading to gate drive circuit malfunctions depending on the severity of conditions. As a pre-caution the behaviour of the diode should be checked thoroughly during validation and a suitable gate resistor should be selected to prevent ringing. Ringing may also occur in any snubber diode. If used it is necessary to carefully choose a snubber diode which generates less ringing.