IGBT 설계 Parameter 연구
A Study on Parameters for Design of IGBT

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ABSTRACT

The development of high voltage Insulated Gate Bipolar Transistor (IGBT) have given new device advantage in the areas where they compete with conventional GTO (Gate Turnoff Thyristor) technology. The IGBT combines the advantages of a power MOSFET (Metal-Oxide Semiconductor Field-Effect Transistor) and a bipolar power transistor. The change of electrical characteristics for IGBT is mainly coming from the change of characteristics of MOSFET at the input gate and the PNP transistors at the output. The gate oxide structure gives the main influence on the changes in the electrical characteristics affected by environments such as radiation and temperature, etc.. The change of threshold voltage, which is one of the important design parameters, is brought by charge trapping at the gate oxide. In this paper, the electrical characteristics are simulated by SPICE simulation, and the parameters are found to design optimized circuits.

1. Introduction

The types of radiation are generally divided into particle radiation and photon radiation. The particle radiation consists of the charged particles which have protons, electrons, αparticles, ions, and neutral particles that are the neutrons. The photon radiation consists of gamma rays and/or x-rays.

A simple method for estimating the threshold voltage shift [1] due to the ionizing irradiation of low dose rate was recently proposed for power MOSFETs. Briefly, the method consists of estimating the threshold voltage shift by the oxide charge trapping at the gate oxide immediately after irradiation.

The IGBT combines the advantages of a power MOSFET [1, 2] and a bipolar power transistor. The input has a MOS gate structure, and the output is a wide base

PNP transistor. The base drive current for the PNP transistor is fed through the MOSFET at the gate. In conduction mode, the epitaxial region is conductivity modulated (by excess holes and electrons) thereby elimination a major component of the on-resistance. The basic equivalent circuit of IGBT is shown in Fig. 1

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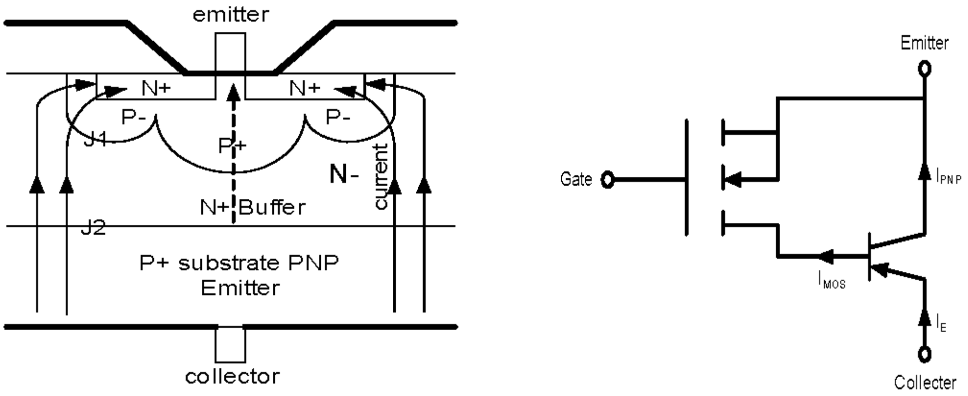


Fig. 1 Basic equivalent circuit of IGBT

IGBT as shown in Fig 1 operates by 'turn off' / 'turn on' and state repeatly for the function of switching as the following steps.

step 1) turn off state;

When the positive voltage is applied to collector at the short between gate and emitter, junction 2 (J2) is in forward bias and junction 1 (J1) is reverse bias. Then, the current is cut off, and it is called 'turn off' state.

step 2)

If gate voltage (VG) is greater than threshold voltage (Vth), the electron is supplied to base region (n− epitaxial layer) through induced channel at p−body surface. Then, the current flows in forward direction at transistor.

step 3)

As collector voltage is increased, the hole is injected to base region at p+ substrate, the conductivity of n− epitaxial layer is increased, which results in reducing the resistivity loss. Then, the switch is at 'turn on' state.

step 4) transition state from 'turn on' to 'turn off' (off−transition state);

The short between gate and emitter makes IGBT turn off, and the channel at p+ substrate is abruptly removed. There exist holes and electrons at n− epitaxial layer. Then, electrons are injected into substrate, and holes moved to p+ body region, respectively. The remaining holes and electrons are diminished through the recombination, and the IGBT changes to 'turn off' state for the function of switching. Go to step 1 for repeat operation.

MOS devices are among the most sensitive of all semiconductor to radiation, in particular ionizing radiation, showing much change even after a relatively low dose. The effect is often considered as a change in gate threshold voltage. The relationship between threshold voltage VT and change Qtot in SiO2 is given by

$$\triangle V_T = -\frac{\triangle Q_{tot}}{C_{OX}} \qquad (1)$$

where C_{OX} is fixed for each different kind of MOSFET, and the change of charge, $\triangle Q_{tot}$, depends on the dose. The change of threshold voltage, $\triangle V_T$, is proportional to $\triangle Q_{tot}$.

2. Simulation SPICE Model

To analyze the radiation effects based on the circuit model as ahown in Fig. 2, we adapt the SPICE model supplied from the IGBT maker International Rectifier (IR). The IGBT SPICE micro–model with a parameter variation dependence of the radiation damage allows the designer to estimate the performance to find the optimal condition of systems including IGBTs under irradiation environments [4, 5].

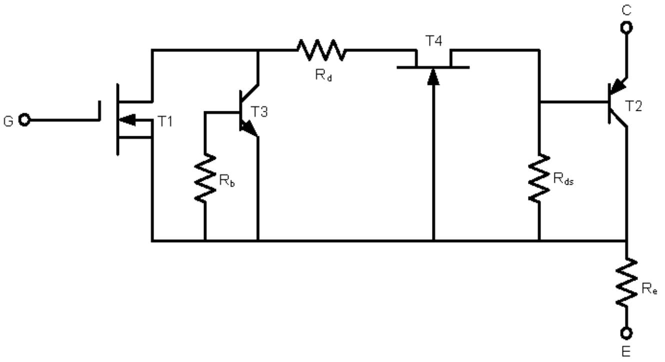


Fig. 2. SPICE Model of IGBT

The model is simplified by removing all elements relating to transistor dynamic behavior dynamics behavior. We modify the SPICE model of 1,200 V 45 A IGBT IRG4PH50S from IR to reproduce the change of electrical parameters [4] occurred during the raidation tests. T1 is the input MOSFET. It is a “LEVEL 1” SPICE model [6].

Table 1. SPICE parameter values of T1 and T2

Parameter (MOS)	Value	Parameter (BJT)	Value
LEVEL	1	IS	10^{-16}
VTO	6.5	BF(β)	10
KP	0.5	NE	2

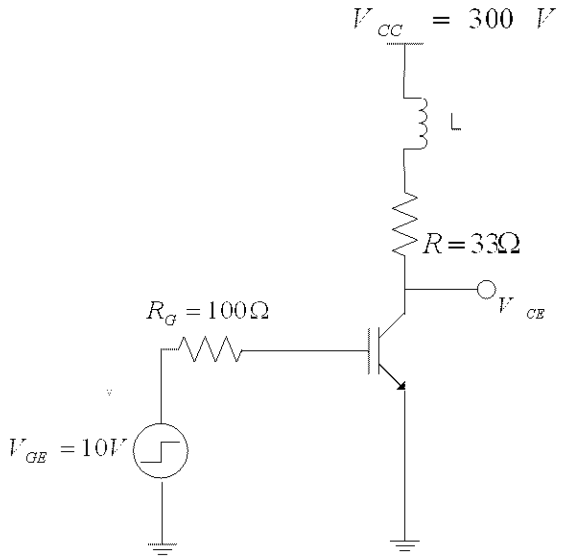


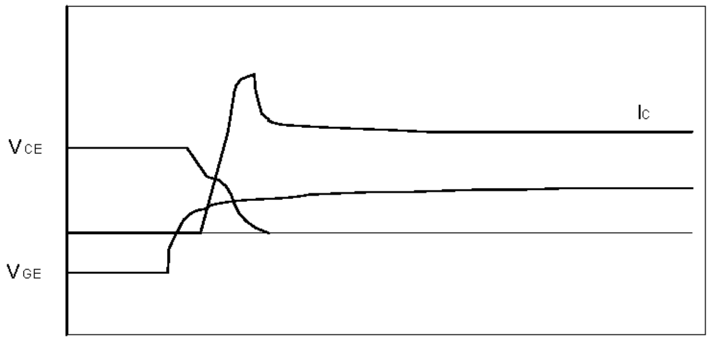
Fig. 3 Inductive load circuit including IGBT

Our study is concerned mainly with the change in parameters, VCE (collector−emitter voltage), VGE (gate−emitter voltage), and VT (threshold voltage).

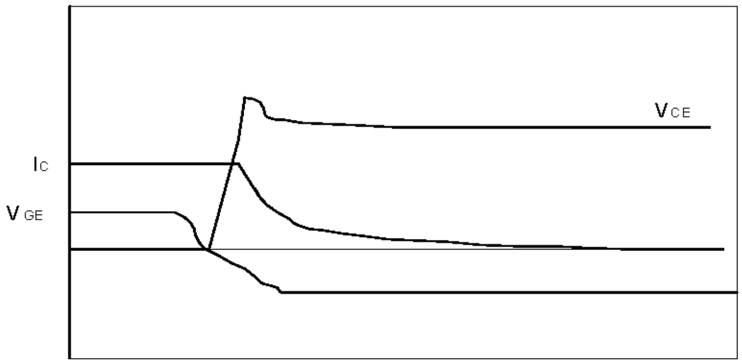
3. Electrical Characteristics

The motor drive application is realized by the high current swithing of IGBTs. With IGBT and diode it is possible to use carrier distribution control technology. The high blocking voltage of the IGBT has a uniform and stable electric field due to the original filed limiting ring and field plate structure. All new IGBTs have a wider reverse bias safe operating area than GTOs. Fig. 7 shows a typical turn−on and turn−off. With falling collector−emitter voltage VCE, the gate bias current is used for changing the charge of $C_{GC}\times\frac{dV_{CE}}{dt}$ and gate voltage remains constant. The collector current IC starts to flow when the VGE is greater than the threshold voltage VT, which occurs at the cross point of VGE with IC flowing. When the collector−emitter voltage has come down, C_{GC} becomes larger. The gate voltage is to rise again when the current needed for charging becomes smaller than the bias supplied current. As the switching−on and off speed of IGBT is faster, the energy loss at the off−transient occurs more frequently, and the appropriate switching frequency is needed for the good performance.

The turning off is starting with VCE low, and VGE positive or greater than threshold voltage VT. The gate voltage first decreases nearly linearly. With low VCE and with moderate increase there is the strongest decrease of CGC. The VGE remains constant when there is a bias source which is drawing current out of the gate. Then, VCE increases and most of the gate discharge current is used up for $C_{GC}\frac{dV_{CE}}{dt}$, and the gate voltage remains constant. When VGE value becomes to less than VT, the collector current IC does not flow for turning-off.



(a) Turn-on wave-form



(b) Turn-off wave-form

Fig. 4 Turn-on and Turn-off of IGBT

The power loss at turn-off in terms of threshold voltage VT. The energy loss decreases as the threshold voltage increases. The engergy loss is obtained as

$$E_{off_{loss}} = V_{CE} \times I_C$$

where I_C is the collector current.

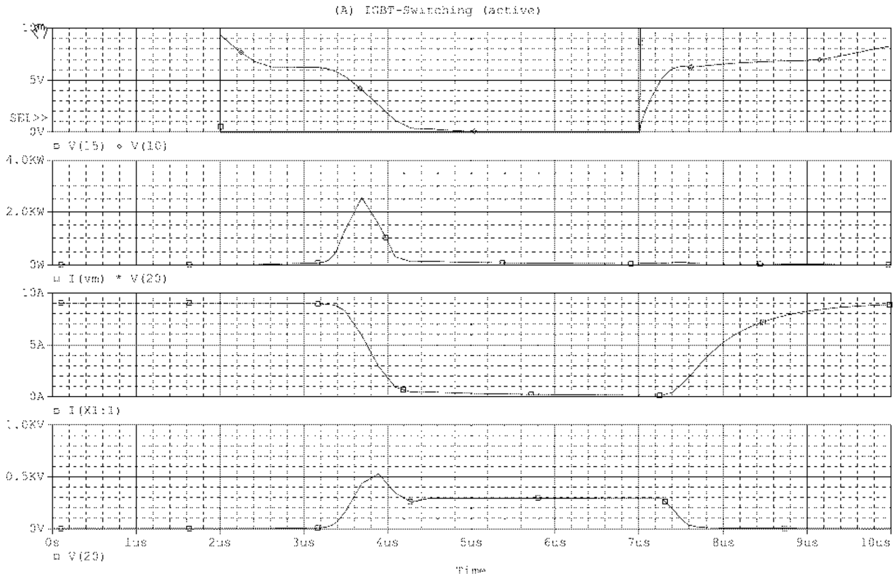


Fig. 5 plots of VGE, Power Loss, IC, and VCE at L= 20 uH

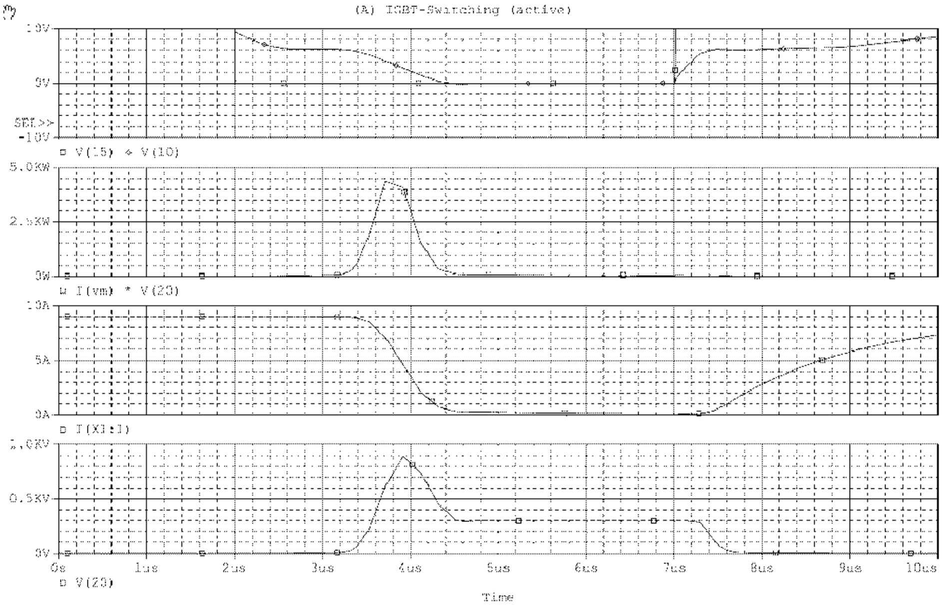


Fig. 6 plots of VGE, Power Loss, IC, and VCE at L= 50 uH

The overshoot value is 500 V and the energy loss is 1 mJ as shown in Fig. 5 at L= 20 uH in the circuit of Fig. 3. The overshoot value reaches to 900 V and the energy loss is 2.5 mJ as shown in Fig. 6 at L= 50 uH. Then, as the inductance value increases under the same values of other components, the energy loss increases.

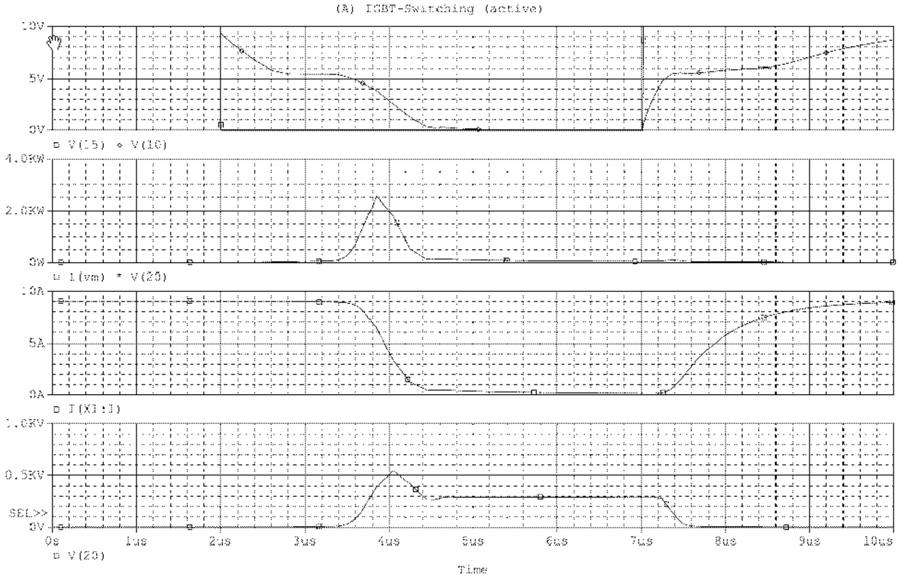


Fig. 7 plots of VGE, Power Loss, IC, and VCE at L= 20 uH and VT= 4.85 V

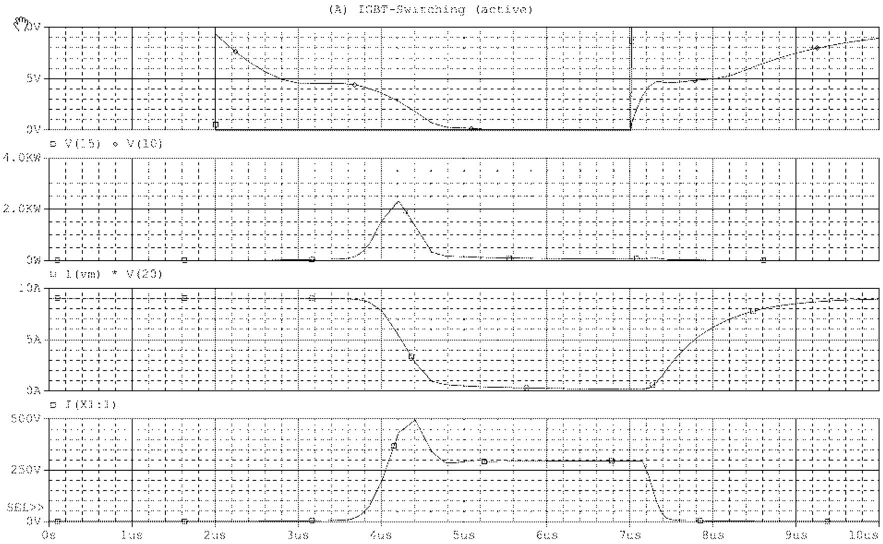


Fig. 8 plots of VGE, Power Loss, IC, and VCE at L= 20 uH and VT= 3 V

As shown in Fig. 7 and 8, as the threshold voltage decreases from 4.85 V to 3 V, the overshoot decreases a little, and the delay time at off-transient is expanded. The power loss remains constant regardless the change of threshold voltage.

4. Conclusions

The IGBT macro-model is implemented, and the electrical characteristics of VGE, VCE, and IC on an IGBT have been simulated for the switching turn-on and turn-off, and the energy loss. It is expected that the results allow engineers to design the related optimal circuits for an IGBT. The motor drive application for switching of IGBTs is to be studied for further research.

References

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