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IGBT FOR MICROWAVE OVEN

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1. FOREWORD

With the change and diversification of eating habits, the microwave oven has become an important cooking tool both in and out of Japan and is becoming quickly popular and its demand is also increasing.

In the past, the microwave oven power supply generated microwaves by double rectification after boosting the commercial cycle voltage with a high voltage transformer and applying a high voltage of 3 to 4kV to a magnetron. However, since this circuit system uses a high voltage transformer to boost the commercial cycle voltage, the high voltage transformer is large and also heavy. Moreover, since the design is different for 50Hz and 60Hz commercial cycle, when used in an area with a different commercial cycle, replacement is necessary. Furthermore, with is circuit system, since the constant output power can only be turned on and off and cannot be adjusted continuously, it could not be applied to a wide range of cooking. Therefore, a method which uses an RF inverter circuit at the primary side circuit of the high voltage power supply was considered to overcome these disadvantages. In the beginning, a bipolar power transistor as used as the RF inverter circuit switching device, but since the bipolar power transistor is a current drive type device, high gate driving power is necessary to operate it at a high frequency and the gate driving circuit had to be complex. Therefore, a IGBT which is a voltage driving device that can operate at a higher frequency than the bipolar power transistor, was developed.

The IGBT is a high performance power device with the low saturation voltage characteristic of the conventional bipolar power transistor and the voltage drive and high speed switching characteristic of the MOSFET. Fuji Electric offers the IGBT for microwave oven and IGBT modules for motor control, UPS, and other equipment.

The IGBT for microwave oven developed and commercialized on this background is introduced.

2. MICROWAVE OVEN RF INVERTER POWER SUPPLY CIRCUIT

2.1 Basic circuit

The RF inverter circuit used at the primary side of the high voltage power supply of a microwave oven uses a voltage resonant circuit like that shown in *Fig. 1*. The voltage resonant circuit consists of an IGBT as the switching device, freewheeling diode connected in parallel with the IGBT, step-up transformer, and resonant capacitor connected in parallel with the step-up transformer. It

Fig. 1 Microwave oven RF inverter power supply circuit

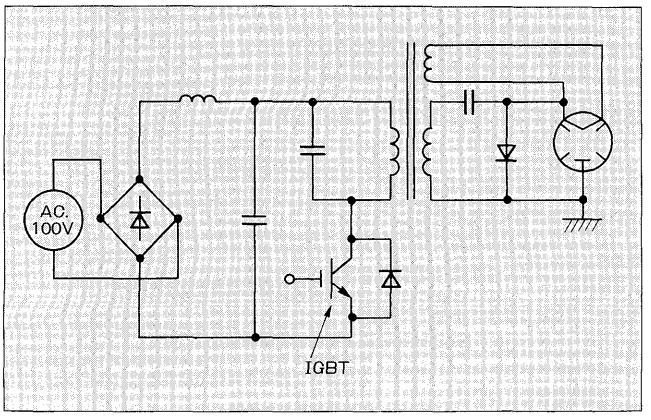
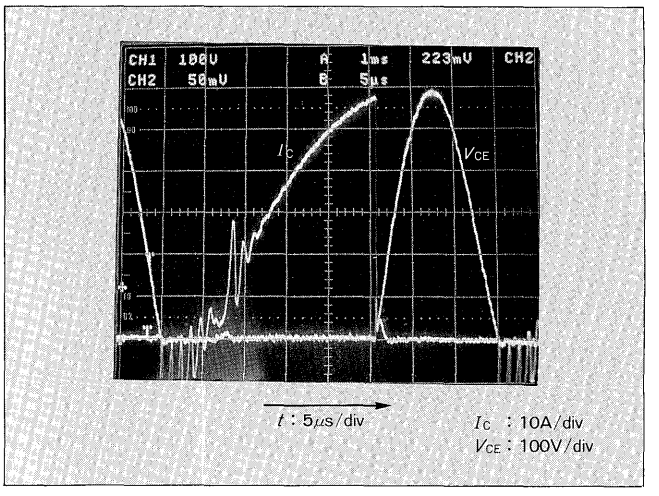


Fig. 2 Operating waveforms of IGBT for microwave oven



operating waveforms are shown in *Fig. 2.* Since the IGBT performs switching by zero voltage when turned on, the switching loss is only the turn off loss and the IGBT loss is reduced and switching at a high frequency is possible by using a voltage resonant circuit like this.

2.2 Advantages of RF inverter

The following advantages are gained by making the high voltage power supply an RF inverter like this.

(1) Smaller and lighter high voltage transformer

The high voltage transformer is about 1/4 lighter and about 3/5 the size of a commercial cycle high voltage transformer, thus reducing the set weight and improving the effective volumetric ratio.

(2) Hertz-free commercial cycle

Can be used at 50Hz or 60Hz commercial cycle.

(3) Stepless and continuous variation of output

The magnetron output can be changed steplessly and continuously and the cooking software is widened.

The following advantage is obtained by using an IGBT:

(4) Miniaturization and simplification of gate driving circuit

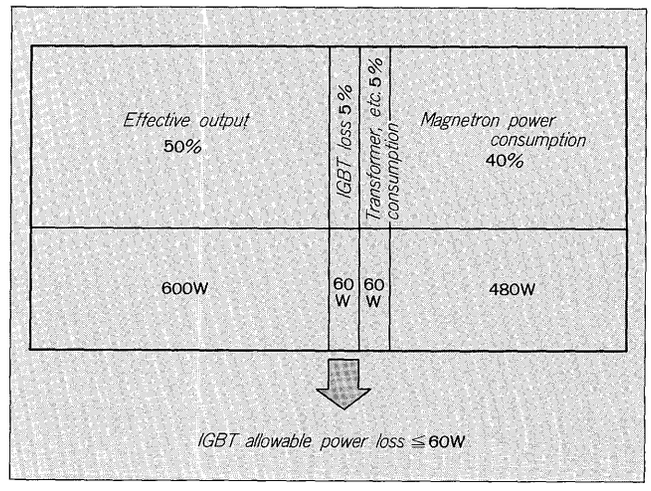
Since the IGBT is a voltage drive type, its driving power is about 1/20 that of the bipolar power transistor and can be driven by 1W or less and the gate driving circuit can be made smaller and simpler.

2.3 Respensibility of IGBT in RF inverter power supply circuit

Generally, biggest problems with switching devices are power loss and ruggedness.

What must be taken into account is that to use an IGBT at the RF inverter power supply circuit, the power loss must not be effectively dropped below than that of the conventional microwave oven. That is, the IGBT power loss must be less than a certain fixed value. Therefore, the loss allowed at the IGBT is found by subtracting the magnetron output, magnetron heater waste of electric power, and transformer waste of electric power from the power input. The various distributions for a 600W microwave oven are shown in *Fig. 3.* From these distributions, the IGBT loss must be less than 60W.

Fig. 3 Output and power consumption distribution for 600W microwave oven



An RF inverter power supply circuit has a latch up strength as the ruggedness demanded of an IGBT for microwave oven. A magnetron is used in a microwave oven. Since a collector current of approximately 200A flows as a resonant capacitor discharge for a pulse width 1.5μs period when the magnetron starts, no latch up for this current is demanded.

3. FUJI IGBT FOR MICROWAVE OVEN

3.1 Description

The IGBT for microwave oven developed this time is shown in *Fig. 4.* Its main characteristics are shown in *Table 1.* The current rating was made 60A for 1.2kW power input, 600W magnetron output and 50A for 1.0kW power input, 500W magnetron output. Because the peak value of the resonant voltage at AC100V input is about 600V, the abnormal voltage generated by power supply voltage changes and abnormal magnetron oscillation was taken into account and the voltage rating was made 900V. The microwave oven IGBT and BJT packages are compared in *Fig. 5.* The packages are TO-3P and TO-3PL. These packages are smaller than that of the BJT.

Table 1 Characteristics of IGBT for microwave oven

Characteristic \ Type	1MB60-090	1MB50-090A	MBT002
V_{CES}	900V	900V	900V
I_C	60A	50A	50A
V_{GES}	±20V	±20V	±20V
	300W	150W	200W
$V_{CE(sat)}$	Standard value 3.5V	Standard value 2.8V	Standard value 2.5V
t_f	Standard value 0.7μs	Standard value 0.6μs	Standard value 0.2μs
$R_{th(j-C)}$	0.41°C/W	0.83°C/W	0.625°C/W
Microwave oven power input	1.2kW	1.0kW	1.2kW
Magnetron output	600W	500W	600W

Fig. 4 IGBT for microwave oven

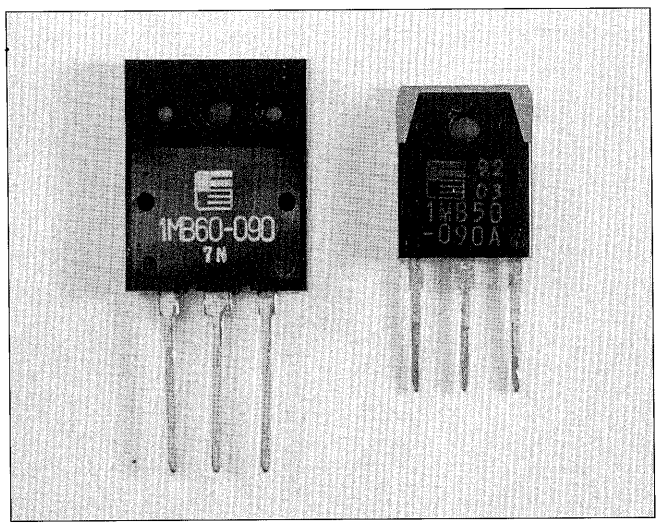


Fig. 5 Comparison of IGBT and BJT packages

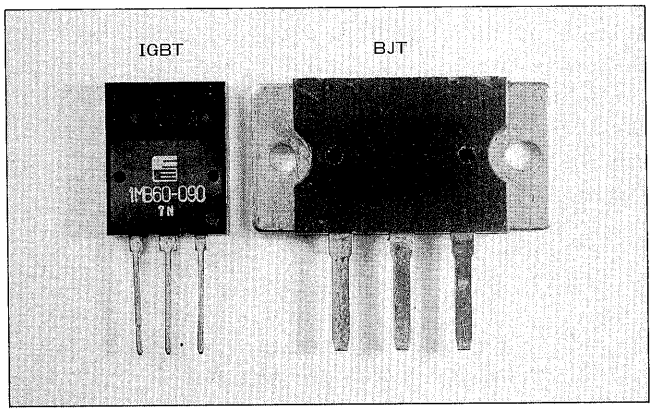
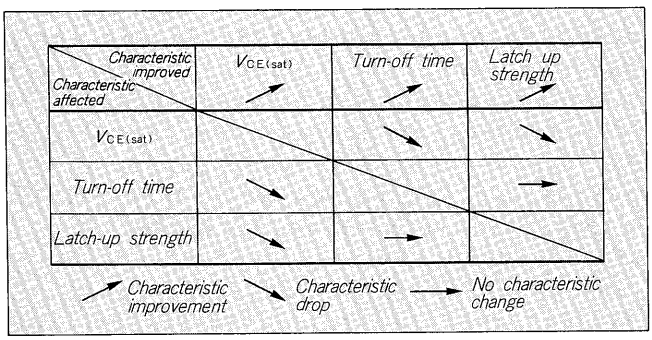


Fig. 6 Tradeoff of characteristics



3.2 Features

As mentioned in *Paragraph 2.1*, the power loss at a voltage resonant circuit should consider the saturation voltage (V_{CEsat}) and turn-off loss. That is, V_{CEsat} and the turn-off time should be reduced. However, V_{CEsat} and the turn-off time have a tradeoff relationship and since these three characteristics, including the latch up strength, have the relationship shown in *Fig. 6*, improving all these characteristics is difficult. The Fuji IGBT for microwave oven was designed to improve the V_{CEsat} and turn-off time tradeoff without lowering the latch up strength by optimizing lifetime control and the dispersion conditions of the channel part.

Fig. 7 Output characteristics of MBT002

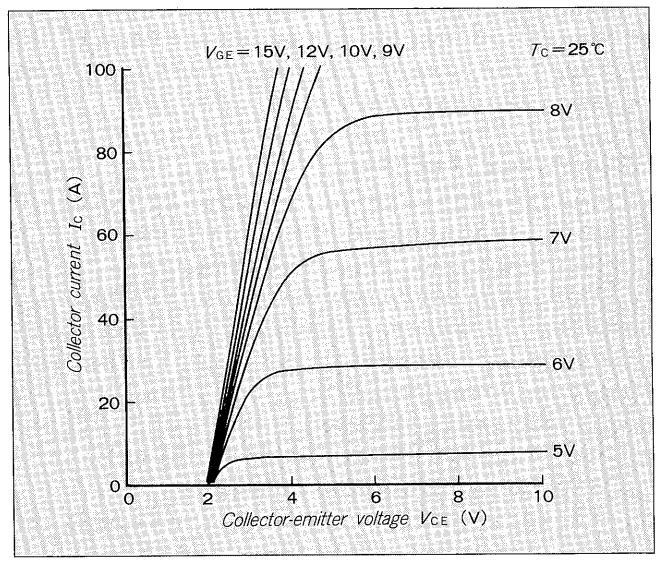


Fig. 8 Switching characteristic of MBT002

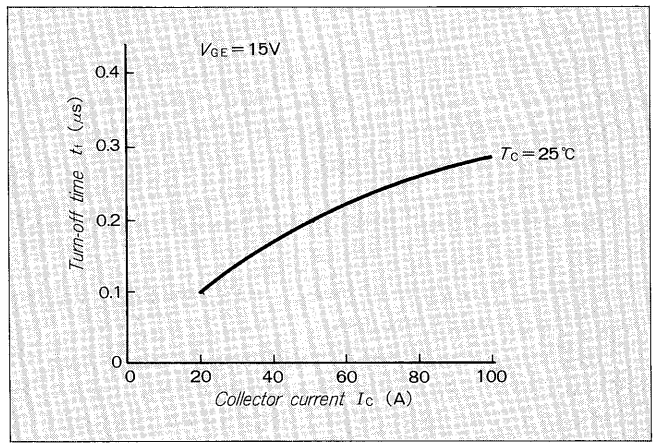
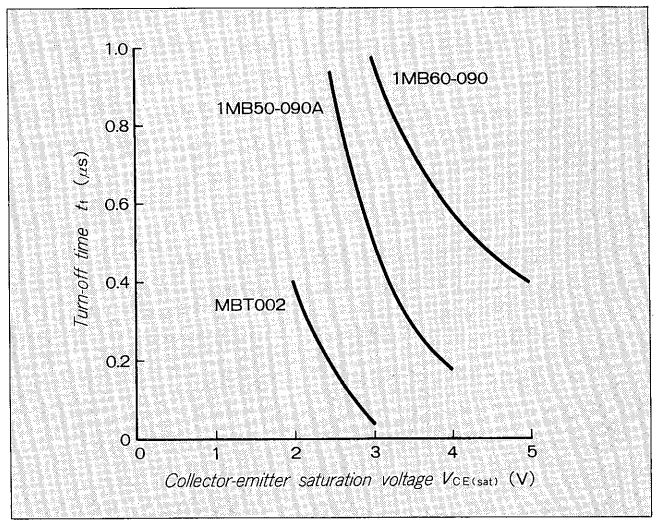


Fig. 9 Improvement of tradeoff of IGBT for microwave oven



From the above, the features of the Fuji IGBT for microwave oven are:

(1) Low saturation voltage (V_{CEsat}).
(2) High-speed switching characteristic.
(3) Since it is a voltage drive type, drive power is low.
(4) Small package.

3.3 Saturation voltage characteristic and switching characteristic

The output characteristics of the MBT002 are shown in *Fig. 7*. A low saturation voltage characteristic is shown even at high current.

The switching characteristic of the MBT002 is shwon in *Fig. 8*. An excellent high-speed switching characteristic is shown despite its low saturation voltage characteristic.

The V_{CEsat} and fall time t_f relationship for each IGBT for microwave oven is shown in *Fig. 9*. The 1MB60–090 developed first is the first generation. The tradeoff was improved and the power loss was also lowered for the second generation 1MB50–090A and third generation MBT002.

4. CONCLUSION

The development aim and features of the Fuji IGBT for microwave oven were introduced above. The RF inverter is making the microwave oven high voltage power supply smaller and more efficient and the effective volumetric ratio of the microwave oven itself is tending to increase. The first of these is compression of the necessary cooling fins by lowering of the power loss of the switching device and the second is considered miniaturization and lightening of the high voltage transformer, etc. by raising of the frequency. To meet these demands, we are pouring our effort into the development of an IGBT with low power loss and faster switching speed.

Finally, the authors express their deep gratitude to our customers and parties concerned for their cooperation in the development of this IGBT for microwave oven and ask for their guide in the future.