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High Performance IGBT for Induction Heating Applications

ON Semiconductor®

APPLICATION NOTE

Abstract

High saturation voltages associated with IGBTs using Non-Punch-Through (NPT) technology are the principal cause of high conduction losses in induction heating applications. These losses, combined with turn-off, and turn-on losses reduce the overall efficiency of IGBTs in these applications.

With Field Stop technology, lower saturation voltages can be achieved, and consequently conduction losses will be reduced. Furthermore, this technology minimizes losses that occur during IGBT turn-off by lowering the concentration of charge carriers left in the drift region. This optimization makes the IGBT ideal for use in induction heating applications.

ON Semiconductor's Field Stop IGBT, optimized for use in soft switching induction heating applications, is being presented in this paper.

Keywords

Induction heating, Field Stop, turn-off switching losses, conduction losses

List of Symbols and Abbreviation

ZVS	Zero Voltage Switching
ZCS	Zero Current Switching
NPT	Non-Punch Through
$V_{CE(sat)}$	Collector Emitter Saturation Voltage
V_{CE}	Collector Emitter Voltage
I_C	Collector Current
E_{off}	Turn-off Losses
D	Duty Cycle
IH	Induction Heating
V_{dc}	Rectified dc Voltage
PT	Punch Through

Introduction

IGBTs used in IH cooking applications dissipate a considerable amount of power especially when the application is operated at high power levels. In order to prevent the IGBT's junction temperature from rising above its recommended specification value, large heat sinks are usually employed.

Using large heat sinks in order to meet the maximum junction temperature requirement adds to the overall cost of production of these IH cookers. The market for induction heating applications will grow tremendously, if production costs can be reduced, and more efficient IH cookers can be developed.

Several parameters are to be considered when optimizing an IGBT. These include physical device properties such as the IGBT's thickness and die size as well as electrical properties such as saturation voltage, blocking voltage, and switching losses. Optimizing any one of these parameters comes at the cost of reducing the performance of another.

Therefore optimal trade-off values for these parameters are necessary in order to achieve the desired improvement in performance.

In this paper, the typical topologies used in IH applications will be presented. Next, the performance of ON Semiconductor's optimized IGBT in a commercially available IH cooker will be evaluated, and compared to that of several competitors.

Typical Topologies for IH Cooker Applications

Figures 1 and 2 show the power stages of the two most common topologies used in IH cooker applications.

In the half-bridge topology of Figure 1, the capacitor C2 functions as a snubber. It regulates the rate of rise of V_{CE} during turn-off, and therefore influences the energy lost during this time. A larger capacitor value causes V_{CE} to rise slowly and results in reduced turned-off energy. The current flowing through IGBT2 and the L_1C_1 resonant circuit is almost sinusoidal. During the positive half of the oscillation, IGBT1 conducts. During the negative half of the oscillation, IGBT2 conducts. The blocking voltage rating of the IGBTs is typically 600 V because they are connected directly to the rectified dc voltage, V_{dc}. Any induced voltage spike will be clamped by the IGBT co-packed diode.
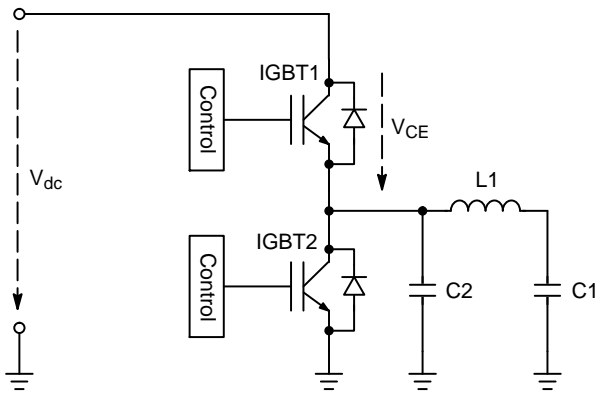
Figure 1. Half-bridge Topology of IH Cooker Power Stage

Figure 2 shows the power stage of a single-ended topology. When the IGBT is turned-on, the current flowing through it and through the inductor rises linearly. When turned-off, the current falls with a fall time governed by the IGBT's parasitic collector-emitter output capacitance. This gives I_C an overall triangular shape. When the L_1C_1 resonant tank oscillates, the voltage across it has a sinusoidal shape. As a result, V_{CE} has a sinusoidal shape at turn-off. The amplitude of the resonant voltage for this topology can be as high as 1000 V. Therefore the blocking voltage for IGBTs used in this topology is typically 1200 V because the collector of the IGBT is connected to the resonant tank.
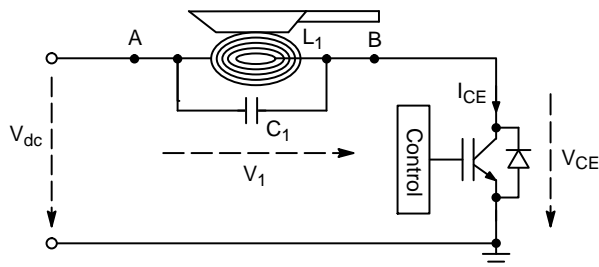

Figure 2. Single-ended Topology of IH Cooker Power Stage

IGBT Performance Evaluation in Single-Ended IH Cooker Applications

The performance of IGBTs used in single-ended IH applications can be evaluated by measuring the amount of power dissipated during operation of the application. Since these applications employ a ZVS technique, conduction and turn-off losses are the most important losses to be considered.

Turn-on losses are negligible, especially at normal and full load conditions because the stored inductive energy in the resonant tank inductor is sufficient enough to swing the voltage at the collector of the IGBT, bringing it to zero or negative. When this happens, the co-packaged diode conducts and the voltage across the IGBT is one diode drop negative. Since power loss is the product of voltage and current, the power lost when the IGBT is turned−on at this time is very small.

In this section, the conduction and turn-off losses of ON Semiconductor's optimized IGBT, the NGTB25N120IHL, will be compared to those of several competitive devices.

The test system used for this performance evaluation is a commercially available IH cooker.

Tables 1 and 2 present a summary of the relevant test system parameters and IGBT switching parameters, respectively. Several representative switching cycles close to the peak of the input line current were used to take measurements. This procedure was repeated for each power level. In order to ensure identical switching cycles were measured for all devices being tested, information about the switching frequency of the IGBT, and the frequency of the input line voltage was used to trigger a digital storage oscilloscope at the specified switching cycle.

Table 1. SUMMARY OF TEST SYSTEM PARAMETERS

Inductor [LC tank] of IH Cooker	112 µH
Capacitor [LC tank] of IH Cooker	0.3 µF
Gate Resistor (NGTB25N120IHL)	15 Ω
Gate Resistor (Competitor Device1)	24 Ω
Gate Resistor (Competitor Device2)	18 Ω
Gate-Emitter Resistor	10 kΩ
Input Line Voltage/Frequency	220 V/60 Hz

Table 2. IGBT SWITCHING PARAMETERS AT DIFFERENT POWER LEVELS

Cooking Power Level (W)	Switching Frequency (kHz)	Duty Cycle (µs)
1000	23.6	17
1300	21.6	21
2000	19.8	24.7

Conduction losses

These losses were computed using the math function utility of a digital storage oscilloscope. For this device performance evaluation, a clamp circuit was used to obtain accurate $V_{CE(sat)}$ measurements. The losses were then measured at different load currents, where the duty cycle varies as a function of the cooking power level as shown in Table 2. Figure 3 compares the $V_{CE(sat)}$ dependence on temperature for different devices. The measurements for Figure 3 were taken at various ambient temperatures using pulsed dc current. Figure 4 shows conduction losses at different IH cooker power levels. These power levels represent different values of the load current, and IGBT duty cycles.
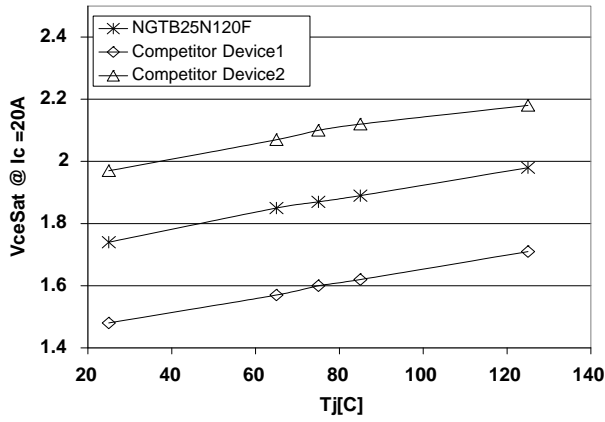
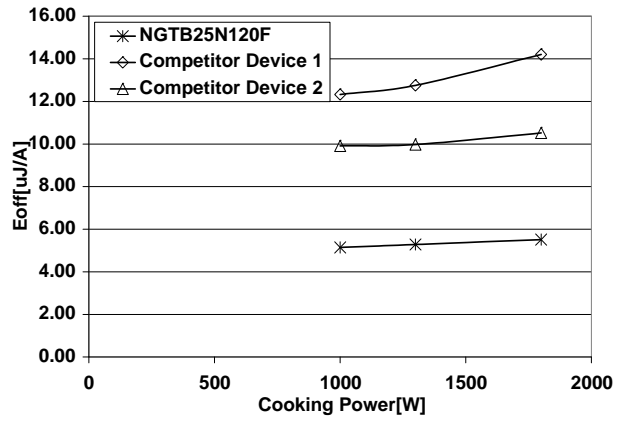**Figure 3. Variation of V$_{CEsat}$ with IGBT Junction Temperature**

Figure 5. Variation of Turn-off losses with Cooking Power
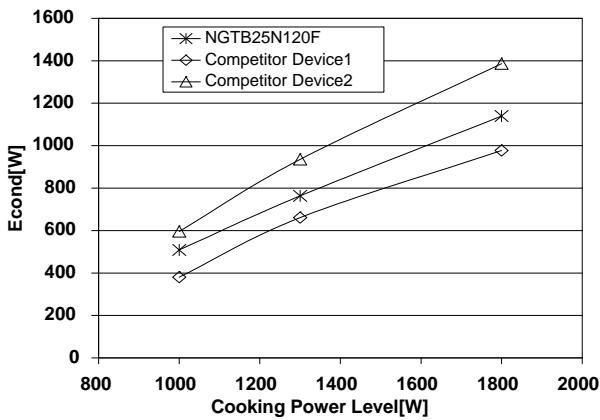

Figure 4. Conduction Losses at Different Cooking Power Levels

Switching Losses

Turn-off power loss is influenced by the rate of decay of the IGBT's residual current.

Figure 5 shows the variation of turn-off losses with IH cooker power for the NGTB25N120IHL and competitor devices 1 and 2. The turn-on time constant of the gate signal was maintained approximately the same for all of the devices by using different values for the gate resistor for each device. E$_{off}$ is normalized using I$_C$ in order to enable direct E$_{off}$ comparison for all the devices.

Total Power Losses

The contribution of turn-on losses to the total power loss becomes significant at light loads. At lights loads, the LC tank inductor does not store enough inductive energy to swing the voltage at the collector of the IGBT before the IGBT is turned-on again. Consequently, the co-packaged diode never conducts and the voltage across the IGBT at turn-on is higher. However, in this evaluation, ZVS was possible at all the power levels used to test the devices. Therefore, the main contributors to the total power loss are conduction and turn-off losses.

Although these measurements were made using selected switching cycles, the validity of the measurements is reflected in the case temperature measurements. A device's temperature rise is proportional to its dissipated power. Therefore, the device with the highest total power loss also has the highest increase in case temperature as represented in Figure 6.
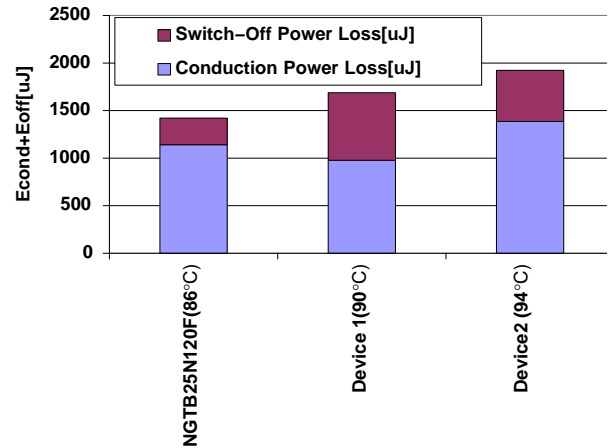

Figure 6. Variation of Total Losses (Conduction and Turn-off) with Case Temperature at 1800 W

Test Results Analysis

The following conclusions can be drawn from Figures 3 to 6:

1. We see from Figures 3, 4 and 6 that, the NGTB25N120IHL's $V_{CE(sat)}$ is slightly higher than that of device 1 but lower than that of device 2 of the competitor. As a result, conduction losses of the NGTB25N120IHL are slightly higher than that of device 1 but lower that that of device 2 from the competitor. Device 2 of the competitor uses NPT technology. Consequently, a higher $V_{CE(sat)}$ value is expected. Device 1 of the competitor uses Shorted-Anode technology which enables lower $V_{CE(sat)}$ values but causes higher turn-off losses at higher temperatures. NGTB25N120IHL's $V_{CE(sat)}$ value represents the optimal trade-off value for minimizing both turn-off, and conduction losses.

2. Figure 5 shows that Device 1 of the competitor has the highest dependence of E_{off} on cooking power level while the NGTB25N120IHL's has the lowest turn-off losses at all power levels. Furthermore, the NGTB25N120IHL has the weakest turn-off power loss dependence on IH cooking power level. This makes it suitable for use in IH applications having a wide range of cooking power levels.

3. We see from Figure 6 that, the percentage of conduction and turn-off losses contributing to the total power loss is different for each device. However, the NGTB25N120IHL has the optimal percentage combination of both types of losses because it has the lowest case temperature of all three devices at the highest cooking power level.

Summary and Conclusions

In single-ended IH applications where ZVS techniques are employed, both conduction and turn-off losses contribute to the total IGBT power loss. The efficiency of IGBTs used in these applications can be improved by designing the IGBT to have optimal trade-off between $V_{CE(sat)}$ and switching speed.

The NGTB25N120IHL has been designed to have these optimal trade-off values, and its performance in a commercially available IH cooker has been verified, and proven to be better than that of competitor devices.