International
IOR Rectifier

# A New SMPS Non Punch Thru IGBT Replaces MOSFET in SMPS High Frequency Application

Richard Francis, Marco Soldano
International Rectifier Corporation
El Segundo, CA, USA

*As presented at APEC 03*

***Abstract*****—** The continuous request from the market for higher power density and lower cost in commercial power supplies has forced semiconductor manufacturer to push device optimization to the limit or to develop new device solutions. Some of the new devices can surely improve performances, but in some cases the price to pay for increased complexity is too high.

The IGBT device has a long history of success in motor drive and inverter applications, where switching frequencies are relatively low compared to SMPS. For this reason the development of new devices has always been driven by different requirements than SMPS ones.

An NPT IGBT family has been developed and optimized targeting specifically SMPS applications. This paper shows the feature of this device in a critical comparison with equivalent products available on the marked today.

***Keywords: Non Punch Through, IGBT, SMPS, tail current, switching losses, current sharing***

## I. INTRODUCTION

Insulated Gate Bipolar Transistors have been available as power switches for more than 20 years now; although largely adopted in motor control and inverter applications, because of the relatively low switching frequency and high current density in those applications, IGBTs found a limited use in SMPS applications, where the trend is a constant increase in switching frequency and power density.

For the same reasons IGBTs manufacturers have focused mainly on developing products tailored on requirements of motion control applications, which in most cases don't meet SMPS needs.

The continuous request from the market for higher power densities seems to lead to a better utilization of silicon. The IGBT seems to meet this requirement providing higher or equivalent current capabilities with smaller die sizes.

A new technology for IGBT manufacturing has emerged in recent years: the use of *ultra-thin wafers* allows to manufacture the so-called Non Punch Through (NPT) IGBT. This paper will present this new product family and propose an in-circuit comparison with equivalent MOSFET solution.

## II. NPT TECHNOLOLGY

Non Punch Through technology is based on the capability to manufacture devices on extremely thin wafers (100µm and below). This technology has found widespread adoption in higher voltage ratings (1200V and above) where requirements for wafer thinning are less stringent.

Today 85µm technology is available and allows developing a broad family of products in the 600V range.

The use of ultra thin wafers allows using a lightly doped collector. This translates in a reduction of stored charge and therefore in better switching performances, especially at high temperatures.

In order to make a conventional Punch-Through device faster, it has to be processed with minority-carriers lifetime killing techniques, such as electron irradiation or metal doping.

One of the side effects of these processes is that the temperature coefficient for $V_{CEsat}$ becomes negative in the operative current conditions: as well known a negative thermal coefficient prevents to easily paralleling devices with natural current sharing.

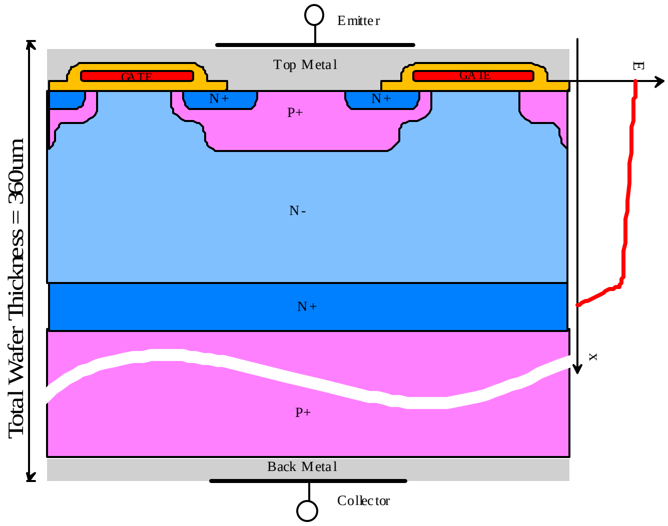

Figure 1 Punch-Through IGBT Structure

Since NPT IGBTs are not processed with lifetime killing techniques they maintain their positive thermal coefficient for

$V_{CEsat}$ allowing easy paralleling. Also the switching characteristics are much less affected at higher temperatures of operation.

On the other hand the thermal coefficient for conduction voltage drop is smaller than equivalent voltage rated MOSFET devices, leading to a more temperature stable operation (Figure 5) compared to MOSFETs.

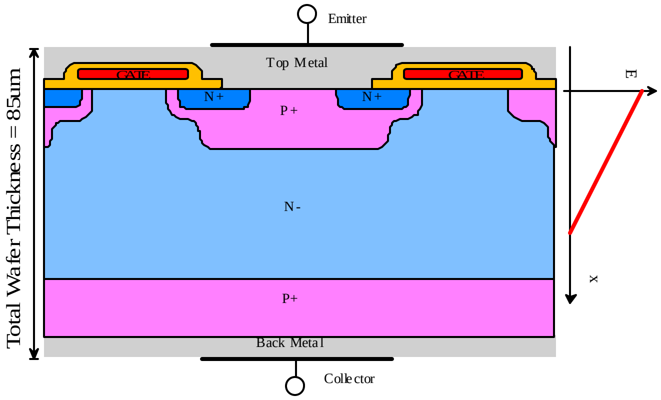

Figure 2 Non Punch Through IGBT Structure

Figure 1 and Figure 2 show a comparison between PT and NPT structures. The main differences reside in the wafer thickness and in the presence of the n+ buffer in the PT structure.

NPT IGBTs are becoming widely adopted in most motor drive applications, mainly because of the improved switching performance compared to conventional PT products. In fact because of the different structure, the shape of the current tail during turn off is significantly different, featuring a much lower current value and overall reducing the turn-off losses.

## III. NPT IGBT DESIGN FOR SMPS APPLICATIONS

The development of a dedicated device for SMPS applications involved major changes in comparison to the standard *"motor drive type"* IGBT.

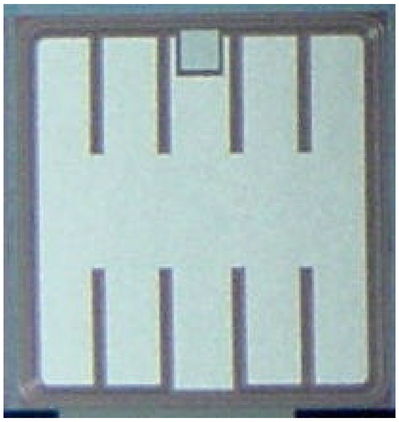

Figure 3 NPT IGBT die layout

The most important is the "short circuit capability" of 10µs, which is generally not required in SMPS applications. This requirement limits the maximum cell density allowable in a given IGBT structure. Relaxation of this requirement allowed to design a higher cell density device and a low polysilicon gate width, which translates in lower on-state voltage drop keeping the same switching performance.

The thickness of the gate oxide can also be reduced consequently [5].

In addition the collector in the SMPS IGBT is even more lightly doped, compared to the equivalent NPT motor drive type reducing the amount of stored charge and therefore amplitude of current tail at turn-off.

Other issues had to be addressed in the new cell design in order to make the transition from MOSFET to IGBT seamlessly.

This includes targeting the threshold voltage to the standard 3÷5V range, minimization of internal gate resistance $R_G$ and optimization of $C_{GC}/C_{GE}$ ratio to increase the dV/dt immunity in hard-switched applications.

## IV. DC PARAMETERS COMPARISON

Comparison between MOS and IGBT can be difficult sometimes because devices are rated in different ways.

MOSFET shows a resistive behavior (and therefore on-state voltage drop increases almost linearly with the current) while the IGBT has threshold like characteristic, where the $V_{CEsat}$ still depends on the current but not linearly.

**Table 1 - Compared devices physical dimensions**

| Device Type | Hex Size | Active Area (mm$^2$) | Die Thickness (µm) | Current Rating (A) |
|---|---|---|---|---|
| N-MOS | 7.3 | 71.55 | 254µm | 40A |
| NPT IGBT | 5.0 | 31.6 | 85µm | 50A |
| PT IGBT | 5.0 | 31.6 | 360µm | 55A |

Therefore the equivalent on resistance for the IGBT ($r_{CEon}$) calculated as voltage drop on forward current, tends to decrease with increasing current, while the $r_{DSon}$ for a MOSFET remains approximately constant: as a result there is a crossover current at which two same current rated devices will have the same voltage drop or equivalent resistance.

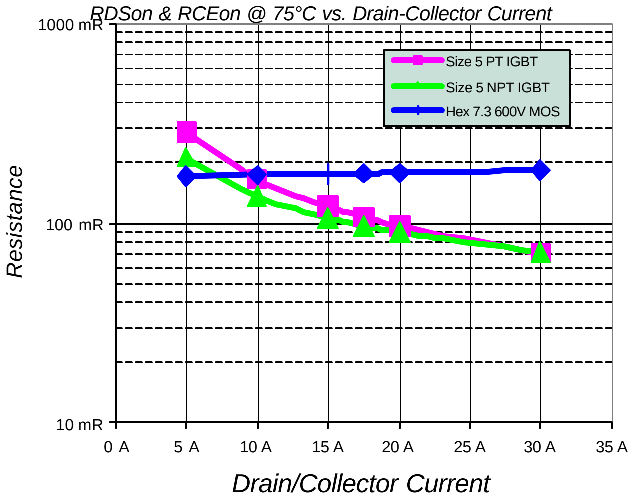

Figure 4 $r_{DSon}$ and $r_{CEon}$ vs. Drain/Collector Current

In a specific case a size 7.3 600V MOS has been compared with an equivalent current rated IGBT (size 5), showing that that value is around 10A for 75°C junction temperature, see Figure 4.

The situation tends to improve for the IGBTs as the temperature increases and the crossover point moves towards lower currents.

It can be noted how the IGBT is a much higher current density device than the MOSFET, allowing a significant reduction in silicon area utilization. As a matter of fact the Hex 7.3 die will require Super-TO247 package while the size 5 IGBTs fits in standard TO247 package, with an additional cost benefit.

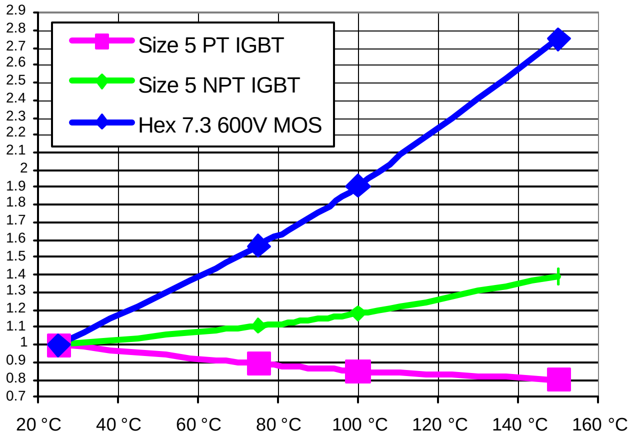

Figure 5 Normalized on-resistance vs. Temperature @ 15A

Figure 5 shows the temperature dependence for normalized on-resistance. Factors of 2 to 3 when temperature rise from 25°C to 150°C are very common for 600V rated MOS. NPT IGBTs show an increase around 30% in the same temperature range.

The significantly lower dependence on temperature for the electrical characteristics make the NPT IGBT a much more stable device than MOSFET, setting a starting point for developing higher temperature rated devices.

## V. IN CIRCUIT TESTING

An in circuit comparison was performed in a conventional 2kW 48V output telecom power supply in the PFC stage at 80kHz switching frequency.

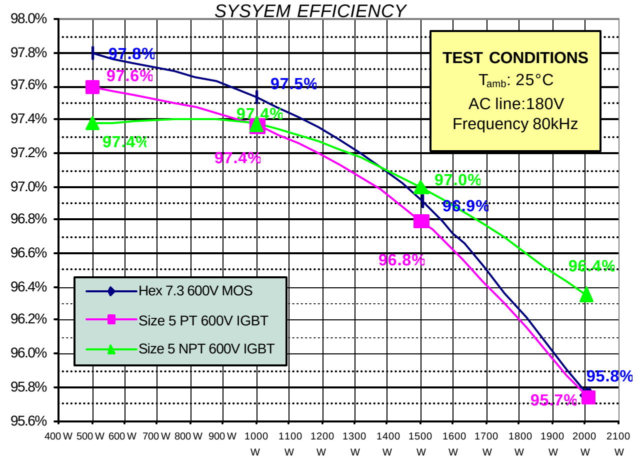

Figure 6 System Efficiency

All tests were performed at room temperature with an AC line voltage of 180V, single phase at 60Hz.

Stage efficiency, power losses and components case temperatures have been monitored and results are shown in Figure 6 and Table 2.

It's worth noting as when the output power increases (and the switch current with it) the NPT IGBT shows the advantage of lower forward drop voltage. The PT IGBT could provide the same advantage, but the performance is affected by the increasingly high switching losses.

In order to equalize the test conditions, the gate driving circuit has been adjusted for each device in order to obtain similar switching conditions.

In fact the MOSFET device, having about double the area than the two IGBTs, required a much higher gate drive current in order to achieve same dV/dt during turn off and dI/dt during turn on.

The turn-off gate drive resistance has been optimized in order to contain the spike over-voltage across the drain/collector within 15% to 20% derating of the $V_{(BR)DSS}$, i.e. in this case around 500V

**Table 2 - Summary Data @ 2kW Output Power**

| PART # | Efficiency | Power Losses | Case Temp. |
|---|---|---|---|
| **Size 5 PT IGBT** | 95.7% | 89.4 W | 69.8 °C |
| **Size 5 NPT IGBT** | 96.4% | 75.7 W | 61.0 °C |
| **Hex 7.3 600V MOS** | 95.8% | 88.9 W | 72.4 °C |

Turn-off waveforms for the three components are shown in Figure 7, Figure 8 and Figure 9.

As can be seen in Figure 9 the PT IGBT shows a very snappy turn-off. This can be minimized at the cost of additional losses (using a turn-off snubber or increasing turn-off gate resistance).

These waveforms have been taken in correspondence of maximum current or peak power level: it can be seen how the PT IGBTs has a considerable tail current that affects switching losses.

For the NPT IGBT the tail current is still present but with a much lower current value.

- Trace 1 is Gate Voltage [BLUE]
- Trace 2 is Drain/Collector Voltage [PURPLE]
- Trace 4 is Drain/Collector Current [GREEN]
- Time scale is 100ns/div for all graphs.

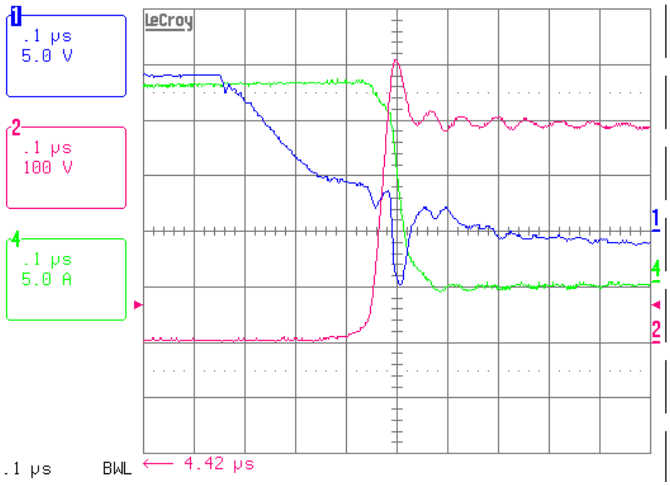

Figure 7 Hex 7.3 600V MOS Turn off

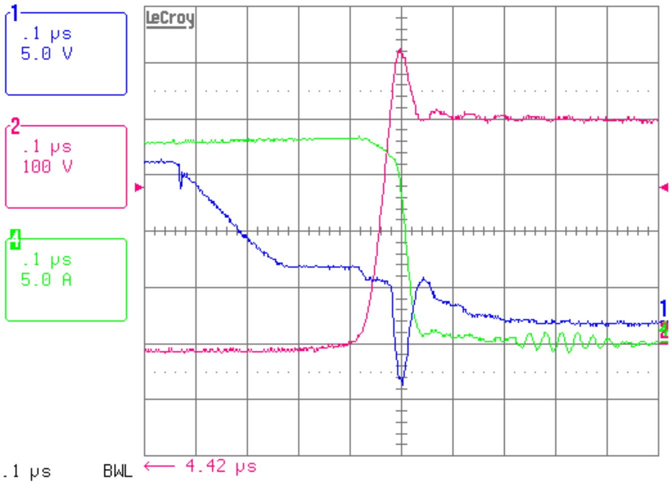

Figure 8 Size 5 NPT SMPS IGBT Turn off

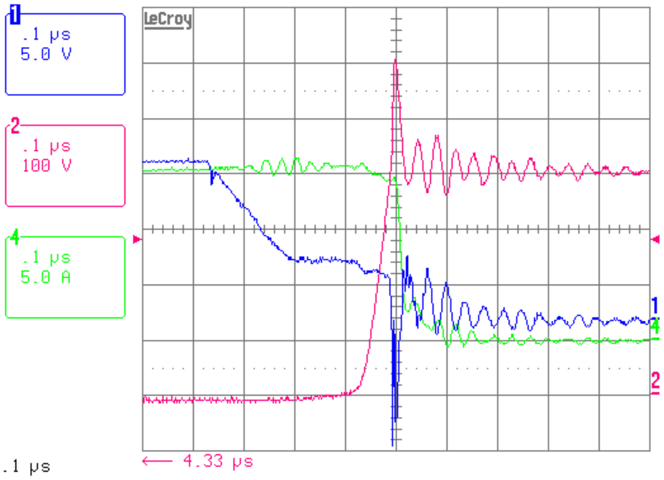

Figure 9 Size 5 PT IGBT turn-off

The energy losses breakdown, measured at the peak power level, is summarized in Figure 10: both IGBTs show a reduction in conduction losses compared to the equivalent industry standard MOS as expected. The peak current is in the range of 18A.

The performance is degraded for the PT IGBT by the high level of turn off losses, due to the current tail.

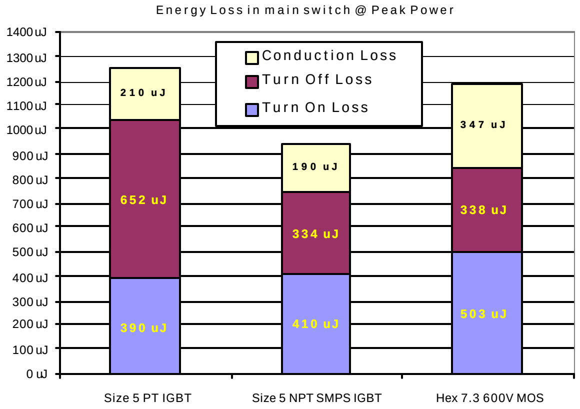

Figure 10 Energy Loss Breakdown in Main Switch

The NPT IGBT shows about the same turn off losses than the Size 7.3 MOS and lower turn-on losses due, possibly, to the smaller die size.

## VI. ADDITIONAL IN CIRCUIT ANALYSIS

Further tests were performed in order to verify the dynamic current sharing capability of the NPT IGBTs.

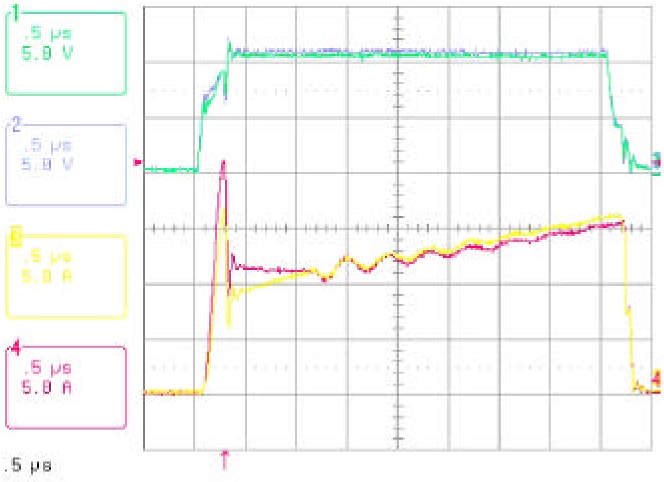

Figure 11 Dynamic current sharing

Two size 5 NPT IGBT devices have been used in parallel in the same PFC function. Devices showed good stability even when a high case temperature difference was present, confirming the good device stability.

## VII. CONCLUSIONS

An optimized NPT IGBT device has been developed targeting specifically SMPS applications. An optimal trade-off between fast switching and low on-state voltage drop has been achieved allowing to match and even improve performances of conventional 600V MOSFETs.

Device performances have been tested and compared versus industry standard 600V MOSFET and PT IGBTs in a typical telecom power supply PFC application.

The NPT IGBTs require a lower cost starting material (25% to 40% lower cost) and at the same time make much better utilization of silicon area.

In the specific case of a 50A rated device, it will fit a standard TO247 compared to the more expensive STO247 required by the equivalent MOS, therefore providing a much more cost effective solution without degradation of performances.

Future reductions in silicon wafer thickness and improved thin wafer handling techniques will allow further improvement in cost and performance for this family of silicon devices.

## REFERENCES

[1] G.Miller, J.Sack, “A new concept for a non punch through IGBT with MOSFET like switching characteristics”. - Power Electronics Specialists Conference, 1989. PESC '89 Record., 20th Annual IEEE , 1989 Page(s): 21 -25 vol.1

[2] “Ultra thin-wafer technology for a new 600 V-NPT-IGBT” Laska, T.; Matschitsch, M.; Scholz, W. Power Semiconductor Devices and IC's, 1997. ISPSD '97., 1997 IEEE International Symposium on , 1997 Page(s): 361 –364

[3] International Rectifiers IRG4PC50W, IRGP50B60WD1 and IRFPS40N60K Data Sheets.

[4] Switching characteristics of NPT- and PT-IGBTs under zero-voltage switching conditions Byeong-Mun Song; Huibin Zhu; Jih-Sheng Lai; Hefner, A.R., Jr. Industry Applications Conference, 1999. Thirty-Fourth IAS Annual Meeting. Conference Record of the 1999 IEEE , Volume: 1 , 1999 Page(s): 722 -728 vol.1.

[5] B.J. Baliga, “ Power Semiconductor Devices”, PWS, 1995

[6] Cotorogea, M.; Claudio, A.; Aguayo, J. “Detailed analysis of different short-circuit conditions for nonpunch-through IGBTs” - Power Electronics Congress, 2000. CIEP 2000. VII IEEE International , 2000

[7] International Rectifiers AN-941 “Paralleling Power Mosfets”

Rev.1.3 – 03/19/2003