Thermal Dependence of E_{off} (V_{ceon}) trade-off performance for TIGBT with Localized Lifetime Control

Radim Pechal, Ladislav Šeliga, Juraj Vavro, Tomáš Bordovský, Adam Kozelský, Adam Klimsza,
Corporate R&D
ON Semiconductor,
Rožnov pod Radhoštěm, Czech Republic

Abstract

Trench insulated gate bipolar transistor (TIGBT) is typically used for high power applications. Power efficiency, which depends mainly on turn-off power losses E_{off} and on-state voltage drop V_{ceon}, is key parameter for those applications. One of the ways to improve E_{off} (V_{ceon}) trade-off performance is localized lifetime control (LLC), which can be realized by helium implantation. TIGBT samples with LLC were manufactured. The impact of LLC on E_{off} (V_{ceon}) performance was more significant at higher temperature (398 K) than at room temperature (298 K). This paper is focused on a description and an explanation how the E_{off} (V_{ceon}) performance for TIGBT with LLC depends on temperature, compared to a standard TIGBT.

Keywords: TIGBT, lifetime control, helium implantation, thermal dependence

I. INTRODUCTION

Trench insulated gate bipolar transistor (TIGBT) is a semiconductor device, which is typically used as an electronic switch in various high power applications. One of the most important parameter for those applications is power efficiency. This parameter depends on turn-off power losses E_{off} and on-state voltage drop V_{ceon} [1]. One of the ways to improve E_{off} (V_{ceon}) trade-off performance is a localized lifetime control (LLC), which can be realized by a helium implantation into a field stop layer. The TIGBT structure with the area affected by the helium implantation is in Fig. 1.

The helium implantation technique for better E_{off} (V_{ceon}) performance has been already described in literature [2], [3], [4]. The benefit of LLC could be affected by operation temperature T. This effect has not been discussed in literature yet.

Fig. 1: TIGBT active cell with LLC area generated by helium implantation at field stop layer.

II. EXPERIMENT

Three TIGBT devices have been used for an experiment:

- *Fast TIGBT*: 1200 V, 40 A, Fast UltraFS TIGBT [5]
- *Low Vceon TIGBT*: 1200 V, 40 A, Low Vceon UltraFS TIGBT [6]
- *TIGBT with LLC*: 1200 V, 40 A, UltraFS TIGBT with helium LLC

On-state voltage drop V_{ceon} (collector current I_c = 40 A) and turn-off power losses E_{off} (gate voltage V_{gate} = 15 V → 0 V, collector current i_c ($t=0$) = I_c = 40 A → 0 A, collector voltage v_c ($t=0$) = 0 V → V_c = 600 V) have been measured for each devices at room temperature (298 K) and higher operation temperature (398 K). E_{off} was calculated by following formula:

$$E_{off} = \int_{t1}^{t2} i_c(t) \cdot v_c(t)\, dt \,, \qquad (1)$$

$$v_c(t_1) = 0.1 \cdot V_c,\; i_c(t_2) = 0.05 \cdot I_c \,.$$

The measured profiles of $i_c(t)$ and $v_c(t)$ are in Fig. 2 and the E_{off} (V_{ceon}) trade-off chart is in fig 3.

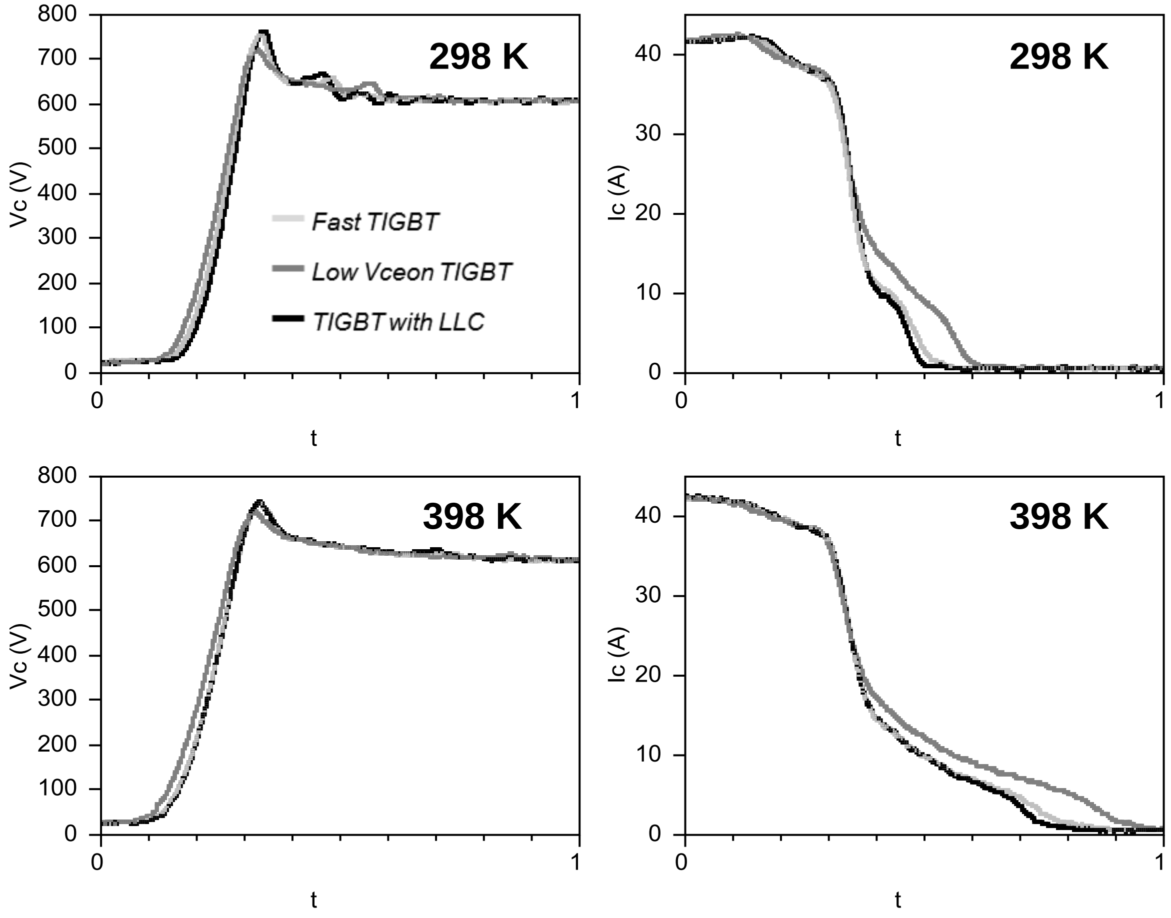

Fig. 2: Switching waveforms during turn-off for 298 K and for 398 K (real measurement data).

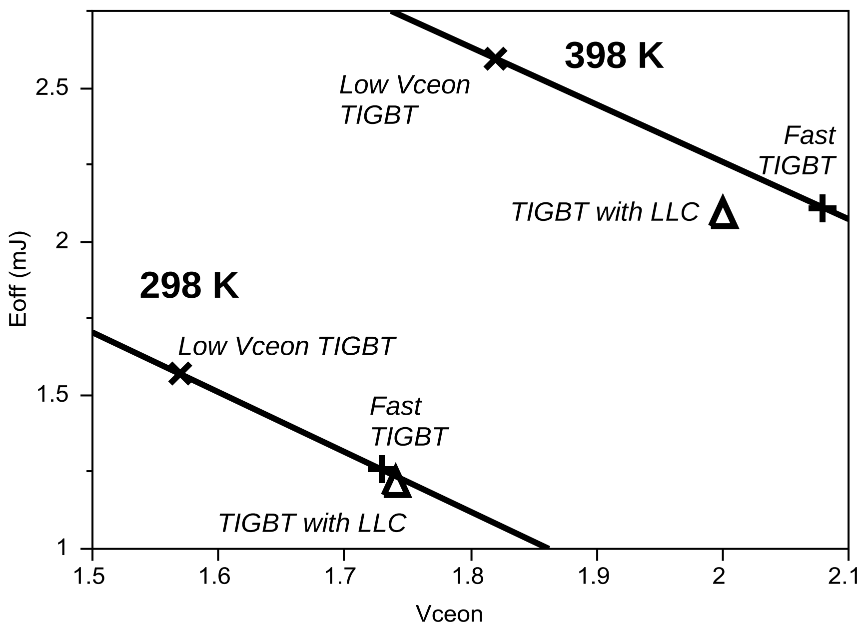

Fig. 3: E_{off} (V_{ceon}) trade-off chart for *Low Vceon TIGBT, Fast TIGBT* and *TIGBT with LLC* for 298 K and for 398 K (real measurement data). All three devices were manufactured with an identical active cell and field stop. *Low Vceon TIGBT* and *TIGBT with LLC* were processed with the same collector dose. *Fast TIGBT* was processed with a lower collector dose.

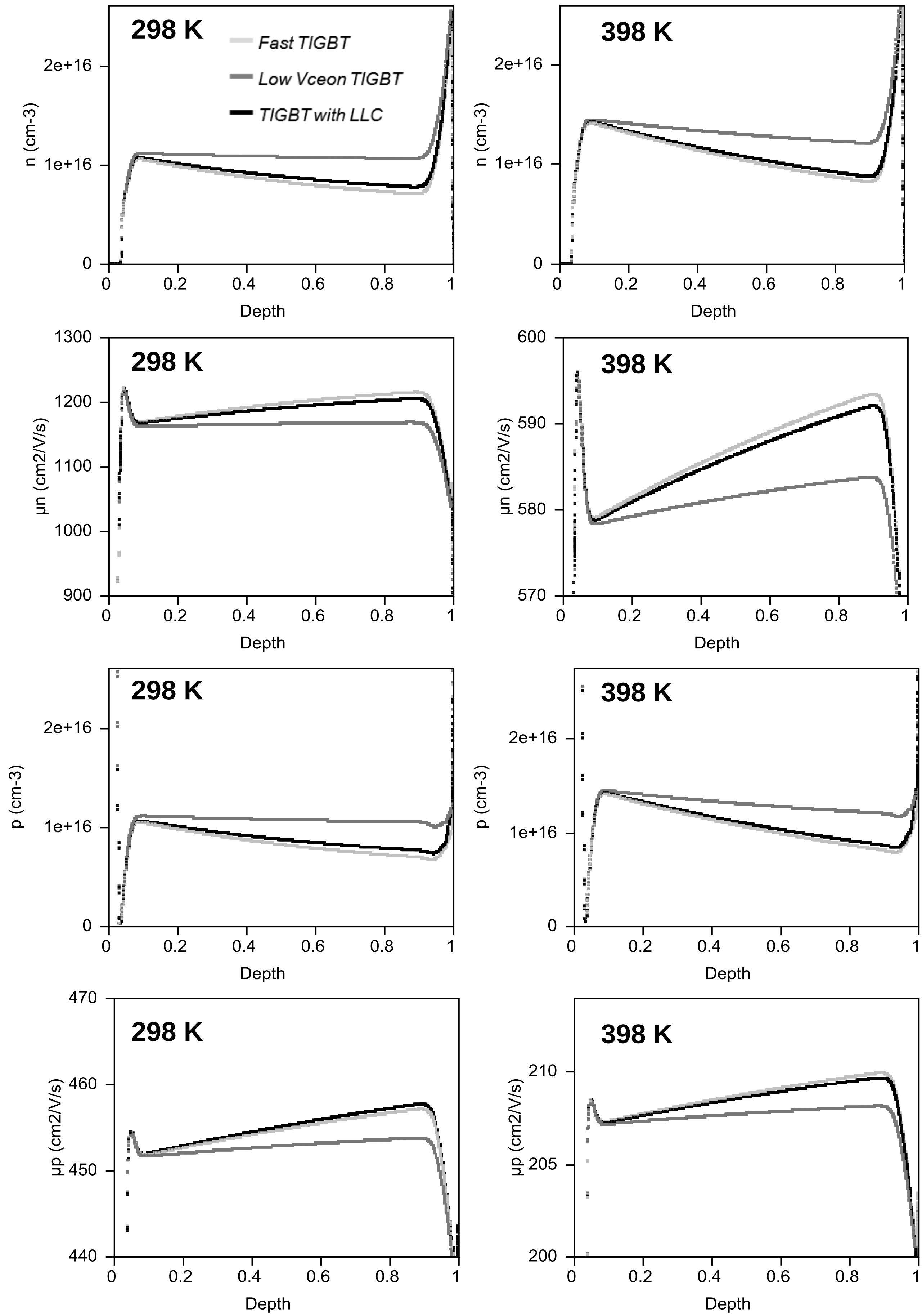

Fig. 4: n, p, μ_n, μ_p profiles for three types of TIGBTs (TCAD simulation).

III. EFFECT OF LOCALIZED LIFETIME CONTROL

V_{ceon} can be calculated by

$$V_{ceon} = \frac{1}{I_c} \int_0^{Wfrthk} \frac{1}{e\left(n(x)\cdot\mu_n(x) + p(x)\cdot\mu_p(x)\right)} dx,$$

where I_c is the current during turn-on, *Wfrthk* is wafer thickness, *e* is the elementary charge, $n(x)$ is electron concentration, $p(x)$ is the hole concentration, $\mu_n(x)$ is electron mobility and $\mu_p(x)$ is hole mobility profiles during turn-on. One possibility how the $n(x)$ and $p(x)$ could be affected is a back-side injection which is driven by the collector dose (compare the *Fast TIGBT* with lower collector dose and the *Low Vceon TIGBT* with higher collector dose in Fig. 3).

The helium implantation is used for defects generation. Those defects bring additional levels into the bang gap [7]. By a right annealing process a level close to the middle of the bang gap could be activated. It causes decreasing of a carrier lifetime and decreasing of $n(x)$, $p(x)$ concentrations. Due to the decreasing of the carrier concentration the V_{ceon} is increased. It could be compensated by increasing of the collector dose concentration (compare the *Fast TIGBT* with lower collector dose and *TIGBT with LLC*, which has higher boron concentration, in Fig. 3). The electron and hole concentration profiles and mobility profiles were simulated by Sentaurus TCAD (see Fig. 4). Simulation is based on the models for the TIGBTs in Fig. 3.

E_{off} is calculated by (1). During the turn-off the TIGBT is depleted and the electrons and the holes are recombined. $i_c(t)$ depends on the carrier lifetime and on $n(X)$, $p(X)$, $\mu_n(X)$, $\mu_p(X)$, where X is position of depletion region. For *TIGBT with LLC* the carrier lifetime is lower in the area affected by helium implantation. Even the $n(X)$ and $p(X)$ are higher for *TIGBT with LLC* than for *Fast TIGBT* the E_{off} is lower (or comparable).

IV. TEMPERATURE DEPENDENCE

The *TIGBT with LLC* has similar E_{off} and V_{ceon} like the *Fast TIGBT* for 298 K. For 398 K the *TIGBT with LLC* E_{off} is comparable with the *Fast TIGBT* but V_{ceon} is higher for *Fast TIGBT* than for *TIGBT with LLC* (see Fig. 3).

The *TIGBT with LLC* has similar profiles like the *Fast TIGBT* for 298 K, but the electron and the hole concentrations are higher for 398 K (the *TIGBT with LLC* V_{ceon} is lower than the *Fast TIGBT* V_{ceon} – see Fig. 3). The bipolar current tail is decreased for the *TIGBT with LLC* even though the electron concentration and the hole concentration are higher concentration than for the *Fast TIGBT*. The recombination is most significant in the area affected by the LLC. The recombination is running until the area is depleted. For higher temperature the recombination is more significant and is running for a longer time. The longer depletion is caused by a lower electron and hole mobility.

CONCLUSIONS

TIGBT with localized lifetime control realized by damage induced by helium implantation has been prepared. Better E_{off} (V_{ceon}) was observed according to literature. Effect of the LLC was significant for higher temperature (398 K). Effect at room temperature was negligible. This phenomena could be explained by electron and hole concentrations and turn-off switching waveforms. Due to higher carrier concentration the lifetime is more significant for higher temperature and bi-polar current tail could be reduced significantly.

ACKNOWLEDGEMENTS

This work has been partially supported by TH03010006 grant awarded by the Technology Agency of the Czech Republic.

REFERENCES

[1] Baliga, B. J: *The IGBT device: physics, design and applications of the insulated gate bipolar transistor*, William Andrew, 2015.

[2] Akiyama, H., Harada, M., Kondoh, H., and Akasaka, Y.: *Partial lifetime control in IGBT by helium irradiation through mask patterns,* Power Semiconductor Devices and ICs, 1991. ISPSD'91., Proceedings of the 3rd International Symposium, IEEE, 1991.

[3] Konishi, Y., Onishi, Y., Momota, S., and Sakurai, K.: *Optimized local lifetime control for the superior IGBTs*. Power Semiconductor Devices and ICs, 1996. ISPSD'96 Proceedings., 8th International Symposium, IEEE, 1996.

[4] Saggio, M., Raineri, V., Letor, R., and Frisina, F.: *Innovative localized lifetime control in high-speed IGBTs,* IEEE Electron Device Letters, 18(7), 333-335, 1997.

[5] *NGTB40N120FL3: Ultra Field Stop IGBT -1200V 40A,* http://www.onsemi.com/pub/Collateral/NGTB40N120FL3W-D.PDF, October, 2017 − Rev. 3

[6] *NGTB40N120L3: Ultra Field stop IGBT - 1200V 40A, Low VCEsat,* http://www.onsemi.com/pub/Collateral/NGTB40N120L3W-D.PDF, February, 2018 − Rev. 2

[7] Siemieniec, R., Niedernostheide, F. J., Schulze, F. J., Südkamp, W., Kellner-Werdehausen, I., and Lutz, J.: *Irradiation-induced deep levels in silicon*. In High Purity Silicon VIII: Proceedings of the International Symposium, The Electrochemical Society, 2004.

Addresses of the authors

Radim Pechal, 1. máje 2230, 756 61 Rožnov pod Radhoštěm, Czech Republic, radim.pechal@onsemi.com

Ladislav Šeliga, 1. máje 2230, 756 61 Rožnov pod Radhoštěm, Czech Republic, ladislav.seliga@onsemi.com

Juraj Vavro, Vrbovská Cesta 2617/102, 921 01 Piešťany, Slovakia, juraj.vavro@onsemi.com

Tomáš Bordovský, 1. máje 2594, 756 61 Rožnov pod Radhoštěm, Czech Republic, tomas.bordovsky@onsemi.com

Adam Kozelský, 1. máje 2230, 756 61 Rožnov pod Radhoštěm, Czech Republic, adam.kozelsky@onsemi.com

Adam Klimsza, 1. máje 2230, 756 61 Rožnov pod Radhoštěm, Czech Republic, adam.klimsza@onsemi.com