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Base Doping Profile Investigation in to Transient base Charge Modeling of IGBT

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Base Doping Profile Investigation in to Transient base Charge Modeling of IGBT

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Abstract- The study of doping concentration in the carrier storage region of IGBT is considered desirable in many power converter applications. This Letter presents base doping profile estimation through investigation into transient base charge modeling of Non-punch through (NPT) Insulated Gate Bipolar Transistor (IGBT). Parabolic profile has been used for base carrier concentration which consequently leads to an analytical model for transient base charge decay of IGBT. The proposed model shows better consistency compared to the previously used linear model in all doping profiles. Finally, the implications of doping dependence on the base charge decay are explained, including implementation of doping profile estimation technique.

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I. INTRODUCTION

Since its invention in 1979 [1], IGBT has been considered a preferred switching device in power electronic systems and significantly improved the quality of life of people. Specially 90% of low voltage products (600V to 1700V) are being occupied by IGBTs. Compared to the first and second generation of NPT IGBTs, the device performance using latest thin film technology has been improved by introducing various doping concentrations in the Carrier Storage Region (CSR), specially known as SPT technology [2] or field stop concept [3]. The advantages of the first two generations have been combined by this technology, resulting in evolution of further generations [4-6]. Different doping profiles have significant effects on the base charge distribution of NPT IGBTs, which can be thoroughly studied by proper estimation of doping concentration in the effective base region (CSR) of IGBT. In recent times, high doping profile has been considered as a matter of concern in the steady-state and transient operation of IGBT. However, with the modern IGBT structure having highly doped CSR, a MOSFET-like behaviour has been seen at low collector-emitter voltage when the gate is fully turned on [7]. Actually increasing the base doping concentration can reduce the on-state loss while maintaining the desirable blocking voltage. But too high doping may affect the injection efficiency of p-emitter and result in some undesirable effects [8], which need to be avoided. This has caused considerable interest in modeling of base doping profile

in DC linked type circuits [9] as well as motor drive applications [10]. However, the accurate and effective study of IGBT requires proper modeling of doping profiles in the CSR with systematic estimation technique. This paper introduces the idea of doping profile modeling in the base through investigation into the transient characteristics of IGBTs. The steady state minority carrier concentration is proposed through a parabolic profile [11]. Using this profile, an analytical model is derived for explaining transient base charge decay during turn-off. Fourth order Runge-Kutta (RK4) method is used to validate the model over a wide range of doping concentration. Finally being consistent with the practical results, base doping profile is investigated through turn-off base charge distribution on different time instances.

II. TURNING OF OPERATION OF IGBT

During the turn-off operation of IGBT the gate voltage is kept less than the threshold voltage. It is assumed that the anode voltage is kept constant during the current decay, but it may be different from the anode voltage of the steady state. Fig. 1 shows the cross section schematic of IGBT half cell and Fig. 2 shows the schematic diagram of excess minority carrier distribution for two doping profiles, Low-doped Base (LDB) and High-doped Base (HDB). The figure shows charge distribution for immediately before (steady state) and after the channel current has been removed. It can be seen that the minority carrier holes decreases quickly to zero after switching in case of LDB, resulting in a large depletion region. This causes the effective base width (W) smaller than the ambipolar diffusion length (L). On the other hand, the HDB causes the carrier reduction much slower after turn-off, causing a smaller depletion region. In this case the effective base width is not very small compared to the total base width (WB), resulting in W being comparable or even larger than L. So the transient operation is very much dependent on the base doping profile.

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$$\frac{dQ(t)}{dt} = -\frac{Q(t)}{\tau_{HL}} - I_n(0) \dots\dots\dots(4)$$

Using the quasi-equilibrium simplification and assuming high-level injection of the holes into the base, an expression for transient base charge decay is found

$$\frac{dQ(t)}{dt} = -\frac{Q(t)}{\tau_{HL}} - \frac{Q(t)^2}{q^2 A^2 \left(\frac{W(t)}{2} - \frac{W(t)^3}{24L^2} \right)^2 n_i^2} \dots\dots(5)$$

where I_{sne} is the emitter electron saturation current and τ_{HL} is high level excess carrier lifetime.

For $W < L$, the equation is reduced to the exact form reported in [12]. Fourth order Runge-Kutta (RK4) method is later used to plot Q vs t graph to validate the

expression numerically with the practical data. Eventually the expression instigates the idea of Base Doping Profile estimation at several time instances.

IV. RESULT AND DISCUSSION FOR TRANSIENT MODELING

Fig. 3, Fig. 4 and Fig. 5 show the simulation results of the parabolic approximation taken in this proposal. Here effective base width (W) is considered to be 4.2×10^{-3} cm. The results are compared to those of experimental data and linear forms used in [12]. Simulations are shown for three cases:

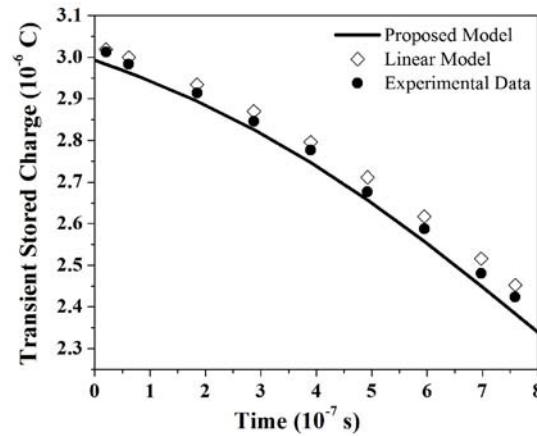


Fig 3 : Transient base charge decay with time for Low doping concentration ($N_B = 0.7 \times 10^{14} \text{ cm}^{-3}$)

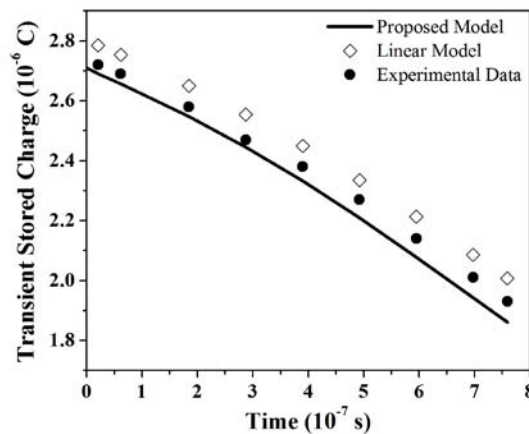


Fig. 4 : Transient base charge decay with time for Moderate doping concentration ($N_B = 2 \times 10^{14} \text{ cm}^{-3}$)

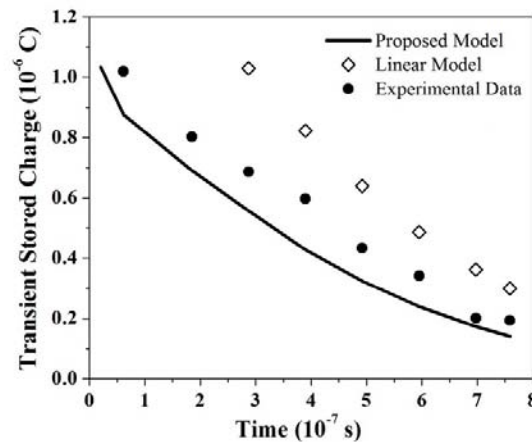


Fig. 5 : Transient base charge decay with time for High doping concentration ($N_B = 3.5 \times 10^{14} \text{ cm}^{-3}$)

a) Case: Low Doping Profile

The case of $N_B = 0.7 \times 10^{14} \text{ cm}^{-3}$ is shown in Fig. 3, which explains the case of high carrier lifetime as well as low doping profile. Both the proposed model and linear model are in good agreement with the experimental data. This follows from the fact that during turn-off operation, a large number of charges fail to recombine resulting lower rate of charge decay in the base. Both the parabolic and linear expression depict this buildup correctly.

b) Case: Moderate Doping Profile

In case of $N_B = 2 \times 10^{14} \text{ cm}^{-3}$, the doping concentration is neither high nor low. From Fig. 4, it is seen that the traditional model shows some deviation with the experimental data, while the proposed model shows better consistency. This is due to the fact that when doping in base is neither high nor low, only some of the charge carriers are able to reach the collector base junction due to significant recombination during turn-off. This results in comparatively higher rate of decay in the transient base charge. The proposed model is able to account for this effect correctly but the linear model fails to do so.

c) Case: High Doping Profile

Fig. 5 shows the case of high doping profile, where N_B is considered to be $3.5 \times 10^{14} \text{ cm}^{-3}$. The parabolic model maintains good consistency with the practical data, while the linear model continues to show deviation as the assumption it is based upon, no longer holds true in case of high doping profile. Base doping being high causes higher rate of charge recombination during turn-off, resulting in conduction of charge approximately to zero. Once again, the proposed model is able to predict this phenomenon, while the linear model falls short.

Different doping profiles considered in Fig. 3, Fig. 4 and Fig. 5 have been shown in tabular form in

Table I in terms of Transient base charge values extracted from the graphs on different time instances, which clearly shows the consistency of the proposed model with practical data. The traditional model provides good results in case of low doping profile only, where proposed model validates the experimental observation in all doping concentrations.

V. INVESTIGATION IN TO BASE DOPING PROFILE

From the following discussion, it is evident that the proposed model shows better consistency with the experimental observations than the traditional linear model. Through this, an opportunity has been created for investigating doping profiles in the Carrier Storage Region (CSR) using dQ/dt dependence of IGBT. Base doping concentrations can be thoroughly estimated through investigation into transient base charge profile on specific time instance. Here the model is analyzed for two time instances; $0.1 \mu\text{s}$ and $0.8 \mu\text{s}$.

Fig. 6 and Fig. 7 show the modeled dependence of base charge decay on base doping profiles at time instance of $0.1 \mu\text{s}$ and $0.8 \mu\text{s}$ accordingly. It can be clearly seen that the proposed model predicts nearly same as the linear one in case of low transient charge, but deviates significantly when charge decays from a higher value. In case of LDB, emitter-base junction current (I_n) depends on the variation of W compared to L . But when doping is considerably high, W becomes insignificant respective to L which causes the prediction of the two models nearly same, which has been shown in Table II.

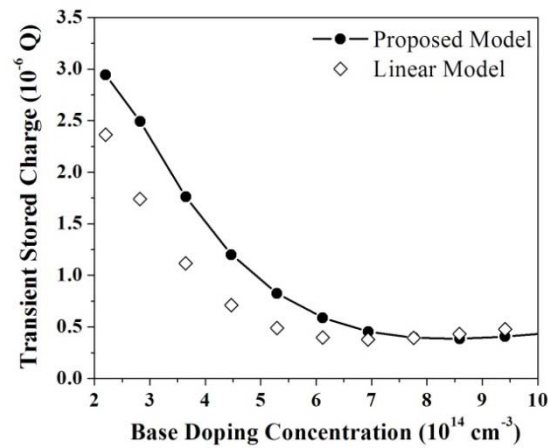


Fig 6 : Modeled dependence of transient base charge on doping concentration at time instance of 0.1 μ s

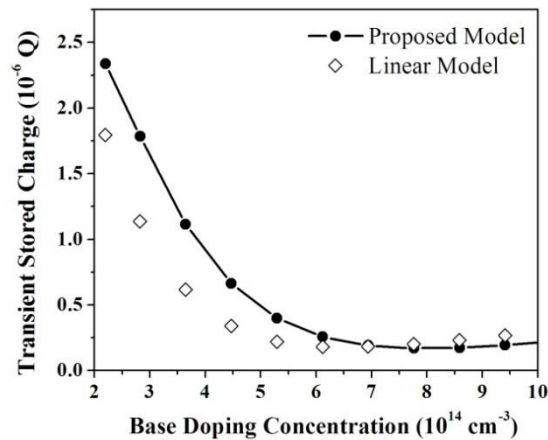


Fig. 7 : Modeled dependence of transient base charge on doping concentration at time instance of 0.8 μ s

VI. CONCLUSION

After review and comparison with the experimental data and linear profiles, a parabolic model is introduced in this Letter to derive the transient base charge decay of NPT IGBT. Better consistency has been

shown through this modeling with practical observations in all base doping profiles. The consequence of this doping dependency is then incorporated in the transient stored charge vs doping profile which is used as a means of base doping concentration estimation.

Table I : Data Analysis of Transient base Decay In Different Doping Concentrations

Base Doping Concentration (10^{14} cm^{-3})	Time (10^{-7} s)	Transient Base Charge (10^{-6} C)		
		Experimental	Proposed	Linear
Low (0.7)	0.2	3.01	2.99	3.02
	2.0	2.91	2.89	2.93
	4.0	2.78	2.75	2.80
	6.0	2.59	2.56	2.62
	7.5	2.42	2.34	2.45
Moderate (2)	0.2	2.72	2.69	2.79
	2.0	2.58	2.55	2.65
	4.0	2.38	2.33	2.45
	6.0	2.14	2.08	2.21
	7.5	1.93	1.86	2.01
High (3.5)	0.2	1.24	1.20	1.66
	2.0	0.81	0.69	1.25
	4.0	0.59	0.42	0.82
	6.0	0.34	0.24	0.48
	7.5	0.19	0.14	0.30

Table II : Estimation of base Doping Concentration

Time Instance (μ s)	Transient Charge (10^{-6} C)	Base Doping Concentration (10^{14}cm^{-3})	
		Proposed	Linear
0.1	2.5	2.8099	2.0853
	2	3.3783	2.4973
	1.5	4.0035	3.1936
	1	4.8845	3.9609
	0.5	6.6892	6.3108
0.8	2	2.5950	2.0113
	1.5	3.1901	2.3644
	1	3.8562	2.9737
	0.75	4.3103	3.4420
	0.5	4.9495	4.4095

REFERENCES RÉFÉRENCES REFERENCIAS

1. B.J. Baliga, "Enhancement and Depletion Mode Vertical Channel MOSGated Thyristors", Electronics Letters, Vol. 15, 1979, pp. 645-647.
2. S. Dewar, S. Linder, C. Arx, A. Mukhitinov, G, "Soft Punch Through (SPT) – Setting new Standards in 1200V IGBT", Proc. PCIM, Nuremberg ,2000, pp. 593 – 600.
3. T. Laska, M. Munzer, F. Pfirsch, C. Schaeffer, T. Schmidt, "The field stop IGBT (FS IGBT). A new power device concept with a great improvement potential", Proc. ISPSD 2000, France, pp. 355 – 358.
4. C. Sabatier, S. Rack, H. Beseaucele, J. Venturini, T.Y. Hoffmann, E. Rosseel and J. Steenbergen, "Laser annealing of double implanted layers for IGBT Power Devices", 16th IEEE conf. on Advanced Thermal Processing of Semiconductors, Las Vegas, USA, 2008, pp. 177-181.
5. T. Gutt and H. Schulze, "Deep melt activation using laser thermal annealing for IGBT thin wafer technology", Proc. ISPSD 2010, Japan, pp. 29-32.
6. C. Zhu, I. Deviny, B. Yu, L. Coulbeck, G. Liu, "Optimization of o-emitter/ n-buffer using laser annealing technique in IGBT design", Proc. IECON 2013, Vienna, Austria, pp. 1128-1133.
7. C. Zhu, I. Deviny, G. Liu and A. Dai, "Study of Failure Mechanism in the Modern IGBT with a Highly Doped N-Buffer Layer", 40th Annual Conference of the IEEE (IECON), Dallas, TX, Oct. 29- Nov. 1, 2014, pp. 1834-1839.
8. V.K. Khanna, A. Kumar, S.C. Sood, R.P. Gupta, K.L. Jasuja, B. Maj and A. Kostka, "Investigation of degeneracy of current-voltage characteristics of asymmetrical IGBT with n-buffer layer concentration", Solid-State Electronics, vol. 45, 2001, pp. 1859-1865.
9. M. Takai, T. Naito and K. Ueno, "Reverse Blocking IGBT for matrix converter with ultra-thin wafer technology", IEEE Proceedings-Circuits, Devices and Systems, vol. 151, issue 3, June 2004, pp. 243-247.
10. J. Itoh, I. Sato, A. Odaka, H. Ohguchi, H. Kadachi and N. Eguchi, "A Novel Approach to Practical Matrix Converter Motor Drive System with Reverse Blocking IGBT", IEEE Transactions on Power Electronics, vol. 20, no. 6, November 2005.
11. A. Das, Md. M. Haq, Md. N. Islam and Md. Z.R. Khan, "Based Stored Charge Modeling of Insulated Gate Bipolar Transistor ", International Journal of Engineering Innovation & Research, vol. 4, issue 2, pp. 248-252, March 2015.
12. R. Hefner and D.L. Blackburn, "An analytical model for the steady-state and transient characteristics of the power insulated-gate bipolar transistor" , Solid State Electronics, vol. 31, no. 10, 1988, pp. 1513-1532.