

# A High Breakdown Voltage Two Zone Step Doped Lateral Bipolar Transistor on Buried Oxide Thick Step

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**Abstract**—A novel two zone step doped (TZSD) lateral bipolar junction transistor (LBJT) on silicon-on-insulator (SOI) with buried oxide thick step (BOTS) is proposed. The concept of linear doping and linear oxide thickness for increasing the breakdown voltage has been replaced by using step in doping and step in oxide thickness. These steps result in the creation of additional electric field peaks in the collector drift region and increases the uniformity of lateral surface electric field and hence the breakdown voltage. Numerical simulations demonstrate that the breakdown voltage of the proposed device is more than 200 % higher than the conventional device

**Index Terms**—Silicon-on-Insulator, Lateral bipolar junction transistor, Breakdown voltage.

## I. INTRODUCTION

The SOI-BiCMOS is emerging as a promising technology for realization of wireless system-on-chip. This technology offers advantages in terms of reduction of parasitic capacitance, high quality isolation and reduction in crosstalk [1]. However, the problem of compatibility lies in the integration of vertical bipolar device with SOI-CMOS [2]. This problem has been reduced by using lateral bipolar device as an alternative to the vertical device. The lateral bipolar junction transistor (LBJT) offers low parasitic capacitance, promises low power consumption and high breakdown voltage.

To obtain the large breakdown voltage, the lateral surface electric field distribution along the silicon surface must be uniform [3]. Several ideas have been used to enhance the breakdown voltage of the lateral bipolar devices. These include Reduced Surface Field (RESURF) principle [4], fully depleted collector drift region [5], graded drift region [6], [7], semi insulating polysilicon (SIPOS) passivation layers [8]. The concept of extended box has been used to increase the breakdown voltage of lateral Schottky transistor [9].

By using linearly varying doping concentration and linearly varying oxide thickness, the lateral surface component of the electric field in the device can be made uniform, and the breakdown voltage can be enhanced.

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But it is extremely difficult to fabricate a device with linearly varying doping concentration and simultaneously having linearly varying oxide thickness [10-12].

In this paper, numerical simulation of LBJT with two zone step doped (TZSD) drift region on buried oxide thick step (BOTS) has been performed. To increase the breakdown voltage and at the same time retain the ease of fabrication of the device, the linearly varying doping and the linearly varying oxide thickness has been replaced with step profile of both. The two zone step doping and thick step oxide results in increased uniformity in the lateral electric field in the drift region, reduction of base-collector junction electric field by using lower doping concentration near the junction and enhancement of collector breakdown voltage. The simulation results using MEDICI [13] has shown that the proposed device has breakdown voltage of more than 200 % higher than the conventional device, that is, TZSD device without BOTS

## II. DEVICE STRUCTURE

The structures of the conventional and the proposed device are shown in Fig. 1 and Fig. 2 respectively. The  $n$  type emitter/collector doping concentration is  $5 \times 10^{19} \text{ cm}^{-3}$ . The drift region consists of two zones  $N_1$  and  $N_2$  of  $n$  type doping concentration of  $n_1 = 3 \times 10^{15} \text{ cm}^{-3}$  and  $n_2 = 5 \times 10^{15} \text{ cm}^{-3}$  respectively. The  $p$  type substrate and base doping concentration is  $5 \times 10^{13} \text{ cm}^{-3}$  and  $5 \times 10^{16} \text{ cm}^{-3}$  respectively. The oxide is  $1.5 \mu\text{m}$  thick and the thickness of BOTS is varied from  $1 \mu\text{m}$  to  $6 \mu\text{m}$ .

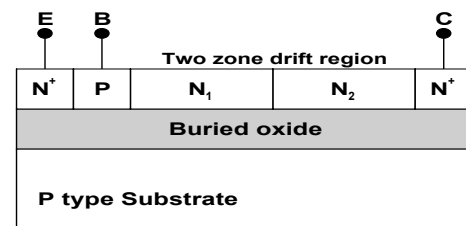


Fig. 1. Structure of the Conventional (TZSD) device.

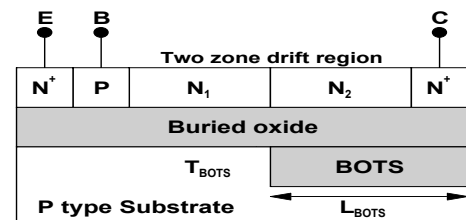


Fig. 2. Structure of the proposed device.

### III. SIMULATION RESULTS

Fig. 3 and Fig. 4 show the structures of the conventional and proposed device generated by MEDICI. These figures also show the output characteristics of these devices for various values of base currents.

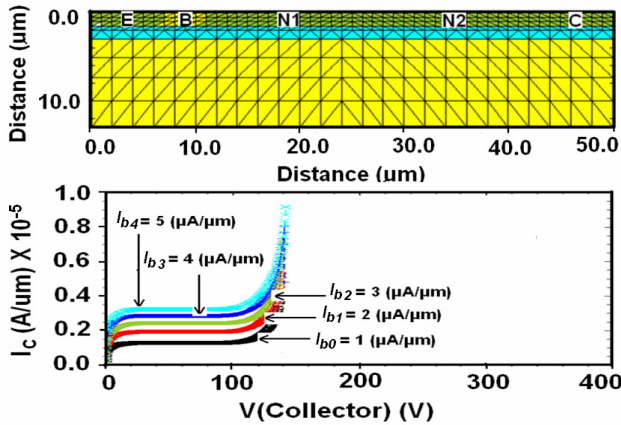


Fig. 3. Output characteristics of conventional device.

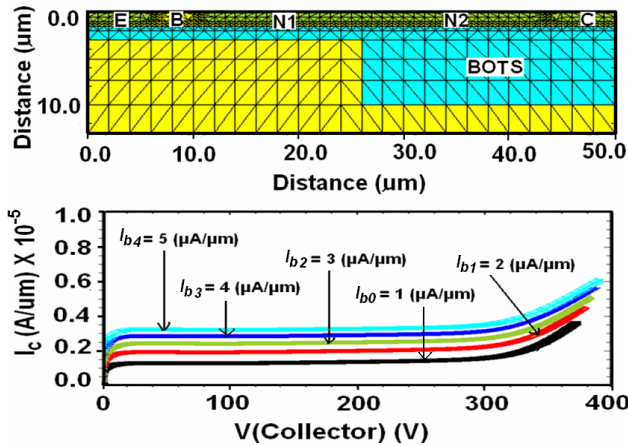


Fig. 4. Output characteristics of the proposed device.

The simulation results have shown that the common emitter breakdown voltage with base open ( $BV_{CEO}$ ) is significantly higher for the proposed structure than the conventional device. For the proposed device with BOTS length of  $18 \mu\text{m}$  and thickness of  $6 \mu\text{m}$ , the  $BV_{CEO}$  is  $290 \text{ V}$ . The  $BV_{CEO}$  of the conventional device is  $124 \text{ V}$ . The reason behind this enhancement in breakdown voltage is explained in Fig. 5, which shows that the lateral surface electric field is more uniform in the proposed structure than in the conventional device. The enhanced uniformity in surface electric field is due to the presence of step in doping and step in oxide [10]. These steps result in the generation of additional electric peaks in the collector drift region, which are shown in Fig. 5. These generated peaks pull down the peaks at the edges of the collector drift region. Further, the thick step oxide reduces the peak electric field at  $n_2\text{-}n^+$  junction by redistributing applied potential in the collector

drift region and in thick oxide. The analytical approach deduced in [12] explains the creation of the electric field component due to BOTS and increase in breakdown voltage.

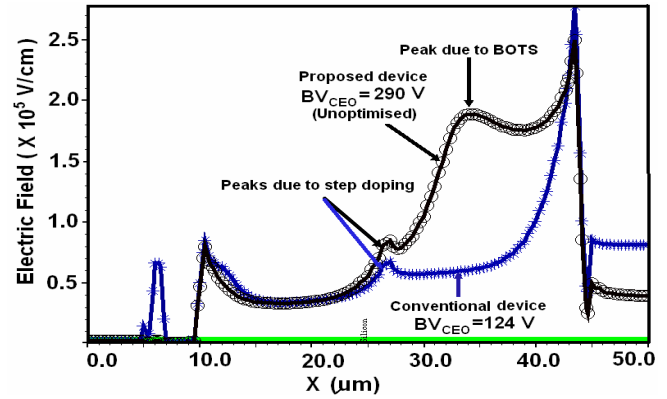


Fig. 5. Electric field profile in proposed and conventional devices.

The potential contours of the conventional and the proposed devices are shown in Fig. 6 and Fig 7 respectively. The crowding of the potential contours along the oxide layer as shown in Fig. 6, results in lowering the breakdown voltage in the conventional device. In the proposed device, BOTS helps in reducing the crowding of the potential contours as shown in Fig. 7. This reduction in crowding of the potential contours in BOTS, makes it possible to apply more voltage to the device before it breakdown.

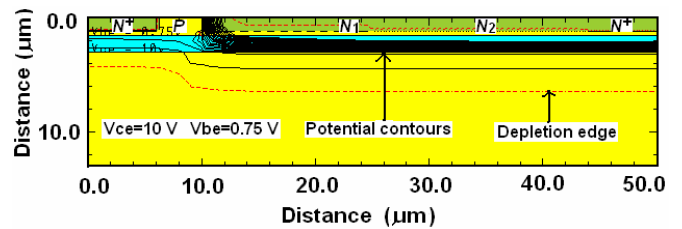


Fig. 6. Potential contours in the conventional device.

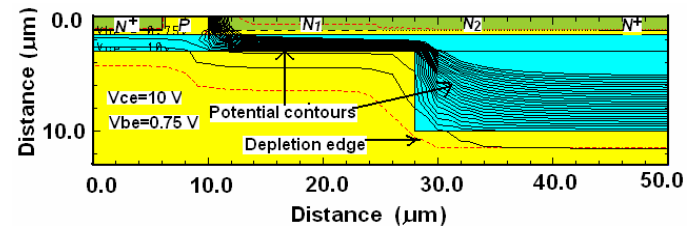
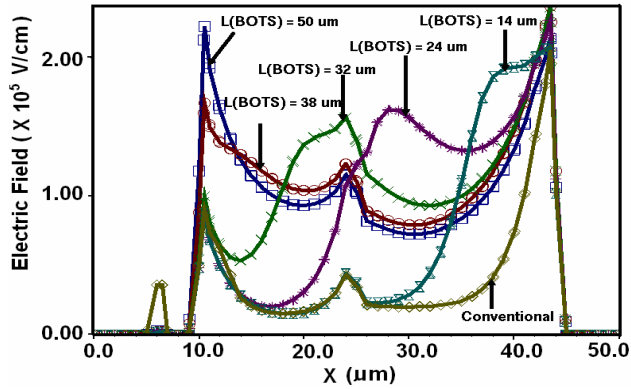


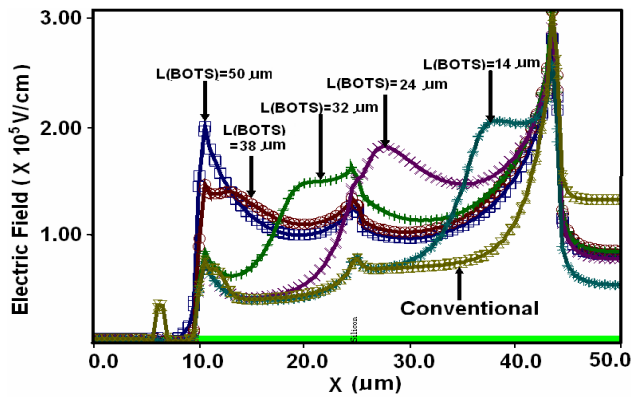
Fig. 7. Potential contours in the proposed device.

Fig. 8(a) and Fig. 8(b) show the electric field profiles at top and bottom of the SOI film respectively. The electric field profile in the oxide layer is shown in Fig. 8(c). These figures also show how the location of electric field peaks vary with BOTS length. It is observed in the proposed

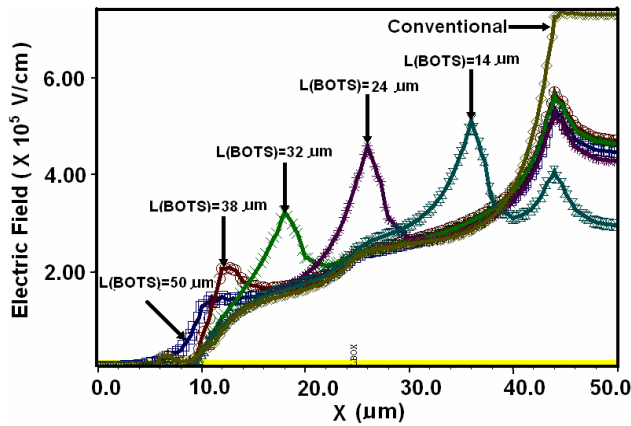
device that the BOTS length of 36  $\mu\text{m}$  gives maximum breakdown voltage of  $\sim 400$  V for specific values of doping concentration in different regions and a specific BOTS thickness. The increase in breakdown voltage can be attributed to how the electric field peaks are distributed in the device for different values of BOTS length.



(a)



(b)



(c)

Fig. 8. Electric field profile in the proposed device at (a) top (b) bottom of silicon film (c) inside the oxide layer for different values of  $L(\text{BOTS})$ .

Fig. 9 gives the breakdown voltage versus BOTS length characteristics of the proposed device. It is quite obvious from the plot that an optimum length of the BOTS is needed to get the maximum breakdown voltage. From this plot it is clear that for the BOTS length of 25  $\mu\text{m}$  to 40  $\mu\text{m}$ , the breakdown voltage is more than three times (for  $T_{\text{BOTS}} = 6 \mu\text{m}$ ) and more than two times (for  $T_{\text{BOTS}} = 4 \mu\text{m}$ ) that of the conventional device.

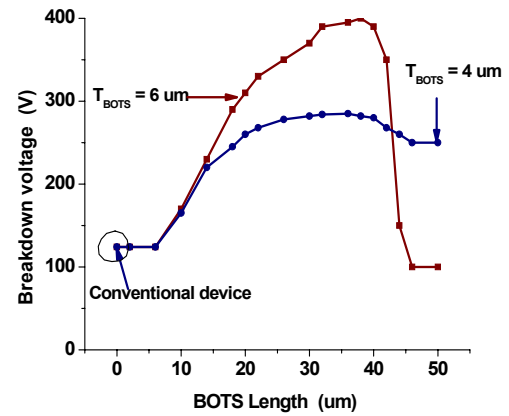


Fig. 9. Breakdown voltage versus BOTS length.

The impact of oxide thickness on breakdown voltage is shown in Fig. 10. It shows that the breakdown voltage first increases with increase in BOTS thickness, then subsequently saturates. This is because thick BOTS helps to sustain high electric field to a value lower than the field causing breakdown in the oxide. Since both horizontal and vertical components of the electric field contribute to the avalanche process, increasing BOTS thickness further does not improve breakdown voltage [9]. The simulation results have shown that for  $T_{\text{BOTS}} = 6 \mu\text{m}$  and  $L_{\text{BOTS}} = 36 \mu\text{m}$ , the breakdown voltage of the proposed device is  $\sim 400$  V and that of the conventional device is 124 V. This shows that the breakdown voltage in the proposed device is enhanced by  $\sim 223\%$ .

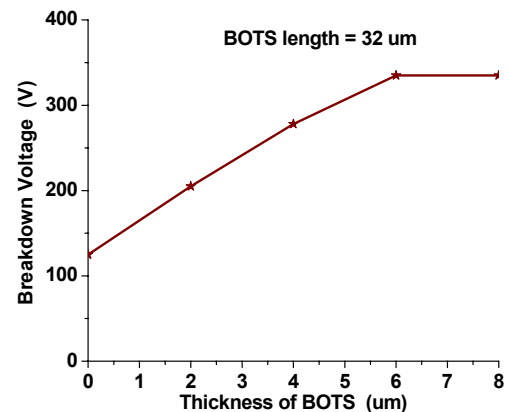


Fig. 10. Breakdown voltage versus BOTS thickness.

Fig. 11 shows the effect of substrate doping on the breakdown voltage. It is observed that there is an optimum doping concentration which gives the maximum breakdown voltage. The effect is explained in Fig. 12, which shows electric field profile at specified values of substrate doping. At high substrate doping concentration, the electric field builds up at the  $n_2-n^+$  junction. This electric field peak breaks down the device at low voltage. At low substrate doping, the electric field builds up at the collector base junction, and ultimately breakdown occurs due to this electric field peak.

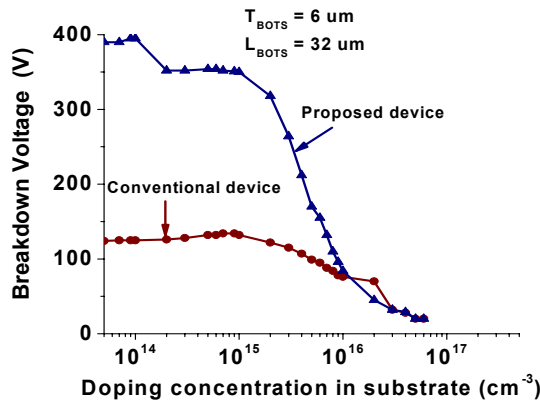


Fig. 11. Breakdown voltage versus substrate doping concentration.

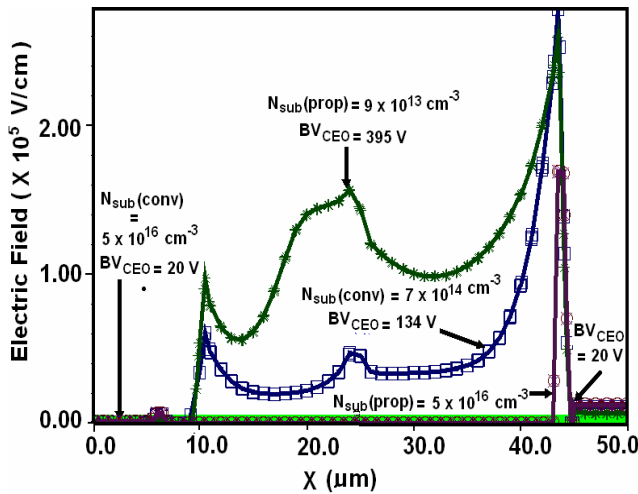


Fig. 12. Electric field profile at specified values of substrate doping concentration.

Fig. 13 shows the effect of varying doping concentration in the two zones of drift region on breakdown voltage. It is clear that there are optimum values of drift region doping concentration in the two zones, which gives maximum breakdown voltage. The optimum drift region doping concentration in  $N_1$  and  $N_2$  is about  $6 \times 10^{15} \text{ cm}^{-3}$ .

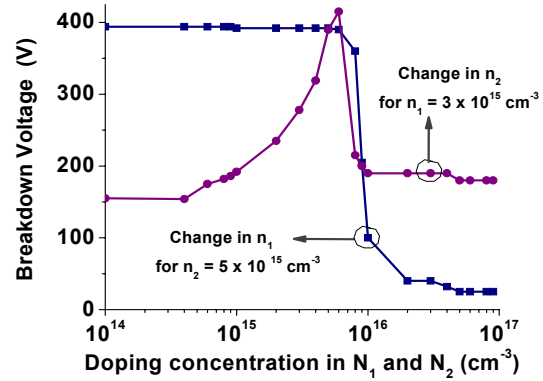


Fig. 13. Breakdown voltage versus drift doping concentration in  $N_1$  and  $N_2$ .

The electric field profile at specified values of doping concentration in two zones  $N_1$  and  $N_2$  is shown in Fig. 14. For  $n_1 = 3 \times 10^{16} \text{ cm}^{-3}$ , the electric field at collector-base junction is high and results in breaking down the device at 40 V. Similarly, at the doping concentration of  $n_2 = 7 \times 10^{16} \text{ cm}^{-3}$ , the electric field peak shifts to  $n_2-n^+$  junction and hence breaks down the device at 180 V. The electric field profile is more uniform for optimum values of  $n_1 = n_2 = 6 \times 10^{15} \text{ cm}^{-3}$ .

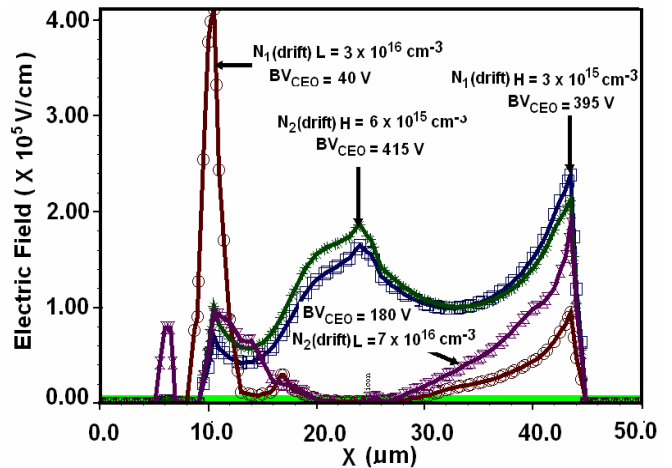


Fig. 14. Electric field profile at specified values of drift doping concentration in the proposed device.

The thermal analysis of the proposed and the conventional structures has been performed for a base current of  $I_b = 1 \times 10^{-6} \text{ A}/\mu\text{m}$ ,  $L_{BOTS} = 32 \mu\text{m}$  and  $T_{BOTS} = 4 \mu\text{m}$ , as shown in Fig. 15. The peak temperature of the conventional device at its breakdown voltage of 120 V is 306.46 K. In the proposed device it rises to 335.76 K, when operated at its breakdown voltage of 290 V. The reason behind this temperature enhancement is the presence of thick oxide under collector and operation at high voltage. However, as the breakdown voltage does not increase continuously with increase in oxide thickness, temperature

of the device can be kept in safe region by choosing optimum oxide thickness.

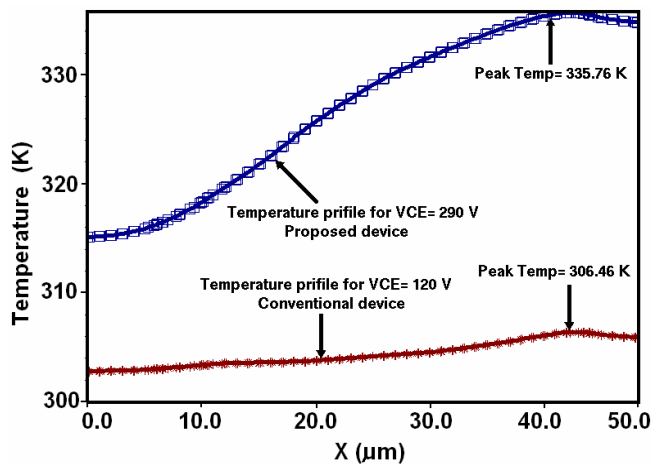


Fig. 15. Temperature profile of the proposed and conventional devices.

## VI. CONCLUSION

Numerical simulation of a novel lateral bipolar junction transistor on SOI has been performed. The novelty in the device is the combination of two zone step doping with the thick step oxide. It is known that the linearly varying drift doping and linearly varying oxide thickness results in maximum breakdown voltage. However, it is very difficult to fabricate such a device. In this paper a device with high breakdown voltage and relatively easy to fabricate has been proposed. The  $BV_{CEO}$  has been maximized by choosing appropriate values of  $T_{BOTS}$  and  $L_{BOTS}$ . The breakdown voltage has been found to be dependent on substrate doping and drift region doping concentration. In this simulation study a more than 200 % increase in breakdown voltage has been observed.

## ACKNOWLEDGMENT

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## REFERENCES

- [1] T.H.Ning, "Why BiCMOS and SOI BiCMOS" *IBM Journal of Res & Dev*, vol 46, no 2/3, Mar /May2002.
- [2] I-Shun Michael Sun et. al, "Lateral High speed Bipolar transistors on SOI for RF SoC applications" *IEEE Transactions on Electron Decives*, vol 52, no.7, July 2005.
- [3] S.D. Roy and M.J. Kumar, "Realizing High Voltage Thin Film Lateral Bipolar Transistors on SOI with a Collector Tub" *Microelectronics International*, 22/1, pp 3-9, 2005.
- [4] Y.S.Huang and B.j.Baliga, "Extention of resurf principle to dielectrically isolated power devices," *Proceedings of the 3<sup>rd</sup> International Symposium on Power Semiconductor Devices and ICs*. pp. 27-30, April 1991.
- [5] M. J. Kumar and K. N. Bhat, "Collector recombination lifetime from the quasi-saturation analysis of high voltage bipolar transistors," *IEEE Trans. on Electron Devices*, vol. 37, no. 11, pp. 172-177, 1995.
- [6] S. Zhang, J. K. O. Sin, T. M. L. Lai, and P. K. KO, "Numerical modeling of linear doping profiles for high-voltage think film SOI devices," *IEEE Transactions on Electron Devices*, vol. 46, no. 5, pp.1036-1041, 1999.
- [7] G.J. Cao, M. M. De Soza, and E. M. S. Narayanan, "Resurfed Lateral Bipolar Transistor for High-Voltage, High-Frequency Applications." *Proceedings of the 12<sup>th</sup> International Symposium on Power Semiconductor Devices and ICs*. Toulouse, France, pp. 185-187. May 2000
- [8] D. Jaume, G. Charitat, J. M. Reynes. and P. Rossel, "High-Voltage planar devices using filed plate and semi-resistive layers," *IEEE Tram. on Electron Devices*, vol. 38, no. 7, pp.1478-1483, July1991.
- [9] Kumar M.J and Roy S.D, "A New High Breakdown Voltage Lateral Schottkey Collector Bipolar transistor on SOI: Design and Analysis" *IEEE transactions Electron Device*, vol 52, no. 11 Nov. 2005.
- [10] R. Sunkavalli et. al, "Step drift doping profile for high voltage DI lateral power devices" *Proceedings of IEEE International SOI Conference*, pp. 139-140, Oct. 1995 2005.
- [11] J.Luo et al, "A high performance RF LDMOSFET in thin film SOI technology with step drift profile", *Solid State Electronics* 47(2003) 1937-1941.
- [12] I.J.Kim, et.al, "Breakdown Voltage improvement for thin film SOI Power MOSFET's by a Buried Oxide Step Structures" *IEEE Electron Device Letters*, vol 15, no. 5 May 1994.
- [13] TMA MEDICI 4.2. Technology Modeling Associates Inc. Palo Alto, US 2006