LATERAL TRANSISTOR GAIN CALCULATIONS

BY

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ABSTRACT

The gain of lateral transistors is calculated with a program entitled "LATERAL". This program uses a profile generated with SUPREM II, and calculates the depletion region edges and the built in potential for the diffused junctions. The effects included are the base width narrowing due to the applied bias and recombination in the base. The results are compared with measured gains, and show good agreement. The effects of lifetime in the base are seen to show a large affect on the calculated gain.

INTRODUCTION

The gain of lateral transistors is an important parameter to consider in the design of integrated circuits. They are used as active loads and are present as parasitic transistors. These transistors need to be characterized in order to allow proper design. The program "LATERAL" was created to model a simple lateral transistor to obtain the gain as a functions of the physical base width, doping, and applied bias. With this program a designer can determine the gain of lateral transistors for layout and circuit design. For a general review of numerical analysis see reference [1].

Lateral transistors are often produced concurrently with vertical transistors and the processing parameters are optimized for the latter. The doping profile is determined by these parameters and is modeled with a program such as SUPREM II. Therefore the program for the lateral gain calculation uses an output file from SUPREM II for the doping profiles. The built in potential and depletion widths are obtained through a solution of Poisson's equation at the depletion edges, and the gain is obtained by evaluating an expression for the collector and emitter currents [2]. The expressions also include effects of recombination in the base region as a result of relatively long base widths, and base width narrowing due to the applied bias to the collector/base junction.

The final evaluation is a comparison of the gains measured on single-diffused lateral transistors with values calculated with "LATERAL".

EXPERIMENTAL

The program "LATERAL" consists of several algorithms which calculate the built in potential and depletion widths described by the solution of Poisson's equation at the depletion edges. Poisson's equation can be expressed as:

$$\text{Potential} = \frac{q}{\epsilon} \sum \left(\sum N dx \right) dx$$

for use in a computer integration algorithm. The two boundary conditions that must be met are:

1. $\sum N_B dx = \sum N_E dx$
2. $V_{bi} = \frac{kT}{q} \ln \left(\frac{N_E N_B}{n_i^2} \right)$

which imply that the net charge and the current densities about the junction are equal to zero.

The individual current components are calculated including recombination effects in the base and are described by:

$$I_E = \left[\frac{qAD_E}{L_E} n_{E0} + \frac{qAD_B}{L_B} p_{B0} \coth\left(\frac{W'}{L_B}\right) \right] (e^{qV_{EB}/kT} - 1) - \frac{qAD_B}{L_B} \frac{p_{B0}(e^{qV_{CB}/kT} - 1)}{\sinh\left(\frac{W'}{L_B}\right)}$$

$$I_C = \frac{qAD_B}{L_B} p_{B0} \frac{(e^{qV_{EB}/kT} - 1)}{\sinh\left(\frac{W'}{L_B}\right)} - \left[\frac{qAD_B p_{B0}}{L_B} \coth\left(\frac{W'}{L_B}\right) + \frac{qAD_C}{L_C} n_{C0} \right] (e^{qV_{CB}/kT} - 1)$$

$$I_B = I_E - I_C$$

with Sinh(Wb/Lb) and Coth(Wb/Lb) being the recombination factors [2]. The appendix contains flow charts for the "LATERAL" main program as well as for the "DEPLETION" subroutine to demonstrate the array manipulation used in the calculations.

The gain is calculated for a common emitter configuration and is equal to:

Beta = Ic/(Ie - Ic)

Base width modulation is also included in the calculations to show the effect of the reverse bias of the collector/base junction. This was included as usually the base region is the substrate itself with relatively low doping which tends to increase this effect.

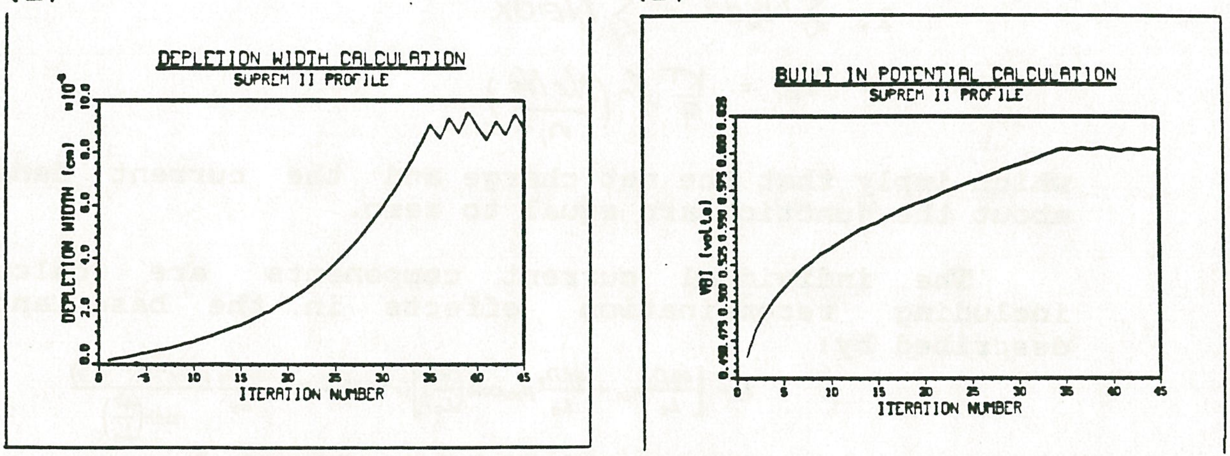
For this program it is important to note that the doping profile for the collector and emitter is the same. This is a valid approximation for the I2L logic fabricated at RIT, and for most other lateral transistors encountered.

RESULTS/DISCUSSION

Shown below in Figure 1 are the calculations of the built in potential and depletion widths as a function of computer iteration number. The profile for this calculation was a step junction and the resultant built in potential and depletion width exactly match those predicted from the equations for a step junction [3]:

FIGURE 1: Calculation of depletion widths and built in potential for a step junction.

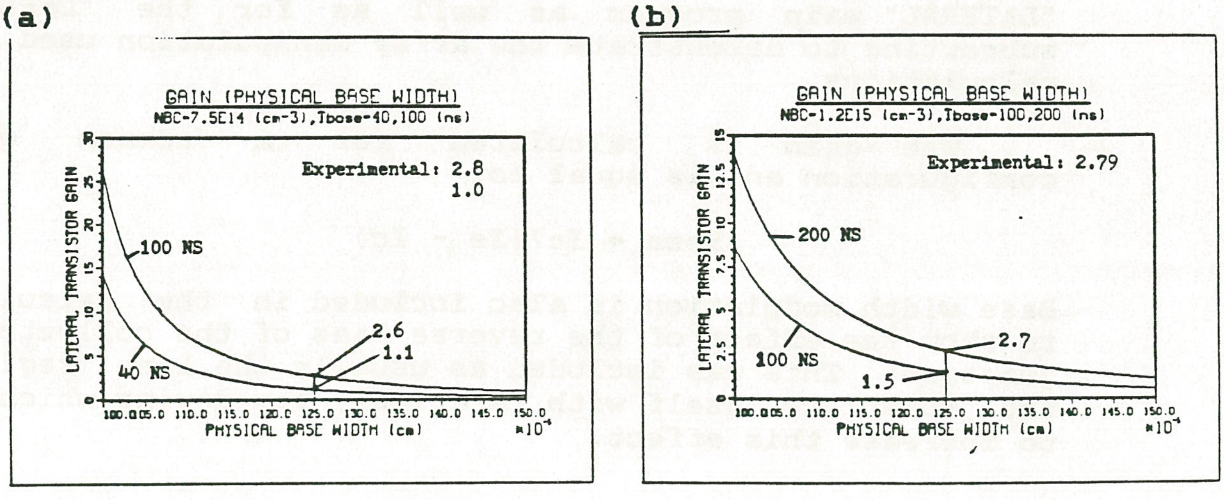
(a) (b)



In Figure 2 the results of the EMCR340 class are shown along with curves generated by the program "LATERAL". As can be seen the gain is dependent on the lifetime in the base.

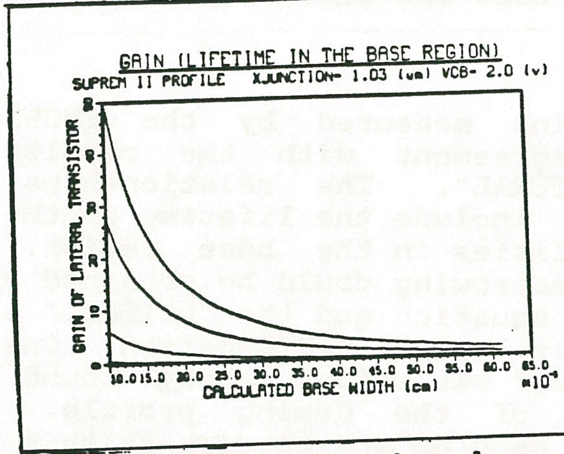
FIGURE 2: The calculated gains for EMCR340 class. Various lifetimes are shown.

(a) (b)



A typical value for the lifetime is 100 ns, and this value for the lifetime did give close agreement for two of the measured gains. By adjusting the lifetime the results agreed with the other measured gains, but this may not be the only factor involved in the discrepancy seen. This effect of the lifetime in the base was investigated with "LATERAL", and the results are shown in Figure 3.

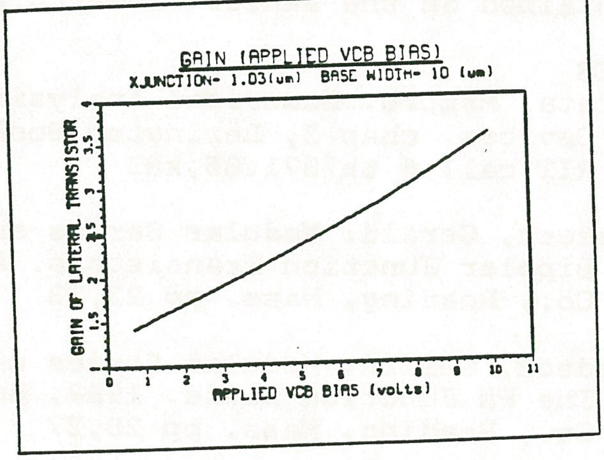
FIGURE 3: The gain as a function of the lifetime in the base. The lifetimes are 500,100,50,and 10 NS.



These results show that the lifetime does affect the gain of the lateral transistors and should be considered in future experimental work in order to determine the approximate values and investigate this dependence in detail.

The effects of applied bias were investigated and the results are shown in Figure 4.

FIGURE 4: The gain as a function of applied collector/base bias.



The applied bias has a larger affect on the gain than expected. A possible explanation for this is that the mobilities in the base region were modeled as being ideal. The free carriers generated in the depletion were neglected which will remain valid for low level injection. With increasing applied bias this approximation gives increasing error. The same discussions also apply to the gain as a

function physical base width seen in Figures 2 and 3. The results for relatively large base widths agree well with the measured gains, but the gain increases rapidly below five microns. It is believed that the effect of nonideal mobility in the base region is the major cause of this discrepancy. A model including these nonidealitites in the calculation of the base width would give better results for high applied bias and small physical base widths.

CONCLUSION

The gains measured by the EMCR340 class showed reasonable agreement with the results obtained from the program "LATERAL". The relationships that need to be investigated include the lifetime in the base, and the free carrier mobilities in the base region. Additionally the base width narrowing could be obtained by a direct solution of Poisson's equation and the "LATERAL" program was written to allow this type of modification. One final note is that a program "bug" was unfortunately found and involves the reading in of the doping profile. The program will occasionally hang up and to correct this the spacing of the doping profile (dysi), and the depth commands for the SUPREM II input deck can be varied until the profile is accepted by "LATERAL".

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