A 2D Analytical Model of Current-Flow in Lateral Bipolar Transistor Structures

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Abstract

In this paper we present a new theoretical approach for analytical models of lateral bipolar transistors (CLBT, LBT) by using conformal mapping techniques. It is shown that this method leads to closed form solutions for the currents in the devices under realistic boundary conditions. Model equations for CLBT's and LBT's are derived and will be compared to numerical simulation results as well as to measurements.

1. Introduction

In the design of analog integrated circuits lateral bipolar transistors offer greater design flexibility despite their behaviour is normally restricted with respect to optimized vertical BJT's. Typical lateral BJT's are shown in Figure 1: they appear as lateral pnp-transistors (LBT) in standard bipolar or BiCMOS-processes or as compatible lateral transistors (CLBT) in CMOS-technology.

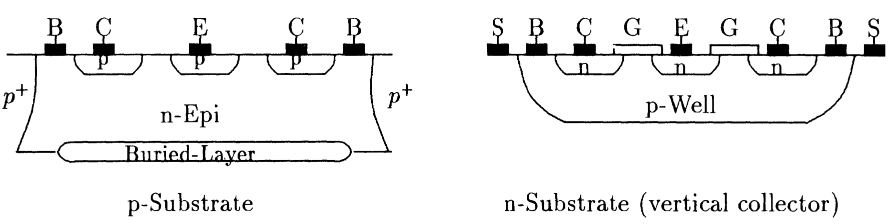

Figure 1: Cross-sections of pnp-LBT and p-well-CLBT

In spite of their widespread use, literature on compact, analytical modelling of lateral BJT's is not too abundant. Nearly all modelling approaches use a Gummel-Poon-Analysis of the device behaviour [1, 2]. But the fundamental assumptions of the Gummel-Poon-Analysis ignore the two-dimensional current-flow in lateral devices and lead to inaccurate results. Other models are numerical and do not offer the possibility to investigate the influence of device-parameters in a handy way [3, 4]. As a result, numerical models cannot properly be used when the layout- and geometry-dependence of electrical parameters has to be investigated.

In this paper we present an approach to describe the current-flow in lateral devices, especially LBT's and CLBT's, that focusses on a two-dimensional,but still analytical description.

2. 2D-calculation of carrier densities and currents by conformal mapping

To calculate the minority-carrier distribution and the collector currents in lateral transistor structures, it can be shown that the Laplacian equation

$$\Delta n = 0 \tag{1}$$

is valid if recombination effects and internal electric fields are neglected. It is possible to solve (1) by using a conformal representation $z = F(w)$, that maps the geometrical structure onto the real axis of the complex plane. A complex minority carrier density function N can then be calculated, whose real part reflects the carrier distribution and whose imaginary part can be regarded as a flux function [6]. It can be shown that the current flowing between two points A and B [1] can then be written as:

$$I' = Im(N(w_B)) - Im(N(w_A)). \tag{2}$$

This shows that in order to calculate the currents in a 2D-device problem it is necessary to first find a mapping function that transforms the device structure into a geometry in the complex plane, where the solution of (1) is known and then to apply (2).

3. Conformal mapping of lateral structures

Fig. 1 suggests a structural affinity of LBT and CLBT. The main difference is the presence of the buried-layer which mathematically imposes different boundary conditions. It can be shown that the general topology of both transistor types can be represented by superposing two separate problems concerning the symmetry of boundary conditions. Fig. 2 shows this decomposition.

Former attempts to describe such geometries in electrostatical problems use Schwarz-Christoffel-transformations [6]. These approaches lead to unsatisfying results concerning the current distribution along the rounded junction corners. The influence of the fringing of current flowlines on the current density cannot be calculated accurately and as a result unrealistic discontinuities occur. A modified kind of transformation was developed that is much better suited to describe junctions corners in integrated devices. The resulting mapping function is:

$$F(w) = i\frac{\nu g}{\pi}(ln\frac{1+\eta}{1-\eta} + 2\sqrt{\varrho}\ arctan(\sqrt{\varrho}\ \eta)) + i(1-\nu)\frac{2g}{\pi}ln(\sqrt{w-q} + \sqrt{w-1}) \tag{3}$$

[1]Throughout this 2D-analysis only line current densities will be regarded.

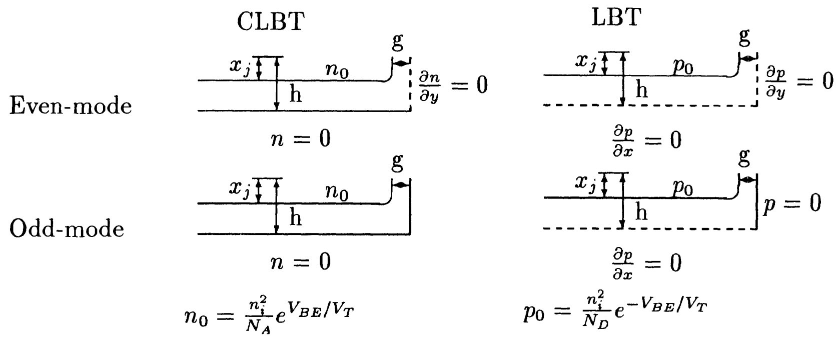

Figure 2: Odd- and even-mode decomposition of LBT and CLBT

$$\eta = \frac{\sqrt{w-q}}{\sqrt{w+1}} \quad (4) \qquad p = \frac{qh^2 - \nu^2 g^2}{h^2 + \nu^2 g^2} \quad (6) \qquad \varepsilon = e^{\frac{x_j \pi}{2(1-\nu)g}} \quad (8)$$

$$\varrho = \frac{p+1}{q-p} \quad (5) \qquad q = \frac{\varepsilon^4 + 6\varepsilon^2 + 1}{(\varepsilon^2 - 1)^2} \quad (7) \qquad \nu = \frac{1}{4}\sqrt{\frac{g}{x_j}} \quad (9)$$

$\eta, \varrho, p, q, \varepsilon, \nu$ are parameters which are needed to map those points of the structure that are relevant for the calculation of currents following the procedure outlined in section 2.

By using this mapping function the 2D-structure is transformed onto the real axis of the complex plane and (1) can be solved in a manner analogous to field plate problems in electrostatical calculations [6].

4. Modelling the collector currents in CLBT's

Under the conditions of homogenous base doping, flat-band-operation and $V_{CB} = 0$, the lateral and vertical collector currents are derived from (3) - (9) and applying (2):

$$I_L' = eD_N \frac{n_0}{2\pi}(arcosh(a) - ln(2a-2)) \quad (10)$$

$$I_V' = eD_N \frac{n_0}{2\pi}(arcosh(c) + ln(2c+2)) \quad (11)$$

with

$$a = \frac{1+2q-p}{1+p} \quad (12) \qquad c = 1 - \frac{2\psi^2(b+1)}{(\psi^2-1)(a+1)} \quad (14)$$

$$b = \frac{1-2q+p}{1-p} \quad (13) \qquad \psi = tanh\left(\frac{\pi(g + \frac{W_E}{2})}{2\sqrt{\varrho \nu g}}\right) \quad (15)$$

To include the effect of internal drift fields it is possible to introduce a drift factor m, that reflects the effect of inhomogenous base doping profiles. Substituting the parameter h by $h/\sqrt{m}$ and multiplying (11) with $\sqrt{m}$ allows to calculate the currents in a CLBT with a drift base.

Figure 4 shows a comparison of numerical simulation results with the presented model concerning the prediction of current-splitting in a CLBT. Measurements at CLBT's,that were fabricated in a $3\mu m$-standard CMOS-technology are in good accordance with the model.

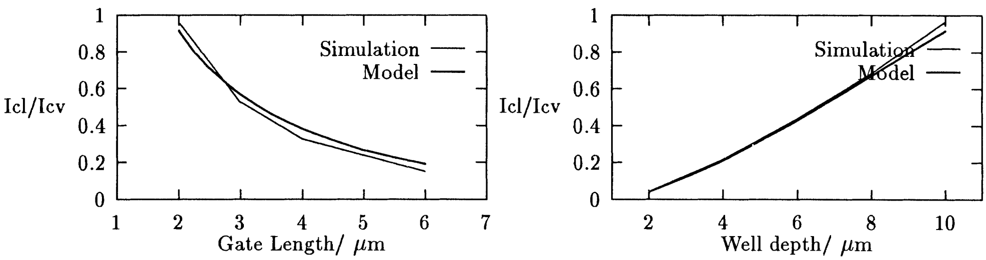

Figure 3: Comparison of simulation results and theory

5. Modelling the collector current in an LBT

Due to the influence of the buried-layer, which is absent in a CLBT, approximately all vertical currents in an LBT are suppressed. Preceeding in the same way as discussed in the above sections, the current in an LBT can be calculated as:

$$I_L' = eD_P \frac{p_0}{2\pi} arcosh(\frac{q+p+2}{q-p}) \tag{16}$$

with p, q according to the mapping definitions in (6) and (7).

6. Conclusions

The theoretical approach presented in this paper leads to a physics-based model for the current-flow in lateral BJT's under shorted collector conditions. Variations of collector potentials can be included by modification of well depth and effective gate length in dependance of the extension of space-charge-regions into the base [5]. The model describes the correspondence of process-, geometry- and electrical parameters of the device in a rather exact, but still analytical way, enabling the circuit designer to calculate currents in the device as well as its scaling behaviour.

References

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