A Computationaly Efficient Technique to Extract Diffused Profiles and Three Dimensional Collector Resistances of High Energy Implanted Bipolar Devices

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Abstract--A computationaly efficient technique to extract the diffused profiles and collector resistances of bipolar transistors formed via high energy implantation is developed. The methodology uses two dimensional process and device simulations to extract three dimensional collector resistances. The bias dependence of the collector resistance is also correctly predicted.

I. INTRODUCTION

The use of high energy implants to form the isolation and tub regions in CMOS processes is rapidly replacing the use of conventional "implant and drive" CMOS processes. In contrast, Lucent's 35HEIBiC (0.35 μm High Energy Implanted BiCMOS) process [1] uses a high energy phosphorus implant to form the collector of the npn transistor. The implanted dopant forms a pseudo buried layer to replace the epitaxial buried layer of older BiCMOS processes. A key issue in the success of such buried layer replacement is the control of collector series resistance (R_c), which limits high frequency operation of the device. In addition, the profile of the diffused collector determines the magnitude of BV_{ceo} (breakdown voltage), and W_b (base width). In this study a simulation methodology is developed to predict (a) the dopant profiles in the various regions of the transistor, and (b) the bias dependent collector resistance of a three dimensional device.

II. PROCESS SIMULATION

The 35HEIBiC bipolar processing uses a modular approach to isolate the bipolar processing from the core CMOS process. The base is formed via a conventional shallow energy implant. However, the collector in the various versions of the process is formed via a high energy (several hundred KeV to MeV) phosphorus implant, followed by a low temperature oxide deposition step. To accurately model the TED (Transient Enhanced Diffusion) kinetics, the "plus-one" model of transient diffusion was applied. The model has previously been shown to give good fits to high energy implant data [2]. The defect assisted diffusion is simulated, using PROPHET [3], in the thermal steps following implantation, accounting for cluster evaporation and the subsequent time dependence of TED.

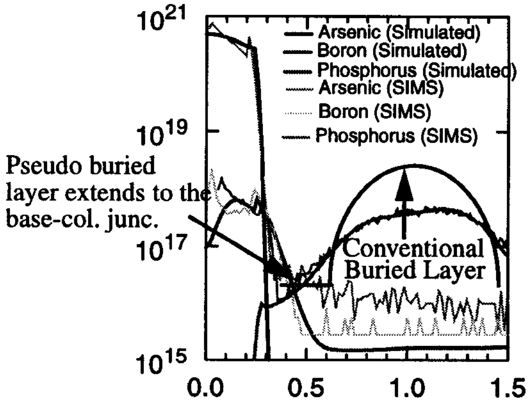

Figure 1 Simulated and SIMS profiles for the active region of the NPN transistor.

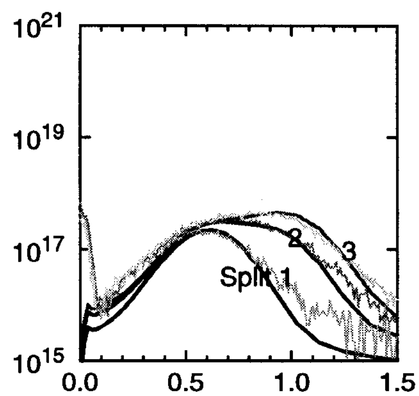

Figure 2 Simulated and SIMS profiles for various splits on the high energy implanted collector process. The profiles are under the active area of the transistor.

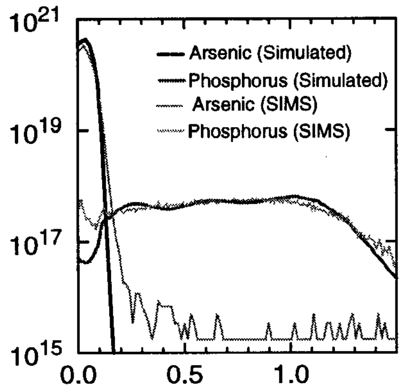

Figure 3 Simulated and SIMS profiles for sinker region (under the collector contact).

Two dimensional simulations were used to extract profiles in: (1) the active region, (2) the isolation region under the field oxide, and (3) the sinker region. The measured and simulated profiles from the active area of the npn transistor are shown in Fig. 1. The simulated base and collector profiles follow the profiles extracted from SIMS. Fig. 2 shows the collector profiles for a variety of collector implant energy splits, while Fig. 3 compares the simulations and the SIMS profiles in the sinker region (below the collector contact). The simulation did not account for extended defect (dislocation loops) assisted diffusion for the high dose source/drain implants which form the low resistance regions under the collector contact. The enhanced diffusion in the tail region (Figure 3) of the arsenic profile seen in the SIMS is absent in the simulations. Since the collector resistance in this region is minimal, the error introduced by this approximation is very small.

III. EXTRACTION OF COLLECTOR RESISTANCE

A detailed extraction scheme for the collector resistance of bipolar device has been developed [4]. Though accurate for the conventional buried layer process, where the epitaxial buried layer is physically separated from the base-collector junction via a layer with the background concentration of the collector (Fig. 1), it fails to model the two-dimensionality of the high energy implanted process, where the pseudo buried layer extends up to the collector-base junction (Fig. 1) and the current flow is at least two dimensional in the region. Also, the extraction of the collector resistance was bias independent.

The three dimensional npn device is pictorially shown in Fig. 4 (a). The emitter-base and emitter-collector planes lie in mutually orthogonal planes. The collector current flows along the X-X′ plane. A cross-section along this plane is shown in Fig 4 (b). For the purposes of modeling the collector resistance the structure is divided into three regions: (1) R_{act} is the resistance under the active and emitter poly regions of the transistor, (2) R_{fox} is the lateral resistance under the isolation field oxide, and (3) R_{snk} is the resistance in the sinker region.

R_{act} represents a three dimensional current flow, i.e. the current flows vertically down (below the base-collector junction) and laterally towards the isolation field oxide. Also, the current flow spreads as the device widens. To extract this resistance from sheet resistance simulations would be inaccurate as it would account for the lateral resistance alone. Several models exist to model the resistance of this two dimensional current flow, but involve approximating the resistivity as an analytical function or involve numerical integration. To minimize such errors, the structure was imported into a device simulator and artificial electrodes attached as shown in Fig. 5. The first electrode was placed at the depletion region edge in the collector, which was extracted by biasing the simulated structure in a numerical device simulator at biases representative of the electrical measurements of the collector resistance. The collector resistance is electrically measured from the slope of the output characteristics in the saturation region.

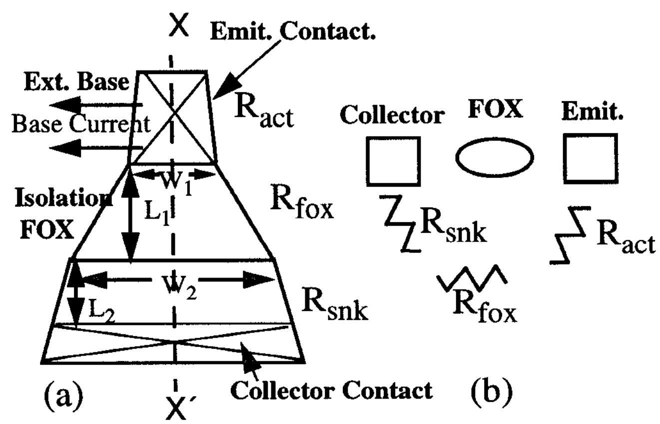

Figure 4 A diagram, (a) plan-view and (b) cross-section (along X-X′), illustrating the various components of the collector resistance. The active area of the transistor is underneath the emitter; the base and collector currents flow in mutually orthogonal directions as shown. The totoal collector resistance is the sum of the resistances under the active, field oxide, and sinker regions.

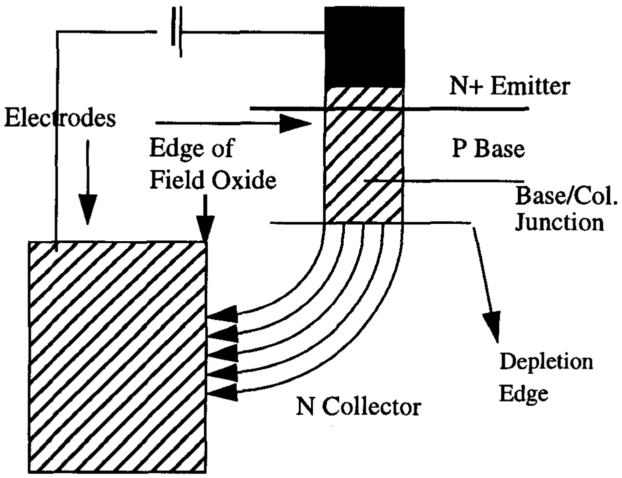

Figure 5 Schematic illustrating the extraction technique for a resistance (R_{act}) representing two dimensional current flow from the base-collector depletion edge to the edge of the isolation field oxide.

This allows for bias dependent.extraction of the collector resistance. The depth of this depletion edge is also dependent on the collector doping profile and thus needs to be extracted for each implant split and bias condition. A potential difference, once again representative of the biases used for the electrical measurements of R_c, was applied to the electrodes as shown, and the current flow simulated. This gave an effective two dimensional resistance. The actual current flow is three dimensional, and this is accounted for by assuming an average width of the device in this region. For the resistance under the field oxide (R_{fox}), the current flow is essentially in the lateral direction and thus the resistance can be extracted as shown in Fig. 4. It accounts for the divergence of the flow lines under the field oxide. Mathematically, the resistance of this non-rectangular region is represented [5] as:

$$R_{fox} = 2 \cdot L_1/(L_1 + 2 \cdot W_1) \bullet R_{sh}(FOX) \qquad (1)$$

where L_1 and W_1 are dimensions as shown in Fig. 4, and $R_{sh}(FOX)$ is the sheet resistance of the buried layer under the field oxide. The resistance R_{snk} represents a three dimensional current flow as the current vector has components in both the lateral and vertical directions. However, plots of current flow lines in this region indicated that the flow is predominantly lateral until the edge of the collector contact and an approach similar to what was used for calculating R_{fox} was almost as accurate as the one used for extracting R_{act}. The net collector resistance is a series combination of R_{act}, R_{fox}, and R_{snk}. Fig. 6 compares the simulated and measured collector resistances for splits on the collector implant dose and energy. As shown, the collector resistances closely track the measurements at two different biases.

IV. CONCLUSION

A simulation methodology, which accurately predicts the diffused profiles of the high energy implanted collector BiCMOS process, has been developed. Using a judicious mix of numerical and analytical techniques, a computationaly efficient approach, which models the collector resistance and its dependencies on bias and routing dimensions of the three dimensional bipolar transistor, has been applied to the process.

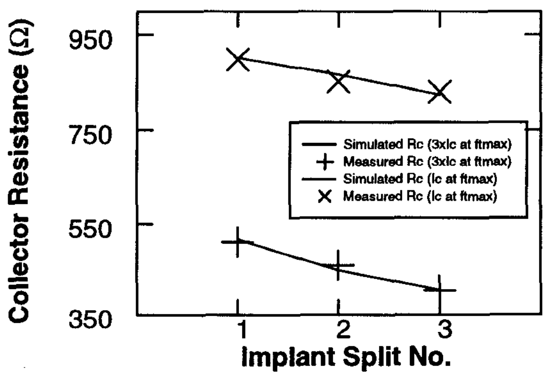

Figure 6 Plot comparing the simulated and measured collector resistances for various implant splits on an npn device. The collector resistance is measured and simulated for two collector currents (I_c): (1) $I_c = I_c$ at the maximum cutoff frequency ($f_t$max), and (2) $I_c = 3xI_c$ at $f_t$max.

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