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Simulation of the Forward Voltage Impact on the Gain of a Narrow-Base Transistor

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Abstract—Equations have been derived that describe the effect of the forward emitter–base voltage of a bipolar narrow-base transistor on the current gain. The results make it possible to use the model for calculating the processes of charge transfer.

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The growing integration density of microcircuits and the efforts undertaken to improve the frequency properties of bipolar transistors necessitate the creation of a relatively narrow base with a gradient of the concentration of doping impurities and a heavily-doped emitter [1, 2]. During the manufacture of transistors it is necessary to monitor the density of embedded charge of main carriers in the quasi-neutral base. The density of embedded charge of main carriers can be presented by the following equation:

$$Q_{\mathrm{b}} = q \int_{0}^{x_{\mathrm{b}}} N_{\mathrm{ab}}(x)\mathrm{d}x, \tag{1}$$

where q is the electron charge, $N_{\mathrm{ab}}(x)$ is the concentration of acceptor dopants in the base, x_{b} is the width of the quasi-neutral area of base. It is also known that the lower is the embedded charge, the higher is the current value at the fixed bias voltage [3, 4].

From equation (1) it follows that the Q_{b} value depends on the distribution law of acceptor dopants $N_{\mathrm{ab}}(x)$ in the base and also on its width. In papers [3, 5] investigations were conducted proving that Q_{b} does not depend on the emitter–base forward bias, provided the base width does not exceed 0.5 μm.

The purpose of this study is to carry out simulation of the impact produced by the emitter–base forward bias (U_{eb}) on the density of embedded charge Q_{b} and the current gain of a transistor having the base width of no more than 0.5 μm.

THEORETICAL JUSTIFICATION OF THE MODEL

Let us consider a bipolar *n–p–n* transistor produced by the double diffusion technique. The distribution profile of doping impurities in the transistor structure is presented in Fig. 1. The concentration of doping impurities corresponds, respectively, to the following areas: *1*—X_{e01}, *2*—X_{e1}, *3*—X_{e}, *4*—X_{e2}, *5*—X_{e02}, *6*—X_{c01}, *7*—X_{c}, *8*—X_{c02}.

Due to the non-uniform distribution of impurities in the base there are flows of electrons and holes that are moving in the opposite directions with respect to each other. They create an electric field in the base that increases the velocity of carriers and the latter inject from the emitter to collector.

Let us assume that the collector is doped with donor impurities of constant concentration, i.e., N_{dc} = const. Then, accordingly, the distribution of acceptor impurities in the base is described by the Gaussian curve

$$N_{\mathrm{ab}}(x) = N_{\mathrm{sb}} \exp\left(-\frac{x}{x_{\mathrm{a}}}\right)^{2}, \tag{2}$$