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Solid-State Electronics 49 (2005) 554–557
SOLID-STATE ELECTRONICS
www.elsevier.com/locate/sse

Optimization of base-to-emitter spacer thickness to maximize the frequency response of bipolar transistors

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Received 4 March 2004; received in revised form 13 December 2004; accepted 1 January 2005

The review of this paper was arranged by Prof. S. Cristoloveanu

Abstract

The impacts of base-to-emitter spacer thickness on the unity gain frequency (f_T), base resistance (r_B), base collector capacitance (C_{BC}) and maximum oscillation frequency (f_{max}) of a bipolar junction transistor (BJT) are studied. Using the extracted *Y*-parameters from a simulated device with structural parameters calibrated to an actual process, the resulting f_T and f_{max} with different spacer thickness is reported. A tradeoff between peak f_T and f_{max} is observed and the process window to obtain high f_T and f_{max} is proposed.

Keywords: BJT; Frequency response; Spacer thickness

1. Introduction

The wireless communication market has experienced a rapid growth in recent years and it is believed that this trend will continue in the coming years. To address the increasing demand, communication systems have to operate at higher operation frequency without significant increase in price. The characteristics of graded-base SiGe HBT have been shown to meet these tough requirements [1,2]. The graded Ge content across the intrinsic base region of SiGe HBT causes band gap narrowing in the base. The band gap narrowing induces a drift field, which helps to reduce the transit time of the injected electron from the emitter across the base and improves the frequency response. Furthermore, the band gap narrowing also enhances the DC current gain. The high DC current gain can be tradeoff for lower r_B by increasing the base doping. As a result, it is possible to achieve high f_T and low r_B simultaneously. Also, with the progress of photolithography technology, the lateral scaling of the emitter width helps to reduce the intrinsic r_B and C_{BC}, which makes SiGe HBT more attractive in high frequency operations. Nevertheless, the lateral scaling does not scale the extrinsic components as for intrinsic ones and the base-emitter spacer thickness becomes more important in determining the overall r_B and C_{BC}. Therefore, it is important to find the optimal spacer thickness at different emitter width.

To evaluate the optimal spacer thickness, two important figures of merit are used for comparison in this paper—f_T and f_{max}. f_T defines the frequency at which the small signal current gain drops to zero when the output is shorted to ground—the maximum frequency that a transistor can still work as a amplifier [3].

On the other hand, the maximum operating power gain, $G_{p,max}$, is defined as the ratio of power delivered to the load from the power input to the network when

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0038-1101/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.sse.2005.01.001

the output is conjugated matched [4]. Although r_B is an important factor in determining the amount of input power loss, it is not taken into account in evaluating f_T. Therefore, f_T cannot give full detail about $G_{p,max}$. Another figure of merit, f_{max}, is the frequency that produces unity $G_{p,max}$. Since $G_{p,max}$ is directly proportional to the square value of f_{max}, a large f_{max} implies a larger the power gain from the input to the output. Therefore, both f_T and f_{max} are important figures in evaluating the device performance and they should be taken into considerations in optimizing the spacer thickness.

2. Structural analysis

The schematic cross-section of a SiGe HBT is illustrated in Fig. 1. As SiGe HBT is more attractive for high-end applications, the device structure and parameters of SiGe HBT are used in this study. But the results can be easily generalized to more generic BJT structure. The structure used in this study is an epitaxial-base SiGe HBT with double polysilicon layers and shallow trench isolation. The device parameters are taken from [5] with slightly simplified structure to remove advanced features such as deep trench isolation and separate collector to keep the structure simple and more general. The shallow emitter is formed by the n^+ diffusion from the n^{++} polysilicon while the out-diffused dopants from the p^+ polysilicon forms the extrinsic base region. The epitaxial-base doping is approximately uniform at 2.7×10^{18} cm^{-3} and the metallurgical emitter junction depth and base width are 30 nm and 82 nm, respectively. Fig. 2 shows the vertical doping profile as well as Ge composition taken through the center of the emitter, which is based on Fig. 2 in [5] with modifications and the structure considered here is a single finger device with emitter length equal to 20 μm. The doping concentration of SiGe HBT with 0.35 μm emitter width and 1 μm spacer width along the horizontal line A–A' of Fig. 1 is shown in Fig. 3 while the Gummel plot of that device is shown in Fig. 4.

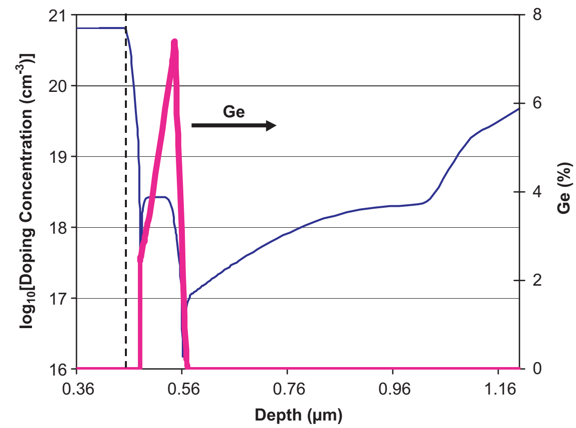

Fig. 2. Doping profile and Ge composition of the SiGe HBT device.

In this study, only the spacer thickness is varied and all other parameters are kept constant while the dopants are set to fully ionize. In order to accurately model the apparent band gap narrowing in calculating the equilibrium *pn* product, Boltzmann statistics and band gap narrowing (BGN) are included [6]. Also, Philips Unified Mobility Model (PHUMOB) is used in the simulations to model the mobility of both majority and minority carriers [5]. As a result, with the 2-D device simulator MEDICI [7], the *s*-parameters are obtained. r_B, C_{BC} and f_T can then be obtained from the simulated *s*-parameters by following the steps described in [8].

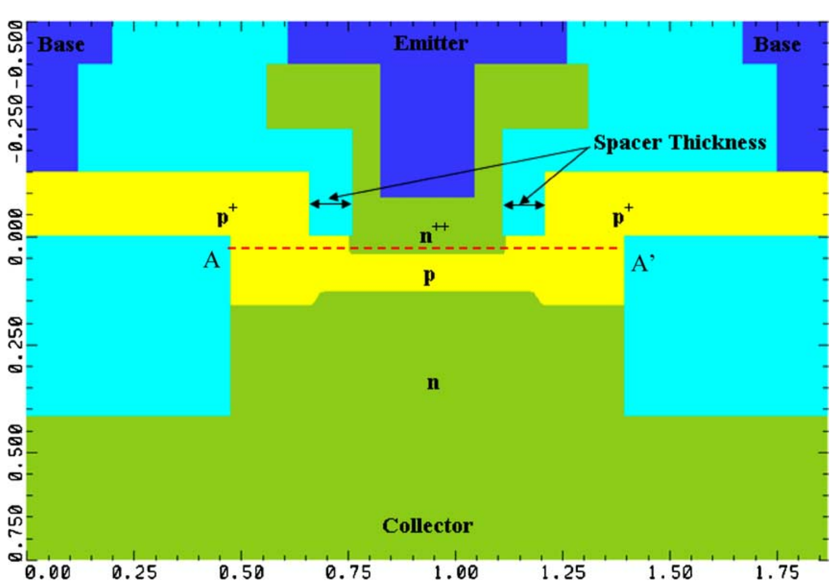

Fig. 1. Schematic cross-section of the SiGe HBT device used in 2-D simulation.