1. Introduction

SiGe and SiGe:C BiCMOS technologies are key enabler for single-chip solutions for broadband and wireless communication systems because combining highest bipolar RF performance with the high level of CMOS integration. Here, we demonstrate two modular SiGe:C BiCMOS processes combining an 0.25µm RF CMOS backbone with different HBT modules. The first process fabricates 200GHz HBTs with much lower process complexity compared to the state-of-the-art. The second process uses a novel one-mask HBT module. It offers ample bipolar performance for the majority of high volume applications at lowest cost. Both the high-speed and low-cost HBT module take benefit from the suppressed B diffusion due to C doping [1].

2. SiGe:C BiCMOS Processes

High Speed SiGe:C HBT Module

High-speed HBTs with above 200GHz operation have been demonstrated recently [2, 3]. Here we show high frequency devices integrated in a 0.25 µm CMOS technology, which use a novel construction without deep trenches, without epitaxially-buried subcollectors and with low-resistance collectors. This facilitates a modular BiCMOS integration with minimal changes of the CMOS process. Fig. 1 shows the cross section of the new HBT structure. The whole HBT is fabricated in one active area without shallow trench isolation between emitter and collector contact. By this way, collector resistances as low as the emitter resistances, reduced device dimensions and lower parasitic capacitances have been achieved. HBTs with $f_T/f_{max}$ values of 200/200 GHz are demonstrated (Fig. 2). Excellent CML ring oscillator delays of 4.2 ps are obtained. Excellent static characteristics and high yield of 4k transistor arrays have been achieved. Details of the process are described in [3].

Low-cost, High Performance HBT Module

This technology is a 0.25µm BiCMOS SiGe:C HBT process with 19 lithographic steps, offering 4 levels of Al and a full menu of active and passive devices. Three different SiGe:C HBTs can be fabricated by adding a single lithography level to the RF CMOS process. These devices offer a wide range of $BV_{CEO}$. We demonstrate HBTs with $f_T/f_{max}$ $BV_{CEO}$ values of 28GHz/ 67GHz/ 7.5V; 52GHz/ 98GHz/ 3.8V; and 75GHz/ 90GHz/ 2.4V. The 19-mask process offers the following key features: 2.5V $V_{DD}$ MOS transistors for digital applications, including an isolated NMOS device for improved signal isolation [4]; high-Q MOS varactors; three polysilicon resistors with sheet resistances of 94Ω. 1kΩ, and 5kΩ; a 2µm thick upper Al layer for high-Q inductor fabrication; and a 1fF/µm² MIM. Note also that by adding only two implant masks, a fourth SiGe:C HBT with $f_T$ and $f_{max}$ values in excess of 100GHz and 2.5V $BV_{CEO}$- and a high-performance LDMOS can easily be included without compromising the other devices [5, 6]. HBT fabrication starts after depositing the MOS gates and a Si$_3$N$_4$ protection layer. Fig.3 shows the SEM cross section of the HBT region obtained after SiGe:C base and Si low-doped emitter layer deposition, L-shaped inside spacers formation, SiC implantation, As-doped emitter Si layer deposition, and applying CMP to remove the emitter and base material from the Si$_3$N$_4$ layer surface to isolate the emitter from the external base. The protective nitride film was removed already by wet etching. Details of the process are presented in [7]. The manufacturability of the new HBT module is demonstrated by Gummel plots for 4k HBT arrays (Fig. 4). The yield exceeds 90%, matching the values obtained with our previous technology generations.

Circuit Applications of SiGe:C BiCMOS Technology

Various circuits have been designed demonstrating the capability of the SiGe:C BiCMOS technology for high frequency applications [8]. A selection of circuits obtained with a previous generation of high-speed HBTs, featuring $f_T$ and $f_{max}$ values of 120 and 140 GHz, respectively, are summarized in table 1.

3. Conclusions

The demonstrated high-speed HBT module combines highest RF performance with low process complexity. It is targeting on very high frequency applications. The presented single-mask HBT SiGe:C BiCMOS process is of exceptional simplicity and flexibility, offering three different devices by adding a single mask level to standard RF CMOS. The bipolar performance of this low
cost technology allows the usage for the majority of high volume applications.

Table I Circuits applications of the SiGe:C BiCMOS technology using HBTs with $f_T$ and $f_{\text{max}}$ of 120 and 140 GHz, respectively.

<table>
<thead>
<tr>
<th>Circuit</th>
<th>Parameter</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage controlled oscillator</td>
<td>Tuning range</td>
<td>58.7 – 68.5 GHz</td>
</tr>
<tr>
<td>LC oscillator</td>
<td>Max. output frequency</td>
<td>76 GHz</td>
</tr>
<tr>
<td>Static divider</td>
<td>Max. input frequency</td>
<td>62 GHz</td>
</tr>
<tr>
<td>Dynamic divider</td>
<td>Max. input frequency</td>
<td>73 GHz</td>
</tr>
</tbody>
</table>

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References