26 GHZ COPLANAR SiGe MMICS

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ABSTRACT

First results on coplanar MMICs with SiGe HBTs are presented. The circuits are fabricated on high-resistivity Si substrates using a double-mesa HBT process. In the Ka-band, an oscillator output power of 1 dBm and 4.4 dB gain for a one-stage amplifier are achieved. This demonstrates the potential of SiGe transistors for applications in the higher microwave range.

INTRODUCTION

With the advent of SiGe Heterostructure Bipolar Transistors (HBTs) the frequency limits of Si-based active elements have been extended to frequencies above 30 GHz. This offers new perspectives for Si circuits and raises questions up to which frequency range Si MMICs can be competitive with GaAs. While results on single HBT devices and hybrid circuits have been published, the problem of integration has not been dealt with so far. This is the objective of the work presented here.

In the following, we report on recent advances in the development of SiGe MMICs in the 26 GHz range. The circuits are fabricated on high-resistivity Si substrates, which constitutes a precondition for low-loss microwave operation [1,2,3,4]. The coplanar concept is used since it provides advantages with regard to both electrical performance and process technology, such as the elimination of backside processing and easy access by on-wafer probing.

In a first step, the passive elements on high-resistivity Si substrate were characterized and the passivation-induced parasitics were investigated [5]. Together with the development of CAD models for the passive part and for the HBT this formed the basis for the second step, the fabrication of active MMICs. Ka-band amplifiers and oscillators were designed, both of them representing key subsystems for most microwave applications.

SiGe HBT

The combination of Silicon substrates with SiGe-transistors offers interesting features for monolithic integration of microwave circuits such as lower wafer costs compared with GaAs, mature fabrication technology, and good thermal and mechanical properties. Our device design relies on the double-

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heterojunction SiGe base approach with inversion of the doping levels ($N_{base} > N_{emitter}$) [6]. Due to the high base-doping level the base sheet resistance is as low as 550 Ω/□. S-parameters were measured on-wafer in common-emitter configuration up to 50 GHz. Transistors with two 1×10 μm^2 emitter fingers yield f_{max} values of about 80 GHz (by extrapolation of the maximum available gain). The MMICs were fabricated on high-resistivity silicon with $\rho > 8000$ Ωcm. The complete layer structure of the HBT was grown without interruption by MBE [6,7]. Details of the passive elements are described in [8]. The SiN-passivation had to be removed from the metal-free surface between the line metallizations. Otherwise, due to the high-resistivity substrate, surface charges in the passivation induce a parasitic conducting layer on the wafer surface that causes prohibitively high losses [5].

CIRCUIT DESIGN

Coplanar waveguides with miniaturized dimensions, i.e., 50 µm ground-to-ground spacing, are used. This keeps parasitics at discontinuities small. Based on field-level simulation by means of a 3D full-wave analysis (Finite-Difference in frequency domain) [9], equivalent-circuit type models for the coplanar discontinuities and junctions have been developed [5]. These models can easily be implemented in the commercial software environment for MMIC design.

Fig. 1 shows the layout of the 26 GHz oscillator. Since it is the first realization in this technology, the design is not yet optimized for minimum chip size. On the same reason, the selection of circuit elements was restricted to 50 Ω lines and metal-insulator-metal (MIM) capacitors. Airbridges are used to suppress the undesired slot-line mode. The MIMs serve as RF-blocks in the bias feeding. The transistor is operated in common-base configuration.

The two emitter fingers of the HBT are connected internally by an airbridge. Emitter bias is fed to the first finger whereas the second finger is connected to an open-stub that realizes capacitive feedback of the reflection-type oscillator. A second short-stub is connected to the base to generate maximum negative resistance at the collector. The connection points for DC bias are located near the low impedance point of the lines in order to minimize interfering effects. At the collector side an output circuit is designed that matches the oscillator impedance to the 50 Ω load.

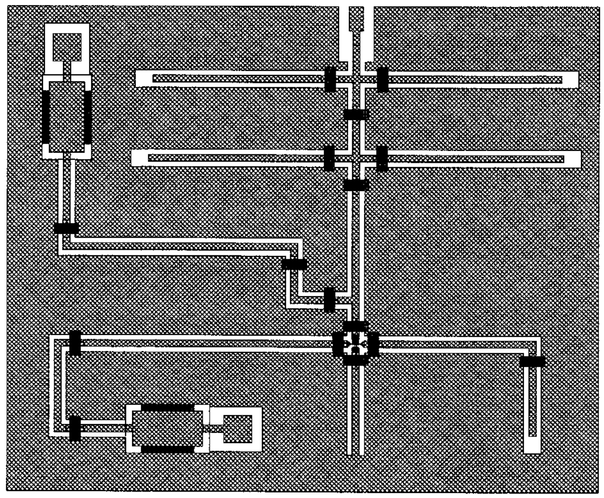

Figure 1: Layout of 26 GHz HBT coplanar oscillator.

Similarly, a HBT single-ended one-stage buffer amplifier for 26 GHz was designed [8].

RESULTS

The measured output power of the oscillator is plotted in Fig. 2 as a function of emitter current. The DC voltage V_{cb} between collector and base is fixed to 4V. The emitter to base dc voltage varies between 0.77 and 0.87 V.

A maximum output power of 1dBm @ 29.3 GHz is measured (I_c = 10 mA). The oscillation frequency is higher than designed. The shift can be attributed to the etching of the SiN passivation layer between the conductors. This step was introduced in the process after the design was completed. It causes a decrease in the CPW propagation constant. Therefore, the frequency of oscillation is shifted towards higher frequencies. Meanwhile, the influence of the passivation layer was included in the CAD models. It is described by a homogenous substrate with reduced permittivity, the value of which is calculated by a full-wave analysis [10]. Fig. 3 illustrates this model.

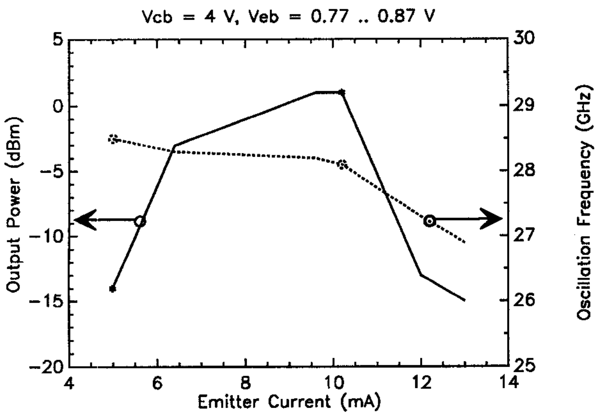

Figure 2: Oscillator output power and frequency against emitter current.

In Figs. 4 and 5, measured data of the buffer amplifier are plotted. Input and output return loss show sufficiently high values. A maximum gain of 4.4 dB is achieved.

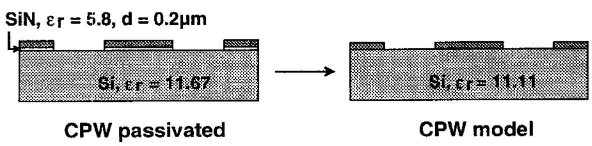

Figure 3: Implementation of the passivation layer in the CPW model.

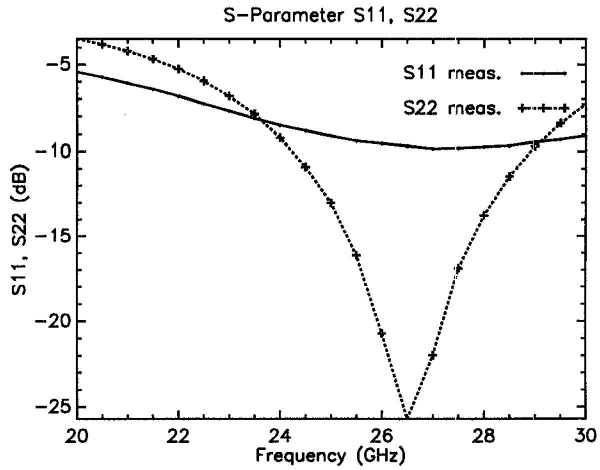

Figure 4: Measured S_{11} and S_{22} of the amplifier.

The amplifier was designed for a maximum gain at 25.5 GHz. Given the uncertainties of a MMIC technology that is still in development, the amplifier performance is in reasonable agreement with the design goal. The stability criteria are not completely fulfilled. But at a termination of 50 Ω even at frequencies below 10 GHz no oscillation tendency could be observed.

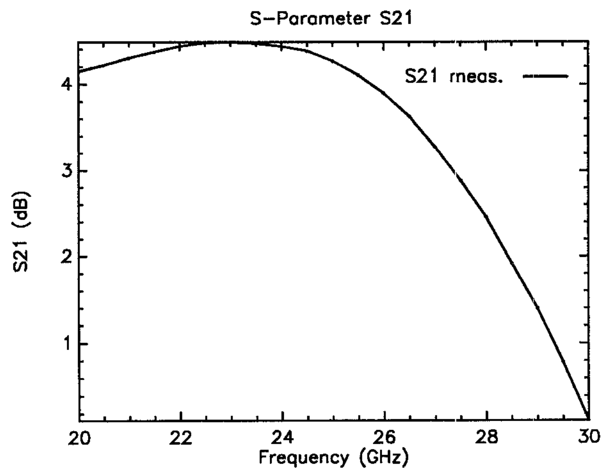

Figure 5: Measured S_{21} of the amplifier.

CONCLUSIONS

The results demonstrate the potential of SiGe-HBT based MMICs for Ka-band applications.

With regard to oscillator performance, the output power values of the first run look promising but phase noise is still a critical issue. The achieved amplifier gain of 4.4 dB represents a first result as well. Optimization of the process as well as of the circuit design should lead to gain levels that are comparable to GaAs in this frequency range. Accordingly, the future work will concentrate on process stabilization and large-signal HBT modelling.

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