A Coplanar 38-GHz SiGe MMIC Oscillator

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Abstract—**Design, technology, and first results of a coplanar Si-SiGe HBT oscillator monolithically integrated on high-resistivity silicon are reported. At 38 GHz, an oscillator output power of 2 dBm with a conversion (dc to rf) efficiency of 6% is measured.**

I. Introduction

NOWADAYS, the demand for microwave and millimeter-wave integrated circuits (MMIC's) is continuously growing. Cost is the most important issue in evaluating suitable technologies and material systems. Therefore, high-resistivity silicon ($\rho \geq 8000$ Ωcm) in conjunction with Si/SiGe/Si heterobipolar transistors (HBT's) may become an attractive candidate, even for mm-wave applications. Approaches using two-terminal Si devices, i.e., IMPATT and Schottky diodes, are already known and find applications in near-range sensors [1], [2]. Critical issues, however, are poor frequency stability and low efficiency. This stands in contrast to the requirements for mobile low-power applications and the necessity of ultra-stable oscillators in communications. Hence, three-terminal devices promise better performance. The latest developments in the fabrication of HBT's using thin SiGe alloy layers for the base lead to cut-off frequencies f_t and maximum oscillation frequencies $f_{\max}$ of 116 and 160 GHz, respectively [3]–[5].

In our approach, HBT technology is combined with coplanar design, which, in comparison with microstrip, simplifies the fabrication process and reduces cost since no backside treatment is necessary.

II. Modelling

The passive elements were extracted from three-dimensional (3-D) finite-difference field simulations [6] and compared with measured test-structures up to 100 GHz. Simple equivalent circuits were developed [7], [8] and implemented into a commercial simulation environment. The CPW-model [9] for the miniaturized coplanar lines with 50 μm ground-to-ground spacing was compiled as a user-defined model. Regarding the electromagnetic behavior, passivation acts as a thin dielectric layer and is taken into account (for details see [7]). Airbridges are used to suppress the unwanted slot-line modes.

The model of the HBT is based on a modified and adapted Gummel-Poon bipolar junction transistor (BJT) model. The main differences are an accurate determination of the parasitic elements and an extended equivalent circuit. On the other hand, due to inverse doping ($N_{\text{base}} > N_{\text{emitter}}$ and $N_{\text{base}} \gg N_{\text{collector}}$), some effects such as basewidth modulation with collector-base voltage variation (Early-effect) can be neglected for the HBT's used. The ideality factors of the diodes and the recombination currents change their values significantly compared to a common BJT. The new model ensures numerical stability for simulations in a transient and harmonic-balance simulator.

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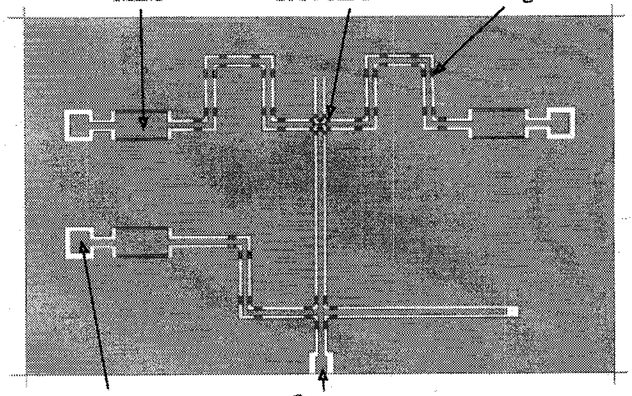

Fig. 1. Layout of the 38-GHz HBT coplanar oscillator (dimensions: 1.4 × 2.2 mm^2).

III. Oscillator Design

Since high-resistivity SiGe substrate is used, transmission-line elements can be applied as well-known from GaAs MMIC circuit design. Fig. 1 shows the layout of the 38-GHz LC oscillator. The design is not yet optimized for minimum chip size. Since this is the first SIMMWIC (silicon millimeter-wave IC) realization in this frequency range, there is still room for improvements. For the same reason, the selection of circuit elements was restricted to 50-Ω coplanar lines and MIM capacitors. The MIM's serve as RF-blocks in the bias feeding. The transistor is operated in common-base configuration.

The HBT has two nonconnected emitter fingers. Usually, when applying the common-base topology the two emitter fingers are shorted by an internal airbridge. In order to circumvent possible technological problems with this airbridge, we use two independent emitter feedings. This configuration offers the additional possibility to balance differences in the two emitters by applying different base-emitter voltages.

The design uses the canonical approach, where the aim is to minimize the number of circuit elements and to combine

TABLE I
LAYER STRUCTURE OF THE SiGe HBT

no.	layer	thickness [nm]	doping level [cm^{-3}]	type
7	E-contact	250	$2\cdot 10^{20}$	n^+ (Sb)
6	emitter	50	$1.5\cdot 10^{18}$	n (Sb)
5	EB-spacer (Ge-cont. 30%)	3	-	i
4	active base (Ge-cont. 30%)	25	$1\cdot 10^{20}$	p^+ (B)
3	BC-spacer (Ge-cont. 30%)	7	-	i
2	collector	300	$5\cdot 10^{16}$	n (Sb)
1	C-contact (BL)	$>1\mu m$	$9\cdot 10^{19}$	n^+ (As)

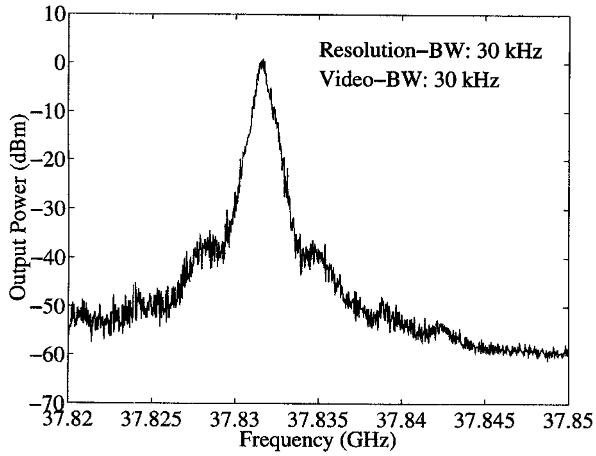

Fig. 2. Power spectrum of the 38-GHz oscillator.

elements in order to reduce losses. For example, the bias feeds for the emitters serve as frequency determining capacitance as well. In the same manner the dc connection of the collector contributes to matching the oscillator output to a nominal 50-Ω impedance.

IV. TECHNOLOGY

The device design relies on the double heterojunction SiGe base approach with inversion of the doping levels ($N_{\text{base}} > N_{\text{emitter}}$) [10]. Table I shows the layer design of the device. Due to the high base-doping level, the base sheet resistance is as low as 600 Ω/□. S-parameters were measured in common emitter configuration up to 50 GHz. Transistors with two $1 \times 10\,\mu m^2$ emitter fingers yield $f_{\max}$ values of about 80 GHz (by extrapolation of the maximum available gain). The oscillator was fabricated on high-resistivity silicon with $\rho > 8000\,\Omega cm$. The complete layer structure of the HBT (Table I) was grown without interruption by MBE [10]. The transistor fabrication process is described in detail in [11] and the fabrication of passive structures in [12].

V. MEASUREMENTS

The performance of the oscillator was tested on-wafer by means of a spectrum analyzer which has been calibrated by a reference generator and a calibrated power meter. Fig. 2 shows the power-spectrum of one measured oscillator. Due to relatively high recombination currents the noise performance is not yet satisfactory (−55 dBc/Hz @ 100-kHz offset), which presumably is due to surface effects. This technological problem will be addressed in the future. At 37.8 GHz, a maximum output power of about 2 dBm is measured.

TABLE II
FREQUENCY POWER AND EFFICIENCY OF THE MEASURED 38.25-GHz OSCILLATORS

no. of measured oscillator	frequency [GHz] nominal 38.25 GHz	output power [dBm]	efficiency [%]
1	38.2357	-8.66	0.8028
2	38.3015	-17.9	0.0585
3	38.2340	-2.36	2.1275
4	38.6806	-10.73	0.3844
5	37.8318	+2.03	5.8363

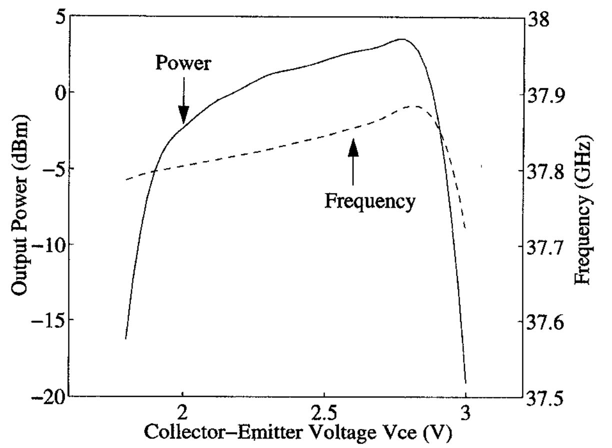

Fig. 3. Power and frequency versus collector–emitter voltage (V_{ce}).

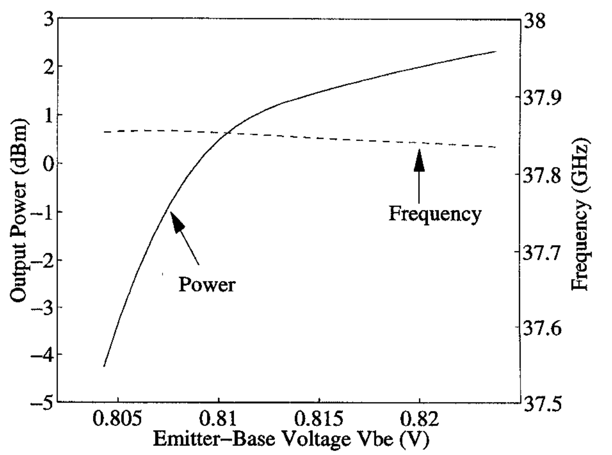

Fig. 4. Power and frequency versus emitter-base voltage (V_{eb}).

The nominal frequency is 38.25 GHz. Five different oscillators were measured. Table II shows the corresponding frequency of oscillation and output power data.

The frequency results show good agreement with the nominal value. This also demonstrates the accuracy of the large-signal simulations.

Fig. 3 shows power and frequency variation against collector–emitter voltage V_{ce}. Over the reasonable range one finds a frequency shift of only 0.5%. With increasing V_{ce} the power increases up to 3 dBm until the optimum oscillation point is left.

The change in frequency against emitter-base voltage V_{eb} can be neglected (see Fig. 4). With increasing emitter-base voltage, the power raises continuously. Overall, there is only a small dependency of frequency against bias variations.

VI. Conclusion

A coplanar oscillator with a monolithically integrated Si-SiGe HBT for 38 GHz was designed and fabricated. To the authors' knowledge, this is the first monolithic SiGe HBT oscillator in the 40-GHz range. At 38 GHz an output power of 2 dBm is measured with a conversion efficiency of 6%. The results demonstrate that state-of-the-art SiGe technology allows to fabricate MMIC oscillators with reasonable output power up to 40 GHz. Further improvements of noise behavior and output power are expected from the next technological run.

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