A Si–SiGe HBT Dielectric Resonator Stabilized Microstrip Oscillator at X-Band Frequencies

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***Abstract*— Design, fabrication, and performance of the first reported hybrid dielectric resonator oscillator (DRO) using a Si–SiGe heterojunction bipolar transistor (HBT) as the active device are described. The employed HBT with layer structures completely grown by MBE exhibits f_T and f_{max} values in the range of 38 GHz. At 9.6 GHz, an oscillator output power of 10 mW with a conversion efficiency of 17.5% is measured. Phase noise N/C$_{FM}$ of −85 dBc (1 Hz) is determined at 100 kHz off carrier.**

I. Introduction

With recent advances in Si–SiGe technology HBT's using this material system are now available. Their fundamental advantages over conventional bipolar transistors are a thin and highly doped base with low resistance leading to f_T values higher 70 GHz [1] and f_{max} values of about 40 GHz [2]. The excellent FM-noise behavior of HBT oscillators [3] in combination with economic silicon technology makes Si–SiGe HBT's attractive components for future monolithically integrated millimeter-wave oscillators on highly insulating silicon substrate (SIMMWIC technology). In this letter, as a first step in investigating the Si–SiGe HBT as active oscillator device, a hybrid microstrip DRO for X-band frequencies is designed, fabicated, and tested.

II. HBT Processing and Characterization

The complete HBT structure is grown by MBE (molecular beam epitaxy) on a high-resistivity p^--substrate with a diffused phosphorus buried layer [2]. Thickness and doping of the collector are 500 nm and 1×10^{17} cm^{-3}, respectively. The 33-nm boron doped base with a Ge content of 28% has a dopant concentration of 4×10^{19} cm^{-3}, the emitter layers are 170 nm at 1.5×10^{18} cm^{-3} and 200 nm at 3×10^{20} cm^{-3} (n^+ top contact). The devices are fabricated using a double mesa structure and a self-aligned base with respect to the emitter [2]. Because of the low intrinsic base resistance of 2000 Ω per square the f_{max} values of the fabricated devices with 1-μm emitter width always reach the f_T-values in excess of 42 GHz. Due to the high-resistivity substrate the contributions of the contact pad capacitances are negligible and hence, deembedding of the S-parameter measurements can be omitted. This technology is ideally suited for future SIMMWIC applications. A schematic cross-section of the device is plotted in Fig. 1(a). Fig. 1(b) is a micrograph of the self-aligned Si–SiGe HBT. The emitter finger can be seen at the left side of the photo. The collector contact to the buried layer is not visible. Fig. 2 shows the measured dc output characteristics of a 1 μm × 20 μm emitter device. For the oscillator circuit a 2 μm × 20 μm sized transistor with an f_{max} and f_T value of 38 GHz is used.

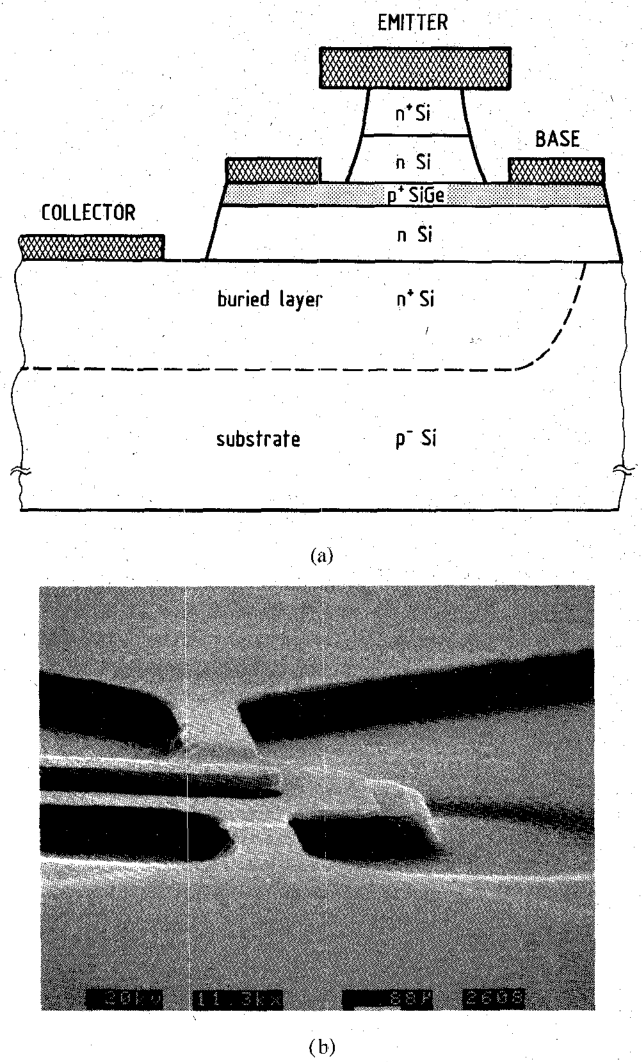

Fig. 1. (a) Schematic cross section of the Si–SiGe HBT. (b) Top view of a Si–SiGe HBT.

III. DRO Design and Performance

An oscillator topology with a series feedback configuration

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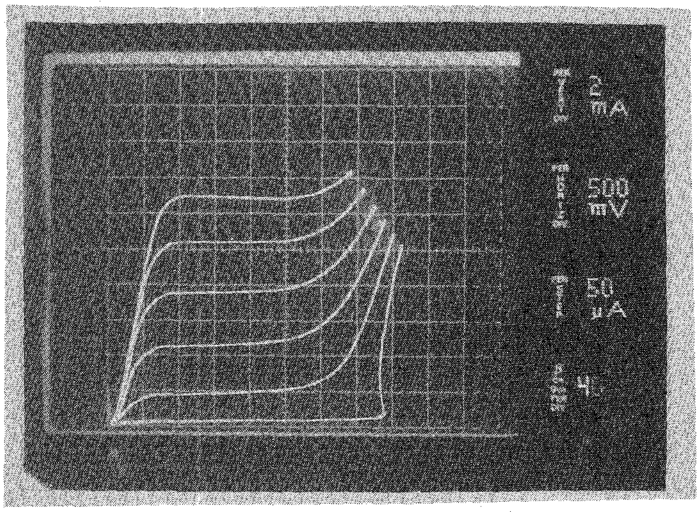
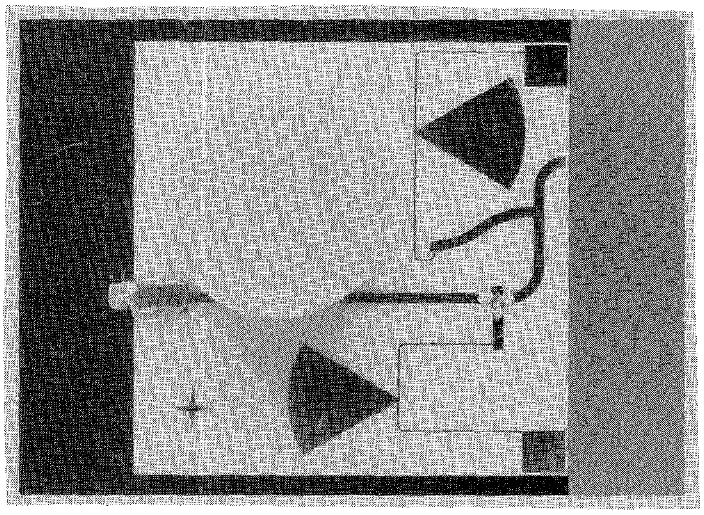
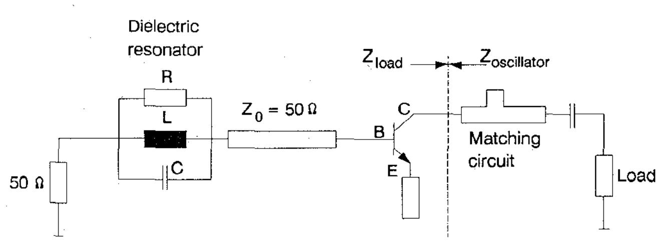


Fig. 2. Measured dc output characteristic of a 1 μm × 20 μm HBT.



(a)



(b)

Fig. 3. (a) Photograph of the DRO chip. Chip size is 10 mm × 10 mm. (b) Equivalent circuit of the oscillator.

and the HBT in common emitter operation is chosen for this work. The RF output port is at the collector side of the transistor, whereas the dielectric resonator is placed at the base side. This type of oscillator exhibits excellent frequency stability and low-phase noise due to the isolation between RF output and frequency determining element [4]. The microstrip circuit is designed using small signal S parameters of the HBT measured up to 20 GHz and inhouse developed linear CAD software. The dielectric resonator coupled to the microstripline is modeled as resonant circuit. The stub length at the transistor emitter and the distance between dielectric

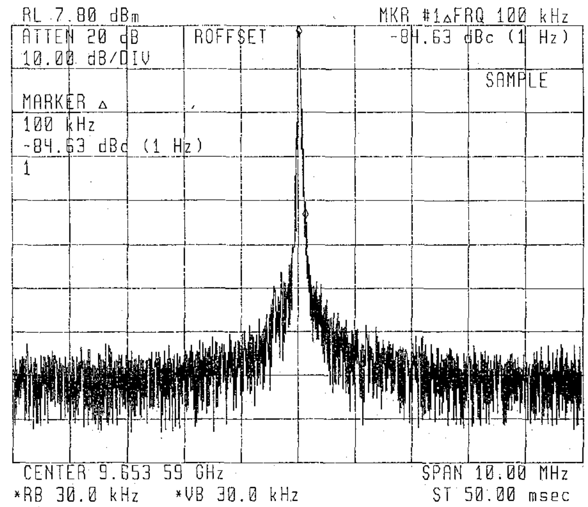


Fig. 4. Oscillator output spectrum. $P_{\max} = +10$ dBm (9.65 GHz).

resonator coupling locus and the transistor base are optimized to achieve maximum negative resistance at the output port (collector). An output circuit is designed to match the oscillator impedance to a 50-Ω load with respect to the oscillation condition $Z_{\text{oscillator}} + Z_{\text{load}} = 0$. Fig. 3(a) shows the realized oscillator circuit. Fig. 3(b) shows the corresponding equivalent circuit. The oscillator is fabricated on a 0.25-mm thick alumina substrate (substrate size is 10 mm × 10 mm). The Si–SiGe HBT chip (0.3 mm × 0.5 mm) with the same thickness as the oscillator substrate is inserted into a hole made in the substrate and connected by an electrically conductive adhesive to the microstrip lines. This technique avoids parasitic inductances of bond wires. The base termination of the transistor is formed by a stripline and a 50-Ω chip resistor adhered to the substrate. The bias networks are realized by quarter-wavelength 75-Ω lines and 60° radial stubs. A dielectric resonator with a diameter of 5.4 mm and a thickness of 2.3 mm (dielectric constant of 29, unloaded Q-value about 5000) is mounted directly on the substrate. The measured output spectrum of the DRO is plotted in Fig. 4. An RF power of 10 mW is measured at 9.6 GHz with a conversion efficiency of about 17.5% (I_B = 0.3 mA, I_C = 15 mA, U_{CE} = 3.8 V). A phase noise N/C_{FM} of –85 dBc (1 Hz) is determined at 100 kHz off carrier, which is a very good value for the first realized Si–SiGe HBT oscillator. Temperature dependency measurements yield in –10 ppm/°C between –10°C and +70°C using a 0 ppm/°C dielectric resonator.

IV. Conclusion

A Si–SiGe HBT dielectric stabilized microstrip oscillator for X-band frequencies has been designed and fabricated. At 9.6 GHz an output power of 10 mW was measured with an associated conversion efficiency of 17.5%. Future improvements in device technology will lead to an increase of $f_{\max}$ values and better phase noise making the Si–SiGe HBT mature for applications in silicon millimeter-wave integrated circuits (SIMMWIC).

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