Monolithic 77- and 94-GHz InP-Based HBT MMIC VCOs

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ABSTRACT

This paper presents the development of 77- and 94-GHz monolithic fundamental mode VCOs using InP-based HBT MMIC technology. The InP-based HBT performance was improved by base mesa undercutting the base ohmic along two sides to reduce the base-collector junction capacitor by 40% which results in f_T and f_{max} of 70 and 170 GHz, respectively. By using this improved HBT device, the 77-GHz VCO exhibits a measured oscillation frequency of 77.6 GHz with a peak output power of -3 dBm, while the 94-GHz VCO demonstrates a measured oscillation frequency of 94.7 GHz with a peak output power of -3.5 dBm. The 94-GHz VCO is the highest frequency fundamental mode oscillator ever reported using bipolar device technology.[1]

INTRODUCTION

High frequency and low phase noise oscillators are key components in millimeter-wave (MMW) systems. Fundamental mode MMIC oscillators using InP-, GaAs- and Si-based (SiGe) HBT devices have been demonstrated up to 62 GHz [1], 80 GHz [2], and 38 GHz [3], respectively. InP-based HBTs have demonstrated promising high frequency performance for both discrete devices and circuits [4]-[5] because of the superior transport properties of InP-based materials when compared with other types of HBTs. Furthermore, they exhibit lower 1/f noise than GaAs HBTs because of the lower surface recombination velocity in InP-based materials and the absence of DX centers in the emitter [6]-[7]. A comparison of phase noise performance between GaAs- and InP-based HBT MMIC oscillators using the same circuit topology at 19.5 GHz has shown that InP-based HBT VCOs demonstrate a 10-dB phase noise improvement over conventional $Al_{0.3}Ga_{0.7}As$/GaAs HBT VCOs at 1 MHz offset [8].

In this work, we further improve our 1-μm InP-based HBT frequency performance over the reported device in [1] via base mesa undercutting the base ohmic along two sides [9] to reduce the collector-base capacitance by 40%, resulting in f_T and f_{max} of 70 and 170 GHz, respectively. Using this HBT device, we have designed and fabricated a 77-GHz and a 94-GHz fundamental mode MMIC VCOs. The 77-GHz VCO exhibits a measured oscillation frequency of 77.6 GHz with a peak output power of -3 dBm, while the 94-GHz VCO demonstrates a measured oscillation frequency of 94.7 GHz with a peak output power of -3.5 dBm. To our knowledge, the 94-GHz VCO is the highest frequency fundamental mode oscillator ever reported using bipolar device technology.

DEVICE CHARACTERISTICS AND CIRCUIT DESIGN

The InP HBT MMIC process has been reported previously [8]. Fig. 1 shows the cross-section of the epitaxial layer structure for the InAlAs/InGaAs HBT device and Fig. 2 illustrates the SEM view for the undercut of the base-

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collector mesa. The 1x10 μm² quad emitter HBT shows a typical β of 22 with a turn on base-emitter voltage (V_{be}) of 0.7V at the operating current density, indicating excellent injection properties through the emitter grade. The Gummel plots revealed near ideal collector and base ideality factors with minimal β degradation at low currents. The undercut structure reduces C_{bc} by 40% resulting in f_T and f_{max} of 70 GHz and 170 GHz, respectively, at I_c = 16mA (20kA/cm²) and V_{ce} = 2V. This represents an improvement in f_T of 10 GHz and in f_{max} of 60 GHz over the standard process [1],[5],[8] without affecting dc and other RF parameters.

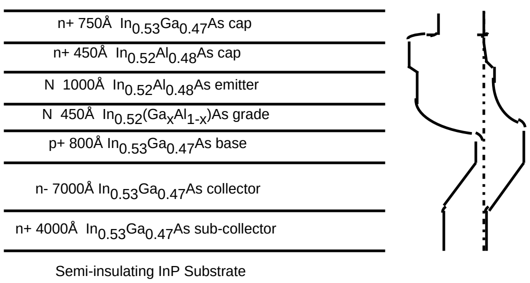


Fig. 1. Cross section of the epitaxial layer structure of an InP-based HBT devices.

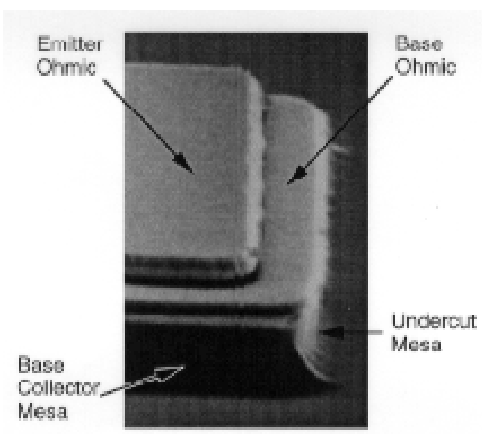
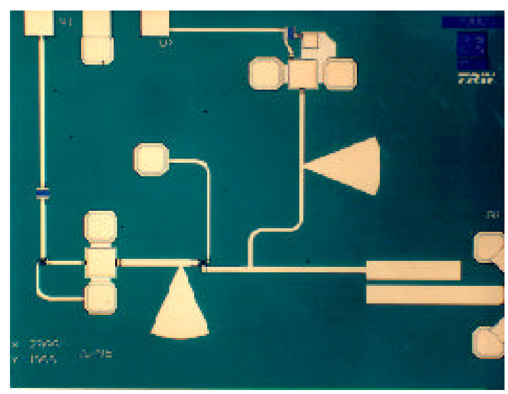
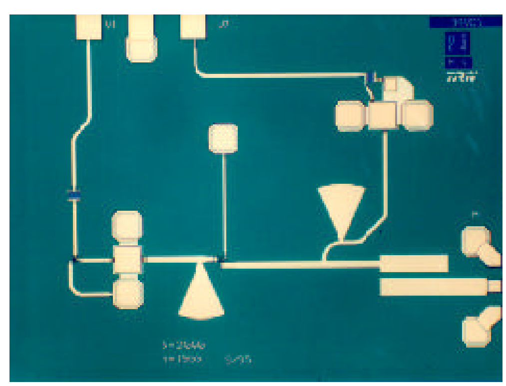


Fig. 2. SEM photograph of the base-collector mesa illustrating the undercut in the HBT device.

Fig. 3 shows the photographs of the 77- and 94-GHz monolithic VCOs. Both oscillators have a common size of 2.0 mm x 1.5 mm and the same common base design topology. The resonator of the oscillator is formed by the on-chip microstrip lines. Base-bias tuning of oscillation frequency is accomplished with a current mirror using the same size HBT. The output power is coupled out of the collector through microstrip edge coupled lines. Radial stubs provide RF bypass for the bias lines, while thin-film resistors and metal-insulator-metal (MIM) capacitors are used for the bias networks. The substrate is thinned and polished to a thickness of 100 μm and via holes are wet-etched to provide low inductance ground connections. The design procedure follows the example illustrated in [10]. A short stub RF ground provided by the quarter wavelength radial stub from the base of the HBT is used as a series feedback element to bring the device to an unstable region. Models for passive elements were obtained from full-wave EM analysis [11] to overcome the inaccuracies of quasi-static models at MMW frequencies.



(a)

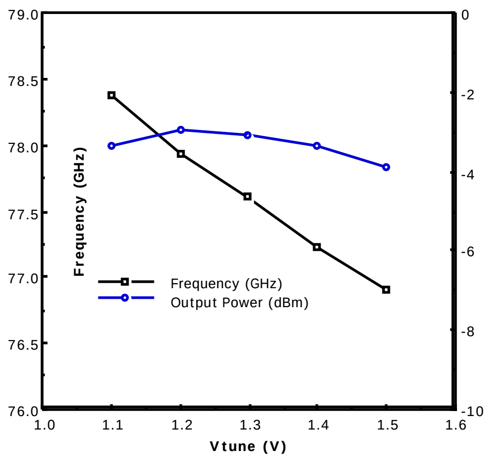


(b)

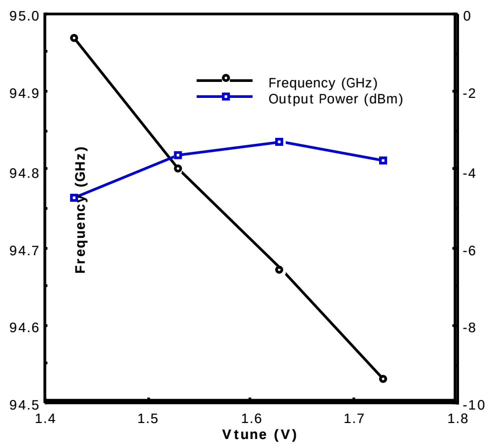
Fig. 3. Photographs of the (a) 77-GHz, (b) 94-GHz, MMIC VCO.

MEASUREMENT RESULTS

Both the 77- and 94 GHz HBT VCOs are measured via on-wafer probing. Fig. 4 plots the oscillation frequency and output power as functions of bias tuning voltage of both chips. The collector bias voltages V_{cc} are fixed at 2V. The 77-GHz VCO exhibits a measured center oscillation frequency of 77.6 GHz with a peak output power of -3 dBm and a tuning range of 1.4 GHz, while the 94-GHz VCO demonstrates a measured center oscillation frequency of 94.7 GHz with a peak output power of -3.5 dBm and a tuning range of 400 MHz. Fig. 5 illustrates the spectrum analyzer plot of the 94-GHz VCO.



(a)



(b)

Fig. 4. The plots of oscillation frequency and output power as a function of base bias tuning voltage for the (a) 77-GHz, (b) 94-GHz, MMIC VCO.

CONCLUSION

We have presented the development of 77- and 94-GHz monolithic fundamental mode VCOs using InP-based undercutting base-collector mesa HBT devices. The new HBT device has a reduced the base-collector junction capacitor by 40% which results in higher f_T and f_{max} and enable higher frequency oscillations than that of the previously reported 62-GHz oscillator [1]. To our knowledge, the 94-GHz VCO is the highest frequency fundamental mode oscillator ever reported using bipolar device technology.

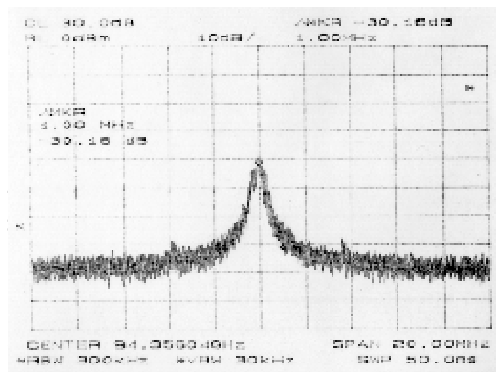


Fig. 5. The spectrum analyzer plot for 94-GHz InP-based HBT MMIC VCO.

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