A Single-Chip 94-GHz Frequency Source Using InP-Based HEMT-HBT Integration Technology

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ABSTRACT

This paper presents the development of a 94-GHz monolithic frequency source using InP-based HEMT-HBT integration technology. This single-chip frequency source consists of five sub-circuits: a 23.5-GHz HBT VCO, a 23.5-GHz HBT buffer amplifier, a 23.5 to 47 GHz HEMT frequency doubler, a 47 GHz HEMT buffer amplifier, and a 47 to 94 GHz HEMT doubler. The source chip has a peak output power of 1.6 dBm, with tuning range from 90.8 GHz to 94.3 GHz. This is the highest-level integration of millimeter-wave solid-state integrated circuits using this technology reported to date.[1]

INTRODUCTION

The development of compound semiconductor HEMTs and HBTs has enabled high performance microwave and millimeter-wave circuits. HEMTs provide high frequency (over 100 GHz) low noise and high power performance, while HBTs exhibit superior 1/f noise performance and higher linearity in amplification function. The ability of monolithic integration of HEMT and HBT is attractive since it allows circuit designer to take advantage of the strengths of each device technology. Monolithic integration of GaAs-based HEMT-HBT microwave circuits has been reported previously [1]-[3]. InP-based HEMT and HBT MMICs have demonstrated excellent performance in millimeter-wave (MMW) frequency range [4]-[5], and therefore to integrate these two devices on a single InP substrate is of great interest for higher frequency applications.

In this paper, we report the development of a 94-GHz frequency source MMIC using InP-based HEMT-HBT integration technology. This single-chip frequency source is based on a 23.5-GHz HBT voltage controlled oscillator (VCO) and buffer amplifier, followed by a 23.5 to 94-GHz HEMT frequency qudrupler which consists a 23.5 to 47-GHz doubler, 47-GHz buffer amplifier, and 47 to 94 GHz doubler. It exhibits a measured oscillation frequency of 94 GHz with a peak output power of 1.6 dBm and a 3.5-GHz tuning range. To our knowledge, this is the highest level monolithic integration of MMIC using InP-based HEMT-HBT integration technology. The same architecture has been used in the reported MMIC-based W-band source module [6] using multiple GaAs-based HEMT and HBT MMIC chips. The complete module is now demonstrated to be achieved via a single chip with great size reduction, as well as much less assembly effort.

InP HEMT-HBT INTEGRATION MMIC TECHNOLOGY

Fig. 1 shows the cross-section of the integrated HEMT and HBT devices on the same InP substrate. Conventional MBE was used for all the growths using Si and Be as n- and p-type dopants. This InP-based HEMT-HBT MMIC process relies on the selective re-growth of HEMT islands on patterned and etched HBT material. The HBT technology utilizes 1-µm minimum geometry emitters with self-aligned emitter and base metals. The profile features an InGaAlAs graded emitter-base junction for low turn-on voltage and a stable 3×10^{19} cm^{-3} Be-doped base. The HEMT technology utilizes 0.1-µm T-gates with a Si planar-doped layer in the InAlAs barrier for high channel aspect ratio and high electron mobility. The passive

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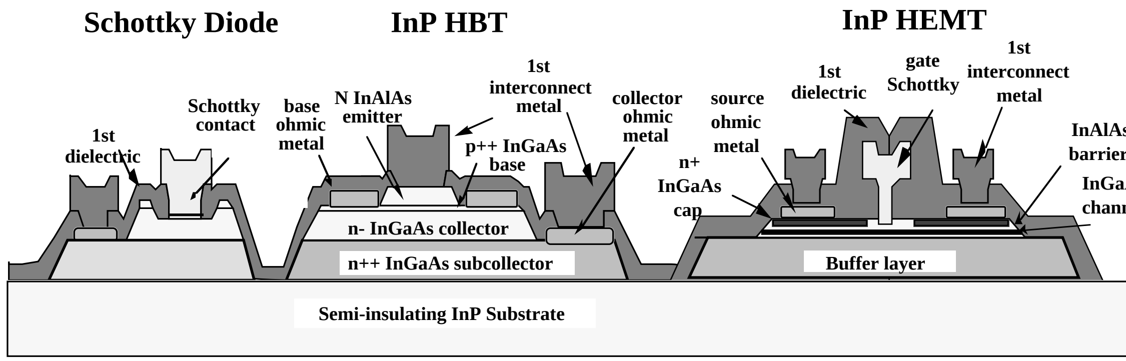
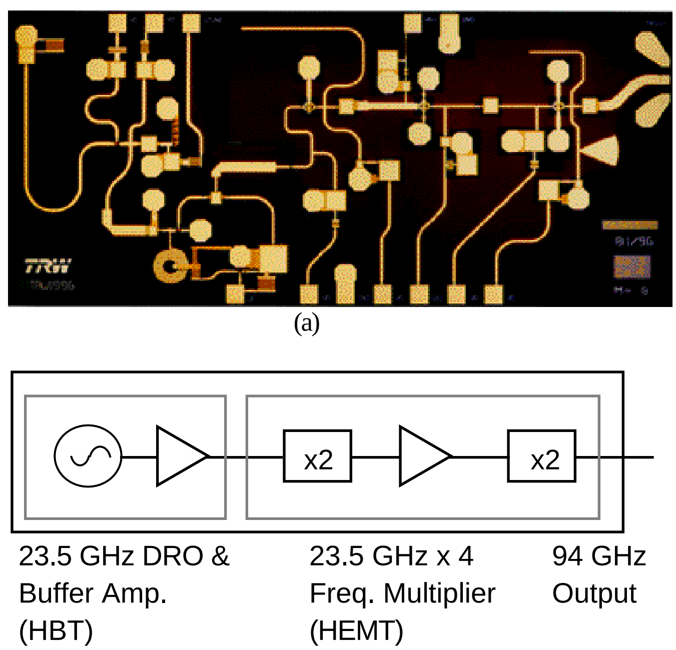


Fig. 1. Cross section of the InP-based HEMT and HBT devices.

components include NiCr resistors, SiN capacitors and air-bridged spiral inductors.The substrates were thinned to 3 mil and back-side via-holes were wet-etched and metalized. The discrete devices using this technology have demonstrated a β of 25 and an f_T of 60 GHz for HBT, while HEMTs have exhibited a G_m of 800 mS/mm and an f_T of 160 GHz on the same InP wafer [7].

CIRCUIT DESIGN AND PERFORMANCE

Fig. 2 shows the photograph and the block diagram of the InP-based HEMT-HBT integrated 94-GHz frequency source, which consists of a 23.5-GHz HBT VCO and an HBT buffer amplifier, followed by 23.5 to 94-GHz HEMT frequency qudrupler which consists a 23.5 to 47-GHz doubler, 47-GHz buffer amplifier, and 47 to 94 GHz doubler. The chip size is 3.7 mm x 1.7 mm. Both of the circuit cells are realized using microstrip-lines as matching elements. The VCO utilizes a quad 1x10 μm^2 emitter HBT and employs common-collector configuration with capacitive loading on its emitter to generate broadband negative resistance. The oscillation condition of the VCO was analyzed by ensuring the total reactance to be non-zero except at the desired oscillation frequency where the real part of the impedance remains negative. The buffer amplifier is a self-biased feedback amplifier using the same 1x10 μm^2 quad emitter size device as that of the VCO and is cascaded with the VCO to desensitize the loading effect of the output port and provide higher output power. MIM capacitors are placed in both input and output end for dc blocking, while shunt RC network are used in gate and drain bias networks for low frequency stability. The frequency doublers utilized four-finger 80 µm HEMT devices. The design follows a conventional single-ended common source configuration design procedure. An open stub providing an RF short at the fundamental frequency is employed in output matching network to suppress the fundamental signal. The HEMT device operates near its pinch-off condition in order to obtain optimal non-linearity for maximum output power of the



(b)

Fig. 2. (a) Photograph, and (b) block diagram, of the single-chip integrated InP-based HEMT-HBT 94-GHz frequency source. The chip size is 3.7 mm x 1.7 mm.

second harmonic signal, thus good dc to RF conversion efficiency can be achieved. The 47 GHz buffer amplifier is a single-ended one-stage design a four-finger 80-μm device. with the reactive matching used for both input and output matching network.

All of the individual components were fabricated separately on the same wafer and measured via on-wafer probing. The 23.5-GHz HBT VCO chip shows an oscillation frequency of 23.5 GHz with -6 dBm output power, under a collector bias voltage of 2 V with a collector current of 10 mA. The 23.5-GHz HBT buffer amplifier demonstrates 6 dB gain from 10 to 25 GHz under a collector bias voltage of 2 V with a collector current of 16 mA, as plotted in Fig. 3. The 23.5 to 47 GHz doubler exhibit a conversion loss of 0.5 dB at 24.5 GHz input with 0-dBm drive, while the 47 to 94 GHz doubler has a measured conversion loss of 7.5 dB at 48 GHz input with input power of 0-dBm drive as shown in Fig. 4. The 47 GHz HEMT buffer amplifier has a peak gain of 7.5 dB at 45 GHz and the small signal gain frequency response is illustrated in Fig. 5. The integrated HEMT-HBT frequency source chip was also on-wafer probed and exhibits 1.6-dBm peak output power and a 3.5-GHz tuning range at 94 GHz, as the spectrum analyzer plot shown in Fig. 6(a). The tuning range and output power vs. base tuning voltage is plotted in Fig. 6(b). The total dc power consumption is 74 mW.

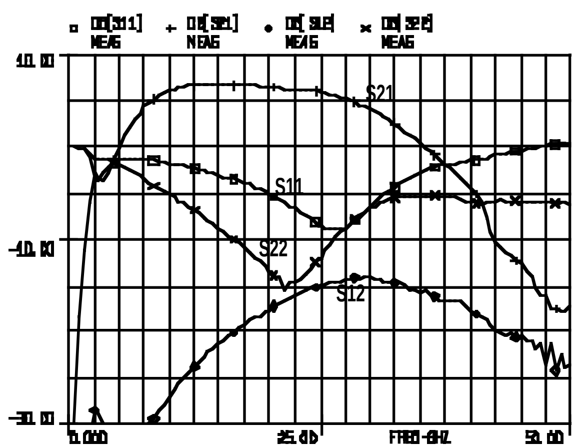
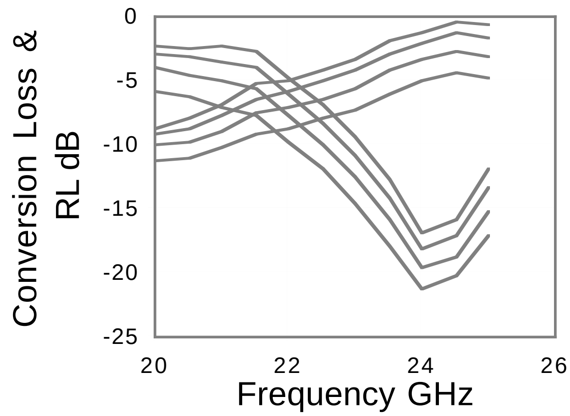
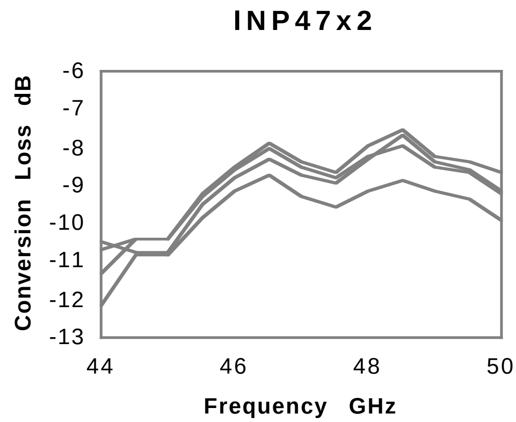


Fig. 3. The plot for the measured small signal gain and return losses of the 23.5-GHz HBT buffer amplifier from 1 to 50 GHz.



(a)



(b)

Fig. 4. The plot for the measured conversion loss and input return loss vs. input frequency at input power level from 0 to 6 dBm of (a) the 23.5-GHz to 47 GHz HEMT frequency doubler from 20 to 25 GHz, (b) the 47-GHz to 94 GHz HEMT frequency doubler from 44 to 50 GHz.

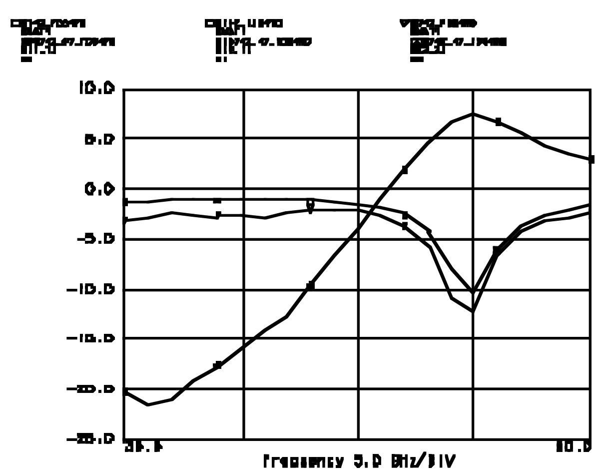


Fig. 5. The plot for the measured small signal gain and return losses of the 47-GHz HEMT buffer amplifier from 1 to 50 GHz.

SUMMARY

The development of a 94-GHz monolithic frequency source using InP-based HEMT-HBT integration technology is presented. This single-chip frequency source, consisting of five sub-circuits, is the highest-level integration of millimeter-wave solid-state integrated circuits using this technology reported to date.

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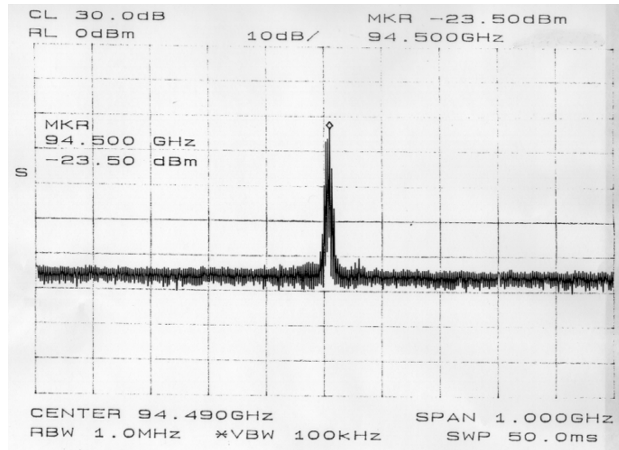
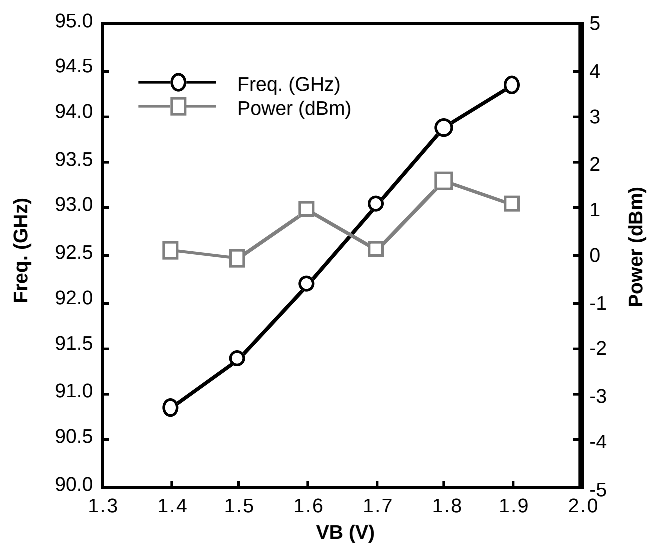


(a)



(b)

Fig. 6. The (a) spectrum analyzer plot, and (b) tuning range and output power vs. tuning voltage, for the single-chip integrated InP-based HEMT-HBT 94-GHz frequency source.