A Monolithic 24-GHz Frequency Source Using InP-Based HEMT-HBT Integration Technology

H. Wang, E. Lin, D. C. W. Lo, R. Lai, L. Tran, J. Cowles,
Y. C. Chen, T. Block, P. H. Liu, and H. C. Yen, K. Stamper*

TRW Space & Electronics Group
M5/1130, One Space Park, Redondo Beach, CA 90278
Tel: (310)-814-5708, Fax: (310)-814-4656
E-mail: huei.wang@trw.com

*U. S. Air Force Wright Laboratory
Wright-Patterson AFB, Ohio 45433

ABSTRACT

This paper presents the development of a 24-GHz monolithic frequency source using InP-based HEMT-HBT integration technology. This frequency source consists of a 24-GHz HBT voltage controlled oscillator (VCO) and a HEMT buffer amplifier, and was fabricated on a single 3-mil thick InP substrate. It exhibits a measured oscillation frequency of 24.6 GHz with an output power of 4.2 dBm. This is the first successful demonstration of MMIC using InP-based HEMT-HBT integration technology.[1]

INTRODUCTION

The development of compounds semiconductor HEMTs and HBTs has enabled high performance microwave and millimeter-wave circuits. HEMTs provide high frequency (up to 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 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 24-GHz frequency source MMIC using InP-based HEMT-HBT integration technology. This chip consists of a 24-GHz HBT voltage controlled oscillator (VCO) and a HEMT buffer amplifier, and was fabricated on a single 3-mil thick InP based substrate. It exhibits a measured oscillation frequency of 24.6 GHz with an output power of 4.2 dBm. To our knowledge, this is the first successful demonstration of MMIC using InP-based HEMT-HBT integration technology. This chip can be further integrated with a InP-based HEMT frequency quadrupler into a single-chip W-band source, following the same architecture as the reported MMIC-based W-band source module [6] using multiple GaAs-based MMIC chips, so as to reduce the module size to a great extend.

InP-BASED 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

[1] This work was supported by the US Air Force Wright Laboratory (Contract No. F33615-94-C-1560).

0-7803-4603-6/97/$5.00 (c) IEEE

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 $3x10^{19}$ 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 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].

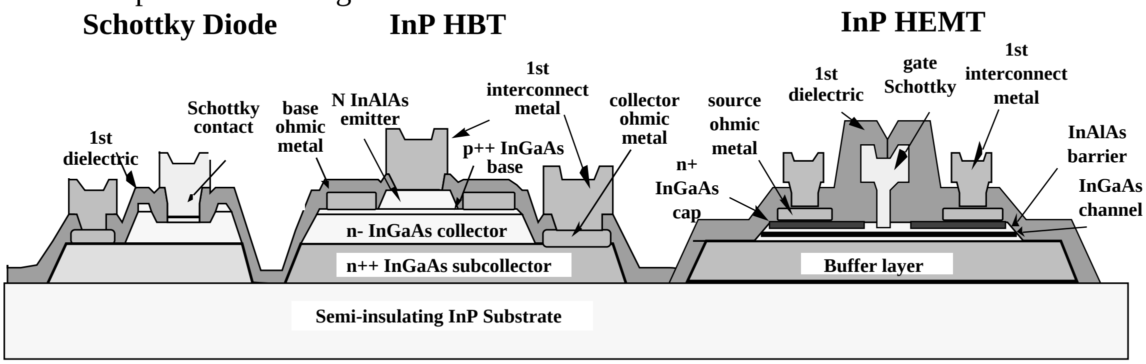

Fig. 1. Cross section of the InP-based HEMT and HBT devices.

CIRCUIT DESIGN AND MEASURED PERFORMANCE

Fig. 2 shows the photograph of the InP-based HEMT-HBT integrated 24-GHz frequency source, which consists of a 24-GHz HBT VCO followed by a HEMT buffer amplifier. The chip size is 2.1 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 designed by ensuring the total reactance equal to zero at the desired oscillation frequency where the real part of the impedance remains negative. The buffer amplifier is a single-stage single-ended design using a 4-finger HEMT with a 200-µm total gate-width. Reactive matching is used for both input and output matching network for high gain performance. 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.

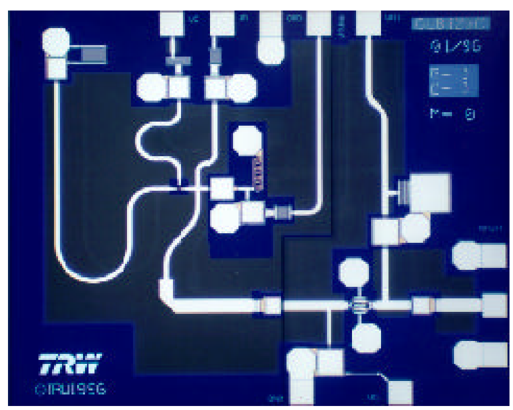

Fig. 2. Photograph of the single-chip integrated InP-based HEMT-HBT 24-GHz frequency source.

Both the 24-GHz HBT VCO and the buffer HEMT amplifier were fabricated separately on the same wafer and measured via on-wafer probing. The 24-GHz HBT VCO chip shows an oscillation frequency of 24.6 GHz with an output power of -6 dBm, under a collector bias voltage of 2V with a collector current of 10 mA. Fig. 3 plots the measured small signal gain and input/output return loss of the buffer amplifier from 1 to 65 GHz. It demonstrates 10 dB gain around 24 GHz and a peak gain of 16 dB at 27 GHz under a drain bias voltage of 0.9V with a drain current of 40 mA. The integrated HEMT-HBT frequency source chip was also on-wafer probed and exhibits 4.2-dBm output power at 24.6 GHz, as the spectrum analyzer plot shown in Fig. 4.

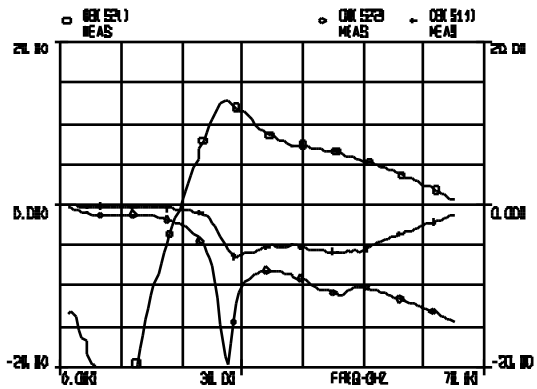

Fig. 3. The plot for the measured small signal gain and return losses of the 24-GHz HEMT buffer amplifier from 1 to 65 GHz.

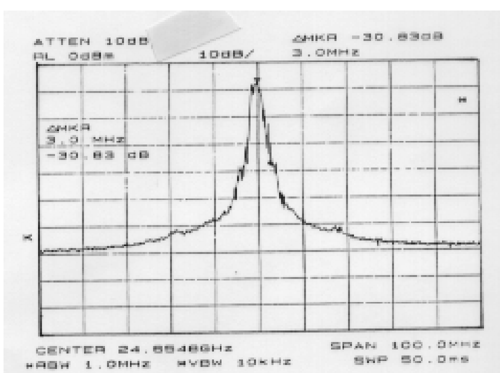

Fig. 4. The spectrum analyzer plot for the single-chip integrated InP-based HEMT-HBT 24-GHz frequency source.

CONCLUSION

We have presented the development of a 24-GHz monolithic frequency source using InP-based HEMT-HBT integration technology with a measured oscillation frequency of 24.6 GHz with an output power of 4.2 dBm. To our knowledge, this is the first successful demonstration of MMIC using InP-based HEMT-HBT integration technology.

ACKNOWLEDGMENT

The authors would like to thank S. Makishi, for layout support; R. Dia, A. Freudenthal, L. Go for MMIC process; D. Tran, N. Nguyen for backside processing; S. Esparza, P. Huang for the help in testing. Thanks also go to the members of the RF Product Center of TRW for their technical support.

REFERENCES

[1] D. C. Streit, D. K. Umemoto, K. W. Kobayashi, and A. K. Oki, “Monolithic HEMT-HBT integration for novel microwave circuit applications,” in 16th Annual IEEE GaAs IC Symposium Digest, Philadelphia, PA, Oct., 1994.

[2] D. C. Streit, D. K. Umemoto, K. W. Kobayashi, and A. K. Oki, “Monolithic HEMT-HBT integration by selective MBE,” IEEE Trans. on Electron Devices, vol. 42, no. 4, pp. 618-623 April, 1995.

[3] K. W. Kobayashi, D. K. Umemoto, T. R. Block, A. K. Oki, and D. C. Streit, “A wideband HEMT cascode low-noise amplifier with HBT bias regulation,” IEEE Microwave and Guided Wave Letters, vol. 5, no. 12, pp. 457-459, Dec., 1995.

[4] H. Wang, K. W. Chang, D. C. W. Lo, L. T. Tran, J. C. Cowles, T. R. Block, G. S. Dow, A. Oki, D. C. Streit, and B. R. Allen, “A 62-GHz monolithic InP-based VCO,” IEEE Microwave and Guided Wave Letters, vol. 5, no. 11, pp. 388-390, Nov., 1995.

[5] H. Wang, R. Lai, D. C. W. Lo, D. C. Streit, P. H. Liu R. M. Dia, M. W. Pospieszalski, and J. Berenz, "A 140-GHz monolithic low noise amplifier," IEEE Microwave and Guided Wave Letters, vol. 5, no. 5, pp. 150-152, May, 1995.

[6] H. Wang, K. W. Chang, D. Smith, G. S. Dow, K. L. Tan, A. Oki, and B. R. Allen, "A W-band source module using MMICs," IEEE Trans. on Microwave Theory and Tech., vol. 43, no. 5, pp. 1010-1016, May, 1995.

[7] L. Tran, J. Cowles, R. Lai, T. Block, P. Liu, A. Oki, and D. Streit, "Monolithic integration of InP HBT and HEMT by selective molecular beam epitaxy," 1996 InP & Related Materials Conf., Swabisch-Gmund, Germany, April, 1996.

0-7803-4603-6/97/$5.00 (c) IEEE