U-Band MMIC HBT DRO

S. Chen, S. Tadayon, T. Ho, K. Pande, P. Rice, J. Adair, and M. Ghahremani

***Abstract*— A 46.3 GHz dielectric resonator stabilized oscillator (DRO) using AlGaAs/GaAs heterojunction bipolar transistor (HBT) and monolithic microwave integrated circuit (MMIC) technology has been designed, fabricated, and characterized. The oscillator exhibits 2.6 dBm output power with 5.8% dc-to-RF efficiency and less than -132 dBc/Hz phase noise at 5 MHz offset from the carrier. To our knowledge, this is the highest frequency oscillator ever reported using HBT devices and MMIC technology.**

I. Introduction

It HAS BEEN WELL KNOWN that HBT's are superior to MESFET's and HEMT-based devices in phase noise performance as applied to microwave and millimeter-wave oscillators because the vertical currents flowing through the device interfaces are well shielded from traps in the surface regions [1]. Superiority of HBT device coupled with the advantages of a DR, high Q, small size, and temperature compensatability, makes the HBT DRO very attractive for microwave and millimeter-wave stable oscillators application [2],[3]. However, HBT DROs above Ka-band have rarely been reported partially because of limitation of the HBT's maximum oscillation frequency ($f_{\max}$) and extremely tight tolerance in DR manufacturing. In this letter, we present the design, fabrication, and measured results of a 46.3 GHz MMIC HBT DRO. Optimization of the HBT structure to achieve 120 GHz $f_{\max}$ will be briefly described. Small signal analysis of the MMIC oscillator circuit and DR coupled to microstrip line, packaging, and experimental results will be addressed. The oscillator drives a frequency doubler to generate a W-band source for missile seeker applications. To our knowledge, this is the highest frequency oscillator ever reported using HBT devices and MMIC technology.

II. HBT Performance

One of the key parameters of the HBT as an active device of an oscillator is maximum oscillation frequency, $F_{\max}$, which must be higher than the oscillator's operating frequency. At millimeter-wave frequencies, the transmission medium is relatively lossy and the resonator's Q is lower than those at microwave frequencies. $F_{\max}$ needs to be at least $1.5 \sim 2.0$ times higher than the oscillation frequency to sustain steady state oscillation. The doping profile and dimension of the HBT have been optimized for $F_{\max}$. The HBT layers were grown by metal organic chemical vapor deposition (MOCVD) technique, with the following layer structure on an SI GaAS substrate : 6 kÅ n^+ GaAs subcollector, 7 kÅ $n^-(5 \times 10^{16}\ \text{cm}^{-3})$ GaAs collector, 800 Å $p^+(6 \times 10^{19}\ \text{cm}^{-3})$ GaAs base, 1 kÅ $n(5 \times 10^{17}\ \text{cm}^{-3})$ $Al_{0.25}Ga_{0.75}As$ emitter, 300 Å n graded AlGaAs, and 2 kÅ n^+ GaAs cap layer. A new self-aligned fabrication process has been employed, featuring a deep wet etching that undercuts the base and the emitter interconnects, and forms micro-bridges for device isolation [4]. The advantages of this isolation process include critical lithographies on flat surfaces, capacitance reduction, and compatibility with thick collector layers. On-wafer microwave measurement on $2 \times 20\ \mu\text{m}^2$ HBT devices, fabricated using the process, yielded F_t and $F_{\max}$ of 60 and 120 GHz, respectively. The high value of $F_{\max}$ is primarily due to low parasitic capacitances.

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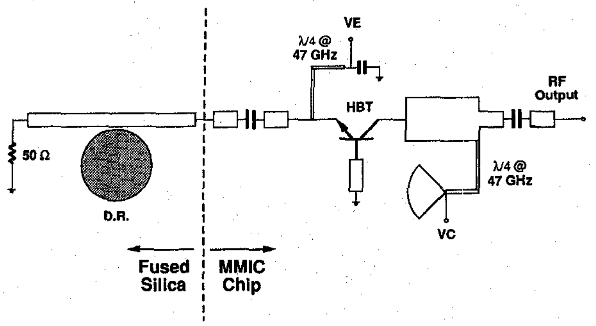
III. Oscillator Design and Measured Results

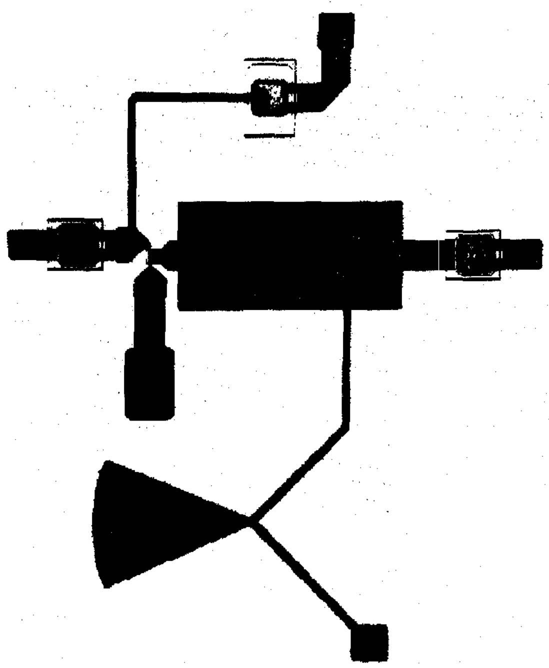
Design of the U-band HBT DRO started with modeling of the HBT device. On-wafer measurement was performed from 1 to 50 GHz using LRM calibration for different biases. Parameters extraction and curve fitting were then performed using an optimizor available from a commercial microwave circuit simulator, with the parameters calculated from device physical model as the initial guesses. Fig. 1(a) shows the schematic of the U-band reflection type DRO, which consists of a MMIC and an off-chip DR coupled to the microstrip line circuit for frequency stabilization. The HBT uses a $2 \times 20\ \mu\text{m}^2$ emitter area for optimum output power and $F_{\max}$ and is operated in a common base (CB) configuration. The short stub from the base of the HBT to ground is used as a series feedback element to bring the HBT to an unstable region. The criteria for initial oscillation condition is

$$|S'_{11}\Gamma_s| > 1$$
$$\text{Ang}[S'_{11}\Gamma_s] = 2n\pi, \quad n = 0, 1, 2, \cdots$$

S_{11} is the input reflection coefficient of the MMIC chip as show in Fig. 1(a). Since the dielectric resonator is a passive element, the reflection coefficient $|\Gamma_s|$ of the DR coupled to a microstrip line is less than one, the impedance of the short stub is chosen such that S'_{11} is greater than 1. To maintain a high loaded Q for the DR, the DR need to be loosely coupled to the microstrip line. The reflection coefficient $|\Gamma_s|$, however, reduces as the coupling is decreased. This imposes a requirement of higher $|S'_{11}|$, which is usually dependent upon the maximum available gain ($G_{\max}$) at the desired oscillation frequency. The phase relation in the initial oscillation criteria can be achieved by adjusting the location of the DR along the microstrip line between the emitter and the 50 Ω termination,



(a)



(b)

Fig. 1. (a) Schematic of the U-band series feedback HBT DRO. (b) Microphotograph of the MMIC oscillator circuit.

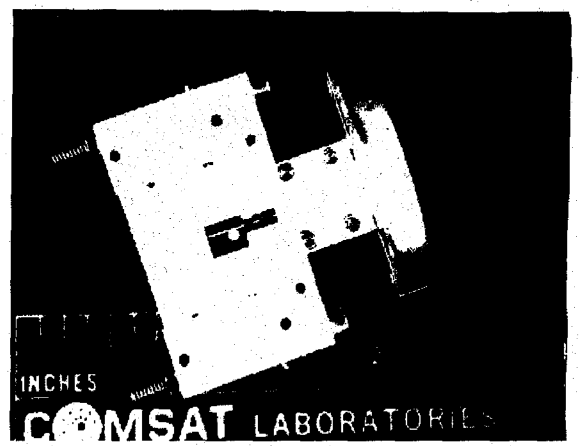


Fig. 2. Photograph of the MMIC HBT DRO mounted on the test fixture with U-band ridged waveguide to microstrip line transition.

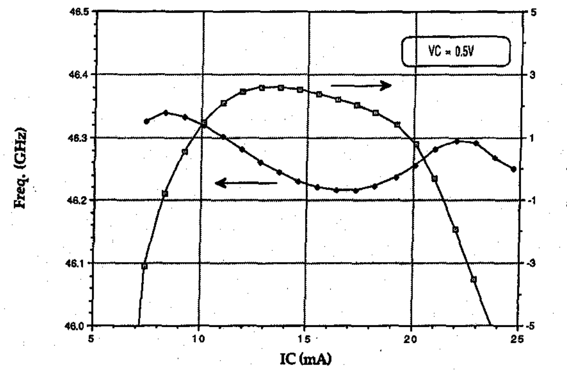


Fig. 3. Variation of output power and frequency as a function of HBT bias.

which is used to suppressed the spurious oscillation due to excitation of other resonant modes. For maximum output power delivery during steady-state oscillation, the negative resistance ($-R_{\text{out}}$) looking into the device is designed to be about three times of the load resistance [5], i.e.,

$$-R_{\text{out}} \simeq 3R_L$$

Fig. 1(b) shows the microphotograph of the MMIC chip of the oscillator circuit. Since the oscillation frequency of a DRO is mainly determined by the resonant frequency of the DR (in $TE_{01\delta}$ mode excitation), the dimension and material of the DR has to be designed and controlled accurately. In addition, the quality factor (Q) of the DR has to be sufficiently high and the coupling coefficient (β) of the DR coupled to the microstrip line has to be small enough to maintain good stability and phase noise performance. A full-wave mode-matching technique has been used to predict the resonant frequencies of a DR located on top of a substrate for various mode excitations, including TE, TM, and HE modes [6]. The aspect ratio of the DR is selected based on optimum Q and spurious free range. For the 46.3 GHz HBT DRO, the DR is made of BaZnTaTi Oxide with dielectric constant of 30. The DR is coupled to a 50 Ω microstrip line deposited on a 5-mil-thick fused silica substrate. A two-part epoxy was used to mounted DR on this 5-mil-thick fused silica substrate. There is no spacing between the DR and the microstrip conductor for the following measurement.

Fig. 2 shows the HBT DRO mounted in the test fixture with a microstrip to ridge waveguide transition, which has a typical insertion loss of 0.25 dB and return loss better than 20 dB over the frequency range from 40 to 48 GHz. The measured DRO performance versus different current is shown in Fig. 3. It has been observed that at VCE $\sim$ 2.1 V and IC $\sim$ 15 mA (emitter current density $\sim$ 5.0 $\times 10^4 \text{A/cm}^2$) the oscillator exhibits optimum output power (2.6 dBm) and voltage push (-0.97 MHz/mV). The oscillator's dc-to-RF conversion efficiency at this bias is 5.8%. Fig. 4 shows a measured output spectrum of the oscillator. The phase noise has been determined to be less than -132 dBc/Hz at a frequency offset of 5 MHz from the carrier by using a phase noise analyzer. To our knowledge, no results have been reported for a MMIC HBT DRO with a higher oscillation frequency than the one described in this letter.

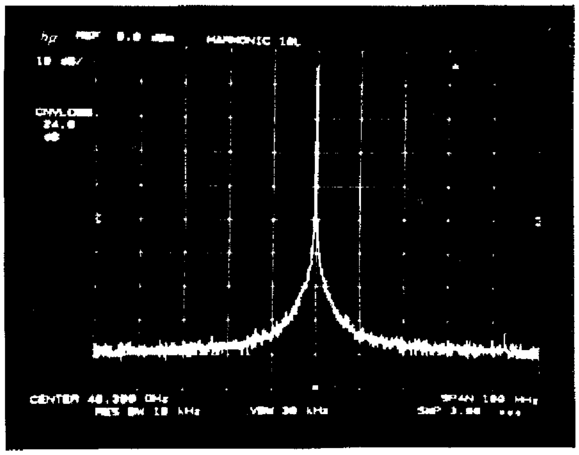


Fig. 4. Output spectrum of the HBT DRO measured with a spectrum analyzer ($V_c = 0.5$ V, $I_c = 15$ mA, output power = 2.6 dBm).

IV. Conclusion

A high performance U-band MMIC HBT DRO using a CB and series feedback configuration has been designed, fabricated, and tested. An HBT device with a $2 \times 20 \mu m^2$ emitter area and 120 GHz $F_{\max}$ was used. A rigorous mode matching method was used to characterized the dielectric resonator, which was coupled to a 50Ω line fabricated on an off-chip 5-mil-thick fused silica substrate. A simplified small signal analysis was used to verify the oscillation conditions of the oscillator circuit. The oscillator showed 2.6 dBm output power at 46.3 GHz with 5.8% dc-to-RF efficiency, and -132 dBc/Hz phase noise at 5 MHz offset from the carrier. This oscillator is used to drive a frequency doubler to obtain a 92.6 GHz signal in a source module for missile seeker application.

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References

[1] P. M. Asbeck, M. F. Chang, K.-C. Wang, D. L. Miller, G. J. Sullivan, N. H. Sheng, E. Sovero, and J. A. Higgins, "Herterojunction bipolar transistors for microwave and millimeter-wave integrated circuits," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-35, pp. 1462–1470, Dec. 1987.

[2] K. K. Agarwal, "Dielectric resonator oscillators using GaAs/(Ga,Al)As heterojunction bipolar transistors," in *IEEE MTT-S Int. Microwave Symp. Dig.*, 1986, pp. 95–98.

[3] K. Ogawa, H. Ikeda, T. Ishizaki, K. Hashimoto, and Y. Ota, "25 GHz dielectric resonator oscillator using an AlGaAs-GaAs HBT," *Electron. Lett.*, vol. 26, no. 13, pp. 1514–1516, Aug. 1990.

[4] S. Tadayon, G. Metze, A. Cornfeld, K. Pande, H. Huang, and B. Tadayon, "Application of micro-airbridge isolation in high speed HBT fabrication," *Electron. Lett.*, vol. 29, no. 1, pp. 26–27, Jan. 1993.

[5] S.-W. Chen, L.-C. Chang, and J. Y. Chin, "A unified design of dielectric resonator oscillators for telecommunication systems," *IEEE MTT-S Int. Microwave Symp. Dig.*, 1986, pp. 593–596.

[6] S.-W. Chen, "Analysis and Modeling of Dielectric Loaded Resonators, Filters, and Periodic Structures," Ph.D. dissertation, Electrical Engineering Dept., Univ. of Maryland, College Park, Dec. 1990.