35–40 GHz Monolithic VCO's Utilizing High-Speed GaInP/GaAs HBT's

K. Riepe, H. Leier, A. Marten, U. Güttich, J. M. Dieudonné, and K. H. Bachem

Abstract— **Design, fabrication and performance of Ka-band voltage-controlled oscillators (VCO's) are described. High-speed self-aligned GaInP/GaAs heterojunction bipolar transistors (HBT's) as active devices and varactor diodes using the base-collector junction of the HBT structure are implemented in the VCO's. The HBT's have an emitter area of 2×1.5 μm $\times 10$ μm and incorporate a highly carbon doped base layer and a thin GaInP hole barrier. Oscillators with center frequencies of 35, 37, and 40 GHz exhibit tuning ranges of up to 1 GHz and typical output powers of 1–3.5 dBm. Best measured phase-noise at 1 MHz off carrier is -107 dBc/Hz.**

I. Introduction

MODERN microwave systems strongly require stable and tunable low phase-noise oscillators with sufficient output power and conversion efficiency.

III–V based heterojunction bipolar transistors are being considered as excellent candidates for active devices of low phase-noise microwave oscillators, since they exhibit a low $1/f$ baseband noise and an excellent high-frequency performance [1], [2]. Most oscillator work in recent years has concentrated on the AlGaAs/GaAs and InGaAs/InP material system. At 22 GHz a free-running AlGaAs/GaAs HBT oscillator with a phase-noise of -78 dBc/Hz at 100 kHz off carrier has been fabricated [3]. An InP-based HBT VCO is demonstrated with a center frequency of 31 GHz [4]. Recently, we have realized state-of-the-art DRO's using GaInP/GaAs HBT's [5].

In this letter we report on the fabrication and performance of monolithic VCO's at Ka-band frequencies utilizing high-speed GaInP/GaAs HBT's [6], [7]. The GaInP/GaAs material system offers several advantages compared to the conventional AlGaAs/GaAs system with respect to physical properties as well as technological simplification [8].

II. Oscillator Circuit Design

The realized Ka-Band VCO's consist of a series feedback topology with the HBT in common emitter configuration. This concept has the advantage of a superior frequency stability due to the high isolation between the frequency determining elements and the output of the oscillator. The varactor diode

TABLE I
Layer Structures Used for HBT Fabrication

		I	II
GaAs	n^+	120 nm, 7×10^{18}cm^{-3}	250 nm, 5×10^{18}cm^{-3}
GaAs	n	120 nm, 7×10^{17} cm^{-3}	125 nm, 5×10^{17} cm^{-3}
GaInP	i	20 nm	20 nm
GaAs	p^+	90 nm, 6.5×10^{19}cm^{-3}	80 nm, 6×10^{19}cm^{-3}
GaAs	n^-	250 nm, 3×10^{16}cm^{-3}	400 nm, 3×10^{16}cm^{-3}
GaInP	i	10 nm	20 nm
GaAs	n^+	585 nm, 7×10^{18}cm^{-3}	600 nm, 5×10^{18}cm^{-3}

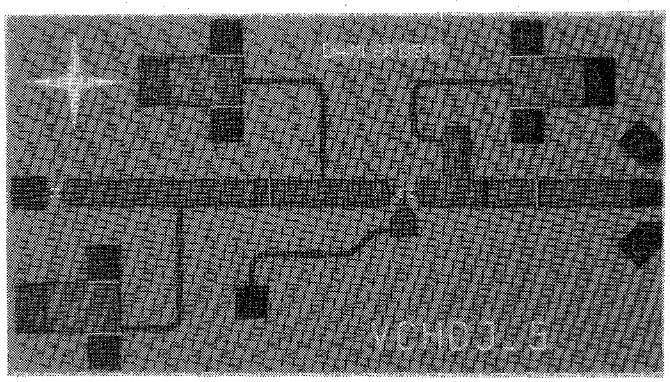

Fig. 1. Photograph of a VCO chip.

is placed between transistor base and ground. The microstrip circuits are designed using small-signal S-parameters of HBT, varactor up to 40 GHz, and linear CAD software. Complex subcircuits are characterized by an electromagnetic 2.5 D simulator.

III. VCO Fabrication

The layer sequences of the fabricated 2-in. MOCVD-grown wafers are given in Table I. The HBT process utilizes a conventional mesa approach and a self-aligned base metallization with respect to the emitter stripe. Standard optical lithography, selective wet etching, and a multi-energy proton isolation were applied. GeNiAu and TiPtAu metallizations were used as the contacts for the n- and p-type layers, respectively. The HBT's exhibit two emitter fingers with an emitter area of 2×1.5 μm $\times$ 10 μm. For this type of HBT layout, the current-gain cutoff frequency is $f_T = 60$ GHz and the maximum frequency of oscillation is $f_{\max} = 80$ GHz.

The varactor diode is defined using the base-collector pn-junction diode of the HBT structure. The chip (see Fig. 1)

Manuscript received April 5, 1994. This work was supported by the European Community (ESPRIT project 5032 AIMS) and by the German Ministery of Research and Technology (Contract No. TK 0354/5).
K. Riepe, H. Leier, and A. Marten are with Daimler-Benz AG, Research Center Ulm, 89081 Ulm, Germany.
U. Güttich and J. M. Dieudonné are with Deutsche Aerospace AG, 89070 Ulm, Germany.
K. H. Bachem is with Fraunhofer Institut für Angewandte Festkörperphysik, 79108 Freiburg, Germany.
IEEE Log Number 9403324.

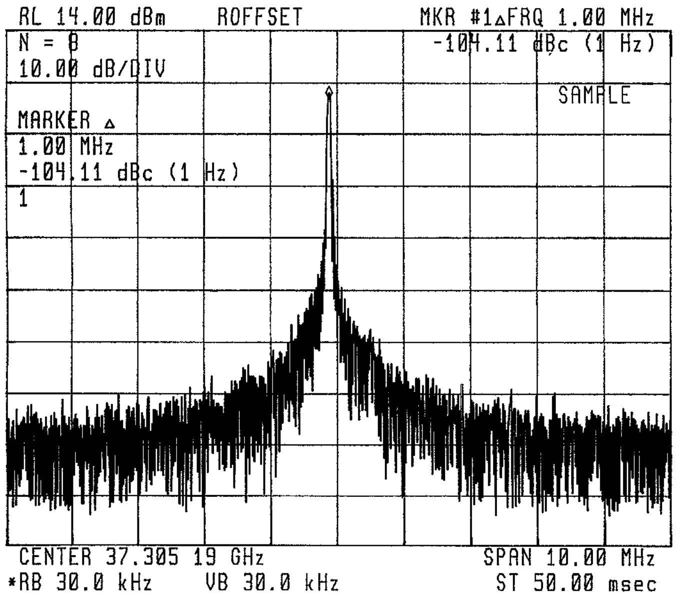

Fig. 2. Output spectrum of the 37-GHz VCO (structure II).

is fully passivated with a Si_3N_4 layer that is also used as the insulator for the MIM capacitors. Electroplated gold was used to form the transmission lines and the airbridges for the interconnections. After thinning the substrate to 150 μm, the via-holes were formed by dry etching. Sputtered and electroplated gold was used for the backside metallization.

IV. Oscillator Performance

VCO's at 35, 37, and 40 GHz have been fabricated and analyzed. The RF-performance of the VCO's has been measured in a low-insertion-loss microstrip test fixture. The phase noise is determined by using a HP 70000 spectrum analyzer.

Fig. 2 shows a typical output spectrum of the 37-GHz VCO. An output power of 2.3 dBm is reached in this case at a varactor and HBT bias of $U_{\text{var}} = 0$ V, $U_{\text{CE}} = 3$ V, $I_{\text{B}} = 2$ mA, and $I_{\text{C}} = 17$ mA. The 37-GHz VCO's can be tuned between 36.2 and 37.3 GHz with only a slight change in output power. In Fig. 3 the tuning behavior of the 40-GHz VCO is shown. The output power varies only slightly with the tuning voltage for $U_{\text{var}} \geq 1$ V, very similar to the behavior of the 37-GHz VCO's. However, the absolute value of the output power ($\approx$ 1 dBm) is lower compared to the 37-GHz VCO's. This can be explained in part by the reduced power gain at higher frequencies and by the differences in the chip design. For voltages above $U_{\text{var}} = 3$ V, the frequency tuning behavior of the 40-GHz VCO saturates. This corresponds to a completely depleted varactor diode ($d = 400$ nm) and a subsequent saturation of the varactor capacitance.

The output power and phase-noise of the 35-GHz VCO as a function of base current is shown in Fig. 4. Phase-noise levels as low as -107 dBc/Hz @ 1 MHz and -80 dBc/Hz @ 100 kHz off carrier have been measured. As expected, the phase noise increases with increasing base current. This behavior corresponds to the increase of $1/f$ noise of HBT's with increasing base current.

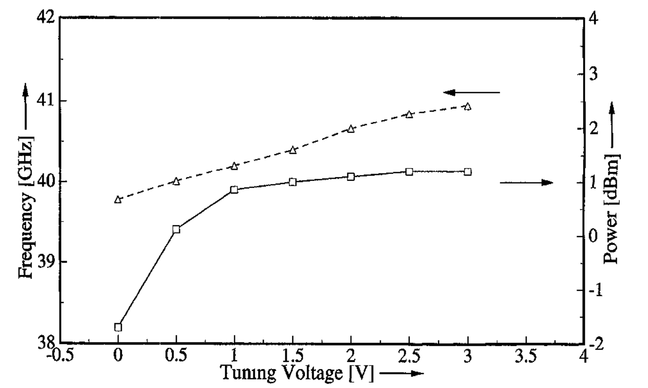

Fig. 3. Tuning behavior of the 40-GHz VCO (structure II).

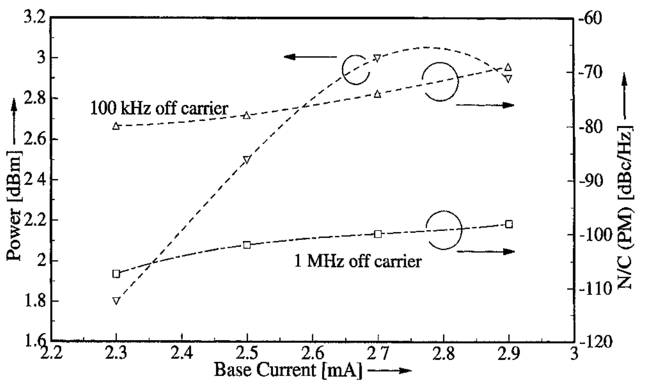

Fig. 4. Output power and phase noise versus base current of the 35-GHz VCO (structure I).

V. Conclusion

Monolithic VCO's at Ka-band have been developed utilizing high-speed GaInP/GaAs HBT's. Tuning bandwidth of more than 1 GHz and phase-noise levels smaller -100 dBc/Hz @ 1 MHz and -80 dBc @ 100 kHz off carrier have been achieved. These results make the GaInP/GaAs HBT's attractive candidates for active elements in low phase-noise millimeter-wave oscillators.

Acknowledgment

The authors would like to thank S. Heuthe, A. Geyer, H. Haspeklo, and J. Wenger for technological and software assistance. The continuous support of this work by P. Narozny and H. Dämbkes is gratefully acknowledged.

References

[1] P. M. Asbeck, M.-C. F. Chang, J. A. Higgins, N. H. Sheng, G. J. Sullivan, and K.-C. Wang, "GaAlAs/GaAs Heterojunction Bipolar Transistors: Issues and Prospects for Application," *IEEE Trans. Electron Devices*, vol. 36, no. 10, pp. 2032–2042, 1989.
[2] T. Ishibashi, O. Nakajima, K. Nagata, Y. Yamauchi, H. Ito, and T. Nittono, "Ultra-High Speed AlGaAs/GaAs Heterojunction Bipolar Transistors," *IEDM Tech. Dig.*, pp. 826–829, 1988.
[3] N. Hayama, J. Shimizu, and K. Honjo, "Large-Signal Parameter Modeling for AlGaAs/GaAs HBT and Its Application to a Monolithic 22 GHz

Oscillator," *IEICE Trans. Electron.*, vol. E75-C, no. 6, pp. 683–688, 1992.

[4] K. W. Kobayashi, L. T. Tran, S. Bui, J. Velebir, D. Nguyen, A. K. Oki, and D. C. Streit, "InP Based HBT Millimeter-Wave Technology And Circuit Performance to 40 GHz," *IEEE MMIC Symp. Dig.*, pp. 85–88, 1993.

[5] U. Güttich, H. Leier, A. Marten, K. Riepe, W. Pletschen, and K.-H. Bachem, "K-Band Dielectric Resonator Oscillator Using a GaInP/GaAs HBT," in *Proc. 20th Int. Symp. on GaAs and Related Compounds*, 1993, Freiburg.

[6] H. Leier, A. Marten, K.-H. Bachem, W. Pletschen, and P. Tasker, "High Speed Selfaligned GaInP/GaAs HBBTs," *Electron. Lett.*, vol. 29, no. 10, pp. 868–870, 1993.

[7] H. Leier, U. Schaper, and K.-H. Bachem, "High Performance GaInP/GaAs Hole Barrier Bipolar Transistors (HBBTs)," in *Proc. 20th Int. Symp. on GaAs and Related Compounds*, 1993, Freiburg.

[8] M. J. Mondry and H. Kroemer, "Heterojunction Bipolar Transistor using a (Ga,In)P Emitter on a GaAs Base, Grown by Molecular Beam Epitaxy," *IEEE Electron Dev. Lett.*, vol. EDL-6, no. 4, pp. 175–177, 1985.