A LOW-NOISE Ku-BAND AlGaAs/GaAs HBT OSCILLATOR

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ABSTRACT

This paper describes design consideration, fabrication and performance for the first low phase noise Ku-band oscillator implemented using a fully self-aligned AlGaAs/GaAs heterojunction bipolar transistor (HBT). The transistor has a measured collector current 1/f noise power density of $10^{-19}A^2/Hz$ at f=400Hz for a collector current of 1.2mA. On the other hand, the developed free-running oscillator represents an output power of 6dBm at 15.5GHz with a SSB FM noise of −65dBc/Hz at 10kHz off-carrier. The noise level is 24dB lower than that for a GaAs FET oscillator, and 2dB lower than that for a Si VCO, respectively. These experimental results give an indication of the low noise, high frequency oscillator performance available with HBTs.

I. INTRODUCTION

With rapid advances in the microwave communication technology, increasing demands for low noise oscillators operating at these frequencies have become more evident. Currently available oscillators fabricated with GaAs FETs suffer from a high phase noise level which comes from 1/f noise generated mainly due to the existence of large numbers of surface trap centers in the GaAs FETs [1]. On the other hand, Si bipolar transistors, featuring appreciable 1/f noise behavior, exhibit excellent applicability to low phase noise oscillators, which are, however, available only at low frequencies. Since the notable 1/f noise characteristics of Si bipolar transistors are due to their vertical structure which can feature drastically small numbers of surface recombination traps [2], it is worthwhile to develop oscillator circuits employing HBTs with can therefore offer both low-noise and high-frequency performance. Low phase noise characteristics of HBT oscillators have been so far experimentally verified at 4GHz [3],[4].

This paper deals with development of a low phase noise 15.5GHz oscillator using a fully self-aligned HBT, which realizes less surface recombination area. The fabricated oscillator represents a free-running phase noise of −65dBc/Hz at 10kHz off-carrier, which is 24dB and 2dB lower than that for a GaAs FET oscillator and a Si VCO, respectively.

The present work reports the 1/f noise characteristics for the fully self-aligned AlGaAs/GaAs HBT, and the design considerations and low noise performance for the Ku-band oscillator implemented using this device.

II. DEVICE STRUCTURE AND PERFORMANCES

A cross sectional view of the HBT used in the oscillator circuit is shown in Fig. 1. The device employs SiO_2 sidewalls to fabricate both base and collector contacts self-aligned with respect to the emitter mesa using a single photoresist mask [5]. In this structure, separation between base and emitter contacts, as well as between base and collector contacts, defined by the SiO_2 sidewall width, is as small as 0.2μm for drastic reduction in the surface recombination region, and thus drastic reduction in the 1/f noise.

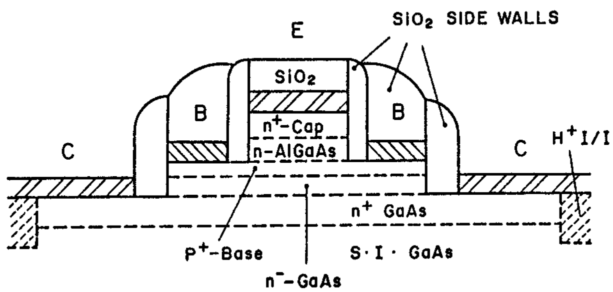

Fig. 1 Cross section for fully self-aligned AlGaAs/GaAs HBT used in the oscillator circuit.

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Table I shows the epitaxial layer structure used for the HBT fabrication. The layers are grown by molecular beam epitaxy on a lightly Cr-doped semi-insulating GaAs substrate. The structure mainly consists of a 0.15μm, $n=3\times10^{17}cm^{-3}$, $Al_{0.25}Ga_{0.75}As$ emitter; a 0.08μm, $p=4\times10^{19}cm^{-3}$, GaAs base; and a 0.5μm, $n=5\times10^{16}cm^{-3}$, GaAs collector.

Fabricated 1.5μm×10μm emitter HBTs exhibit typical common emitter dc current gain $\beta=30$, transconductance $g_m=30mS$, maximum oscillation frequency $f_{max}=27GHz$, and cut off frequency $f_T=47GHz$.

Table I MBE layer specification for fully self-aligned HBT.

Layer	Thickness (Å)	Doping (cm⁻³)	Al(In) Composition
n^+-InGaAs	500	2E19	0.5
n^+-InGaAs	750	2E19	0.5 → 0
n^+-GaAs	500	6E18	0
n-AlGaAs	300	3E17	0 → 0.25
	1500	3E17	0.25
	200	3E17	0.25 → 0
	100	0	0
p^+-GaAs	800	4E19	0
n^--GaAs	5000	5E16	0
n^+-GaAs	4000	3E18	0

Fig. 2 shows a measured collector current noise power spectrum for a 1.5μm×10μm emitter HBT. To observe the 1/f noise, a 1kΩ feedback resistor was inserted between the base terminal and ground, to reduce thermal noise power at the collector terminal. Moreover, the base terminal was RF-grounded to suppress external noise. The spectra clearly show a noise level 1/f dependence. The power density of $1\times10^{-19}A^2/Hz$ is achieved at f=400Hz for a collector current $I_c=1.2mA$. The noise level is 10dB and 40dB lower than that for a non self-aligned HBT and a GaAs FET at the same base-band frequency, respectively [6][7]. The 1/f noise corner frequency for the fully self-aligned HBT is 400Hz. However, the non self-aligned HBT and the GaAs FET show corner frequencies exceeding 1kHz and 100kHz, respectively.

These indicate that fully self-alignment technology application to HBTs for reduction in the base surface recombination area plays an important role in improving device 1/f noise behavior.

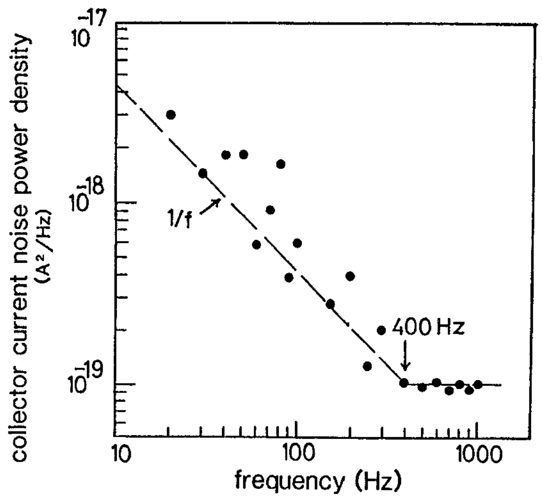

Fig. 2 Base band noise performance for fully self-aligned AlGaAs/GaAs HBT.

III. OSCILLATOR CIRCUIT DESIGN

Fig. 3 shows an equivalent circuit for the HBT oscillator having a series feedback configuration.

A small signal design technique was applied to optimize the oscillator circuit parameters. Using measured S-parameters for the device at frequency range of 0.1-20.1GHz, a Super-Compact CAD program was used to determine feedback elements L_B and L_E for realizing an impedance $(-Z_{in})$ with a sufficient small signal negative resistance value, to initiate oscillation, at the collector terminal. Simulation results indicated the circuit potential for oscillation at any single frequency in a 14-17GHz range for the $L_B=0.1nH$ and $L_E=1.3nH$ optimum values. Loaded quality factor, Q_L, for the circuit impedance is estimated as low as 10-20.

Then, load impedance Z_L, consisting of the transmission lines Z_1, Z_2, and Z_3 and 50Ω load resistance, was optimized to satisfy oscillation condition at 15.5GHz, and to provide a perpendicular impedance locus Z_L to the device line Z_{in}, at the operating point, for minimizing device-circuit interaction effects on the oscillator phase noise characteristics [8].

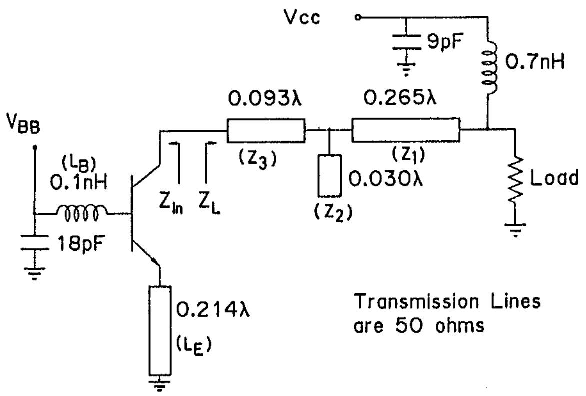

Fig. 3 An equivalent circuit for Ku-band HBT oscillator.

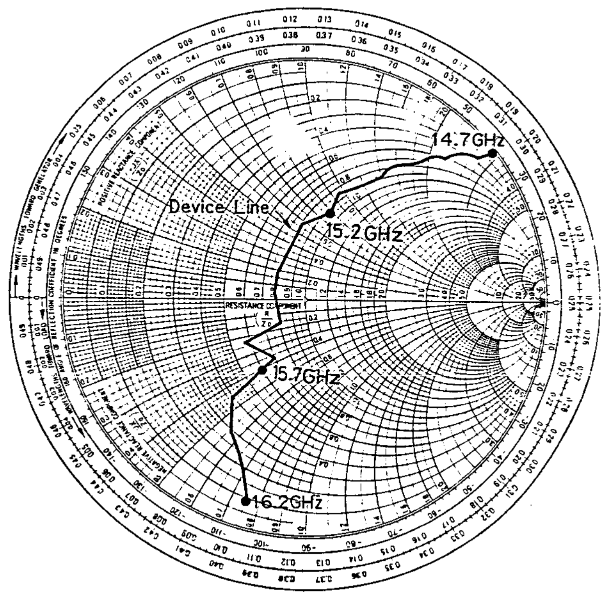

Fig. 4 Measurement small signal device line (−Zin) for fabricated oscillator.

IV. CIRCUIT FABRICATION AND RF PERFORMANCE

Based on the simulation results, an oscillator circuit was constructed using the microstrip circuit on a 0.26mm alumina substrate. The feedback elements as well as matching network were realized using 50Ω lines.

Fig. 4 shows the measured small signal device line (Z_{in}) for the fabricated oscillator. From the figure, the circuit has the potential to oscillate at a frequency in the range 14.6-16.3GHz, which reasonably agrees with the simulation results.

Oscillator performances versus both collector and base voltages are shown in Figs. 5 and 6, respectively. Oscillation started at a collector voltage V_{CE} as low as 2.0V and an output power as high as 6dBm in a 50Ω load at 15.5GHz, with a collector efficiency of 13 percent was achieved.

To investigate the oscillator noise performance, the SSB FM noise normalized to 1Hz bandwidth was measured. Results for off-carrier frequencies up to 200kHz are shown in Fig. 7. The figure indicates SSB FM noise levels of −96dBc/Hz, −65dBc/Hz, and −34dBc/Hz, respectively, at 100kHz, 10kHz, and 1kHz off-carrier. Despite application of a low Q_L load impedance, the free-running oscillator phase noise was comparable to a 16.2GHz silicon VCO giving −63dBc/Hz at 10kHz off-carrier [9], and 24dB lower than phase noise of a 14GHz GaAs FET oscillator giving −41dBc/Hz at 10kHz off-carrier [10].

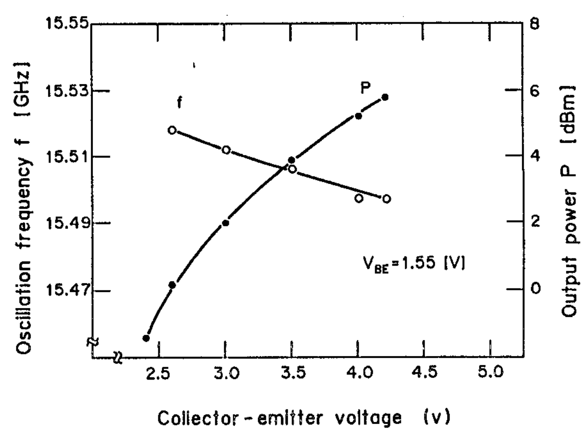

Fig. 5 HBT oscillator performance versus collector voltage.

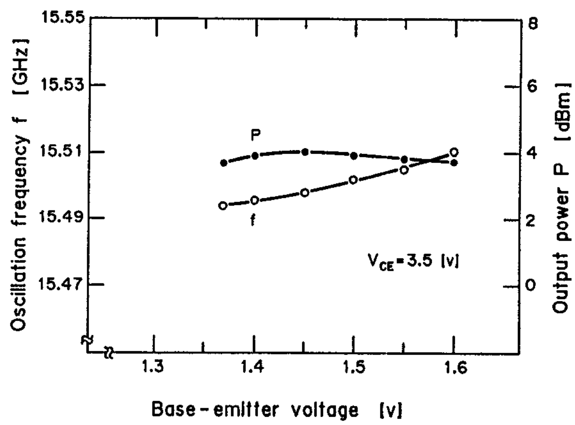

Fig. 6 HBT oscillator performance versus base voltage.

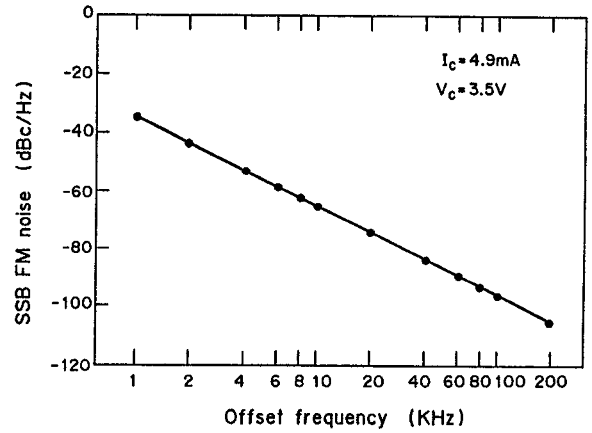

Fig. 7 SSB FM noise performance for the 15.5GHz free-running HBT oscillator.

V. CONCLUSION

It has been demonstrated that significant reduction in 1/f noise can be realized using fully self-aligned AlGaAs/GaAs HBTs. Applying the device, a microstrip oscillator, operating at Ku-band frequencies, has been designed, fabricated, and tested. The developed free-running oscillator, operating at 15.5GHz, represents a SSB FM noise level of −65dBc/Hz at 10kHz off-carrier. Further improvement in the phase noise is possible using high Q circuits, such as dielectric resonators. These experimental results give an indication of the low noise microwave and millimeter-wave oscillator performance available with HBTs.

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