Study of 1/f and 1/f^2 Noise for InP DHBT

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Abstract

This work reports experimental data comparing the low frequency noise spectrum of InP based HBTs. Double heterojunction device structures are examined with and without surface passivation ledges.

INTRODUCTION

Compound semiconductor InP heterojunction bipolar transistors (HBTs) hold great promise for ultra high-speed analog microwave circuit applications. The low frequency noise characteristics of HBTs are of interest in the design of low phase noise microwave oscillators where such noise can be upconverted to near carrier frequencies and appear as phase noise. [1]-[2]

In most HBTs, the generation-recombination current in the base-emitter junction and the exposed base surface are the dominant sources of 1/f noise. It has been shown that by using a thin depleted AlGaAs surface passivation ledge the 1/f noise of AlGaAs/GaAs HBTs can be significantly reduced, by as much as 17dB, through a reduction in base surface recombination. [3] However, because the recombination velocity of the InP/InGaAs system is much lower than in the AlGaAs/GaAs system, it is relevant to examine whether a similar result will be obtained for the InP/InGaAs system. This work examines low frequency noise characteristics of InP/InGaAs double heterojunction (DHBT) devices with and without surface passivation ledges.

DEVICE STRUCTURE

The devices used in this study were grown by commercial MBE on semi-insulating Fe-doped InP substrates. All devices used in this study had dimensions 2x10μm^2. Device layer structure information is shown in Table 1. Non-ledge devices have identical emitter, base, and collector layers, but do no have the etch stop and ledge. Ledge devices were fabricated using the double etch stop ledge (DESL) process. Non-ledge devices were have self aligned bases.

TABLE I
DEVICE LAYER STRUCTURE

Layer	Material	Thickness Å	Doping cm^{-3}
Emitter	InP	750	5E+13
Etch Stop	InGaAs	50	3E+17
Ledge	InP	250	3E+17
Base	InGaAs	550	3E+19
Collector	InP	7,500	2E+17

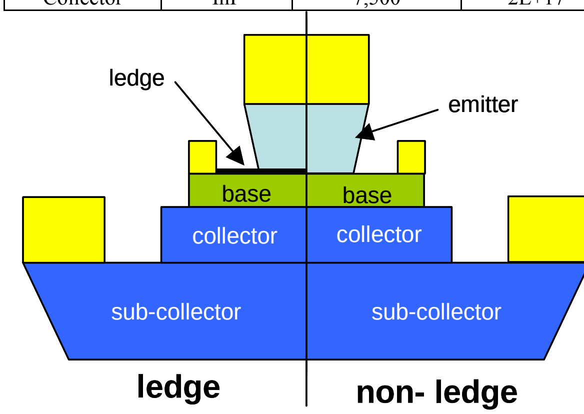

Figure 1: diagram comparing ledge and no-ledge HBTs

EXPERIMENTAL SETUP

The collector noise current was acquired using the setup shown in figure 2. RF GSG probes are used to probe the device on wafer. The collector-emitter side of the device is connected by the RF probe to a Stanford Research SR570 current amplifier. The input of the SR570 includes circuitry to bias the collector-emitter side of the device as described in [4]. A current amplifier is used instead of a voltage amplifier because with a voltage amplifier the output resistance of the device must be known to calculate a collector current. Since an HBT is a current based device, the use of a current amplifier saves time and simplifies the measurement process. The output of the SR570 connects to an HP 8565E spectrum analyzer. The base-emitter side of the device is biased with a low noise bias network powered by a battery.

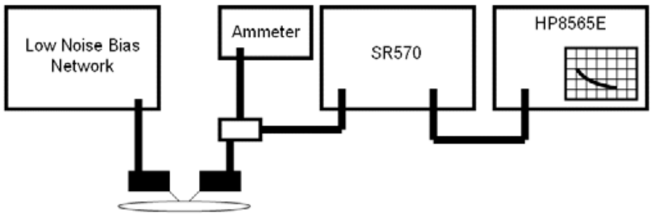

Figure 2: Low frequency noise setup. The ammeter can bet switched out of the measurement path during actual measurement.

A low noise bias network is used instead of a HP4142 or other standard DC source because low frequency noise from the source itself, including a strong signal at 60Hz from the source's AC power will distort the device's noise spectrum. The DC bias network has several important features that are outlined below in figure 3.

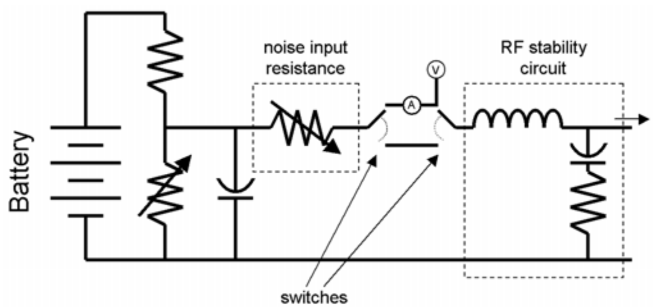

Figure 3. The RF stability circuit presents a 50 ohm impedance to the input of the device at RF frequencies. The left capacitor shorts the bias resistors so that noise input resistor can control what impedances are presented at noise measurement frequencies. The ammeter and voltmeter can be switched out of the measurement path during measurement.

First, a variable noise input resistance allows different impedances to be presented at the noise frequencies of interest. A large capacitor is used to short the bias resistors at noise measurement frequencies. Typically, as long as the noise input impendence is high enough not to short out the noise source in the base emitter junction, it has negligible effect. During measurements this is typically kept at its maximum value, and is only changed to verify that its effect is negligible. Also, an RF stability circuit is included to present 50 ohms to the device at RF frequencies and prevent the device from oscillating.

The collector noise current spectra S_{IC} can be converted to a base noise current spectra S_{IB} by assuming that they are related by the DC current gain β as follows:

$$S_{IB} = {S_{IC}}/{\beta}$$

To measure the noise spectra, a bias condition is set using the bias network, I_B, and the bias circuitry of the SR570, V_{CE}. Once the bias conditions are recorded, all ammeters and voltmeters are switched out of the measurement path. The HP8565E measures the amplified current spectra of the collector.

RESULTS

The resulting low frequency noise spectra are shown in figures 4 and 5. The data was collected for I_E currents of 60, 160, and 600 µA, which equates to low current densities of 300 800, and 3000 A/µm^2. At all current conditions, V_{CE} was set to 1V.

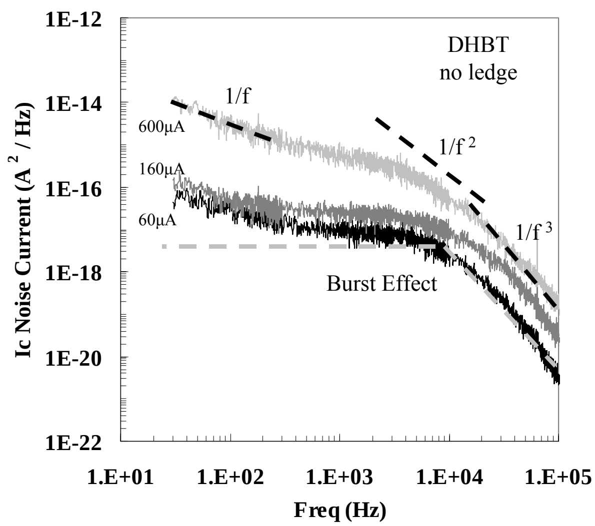

Figure 4: DHBT without ledge low frequency noise with I_E = 60, 160, 600uA

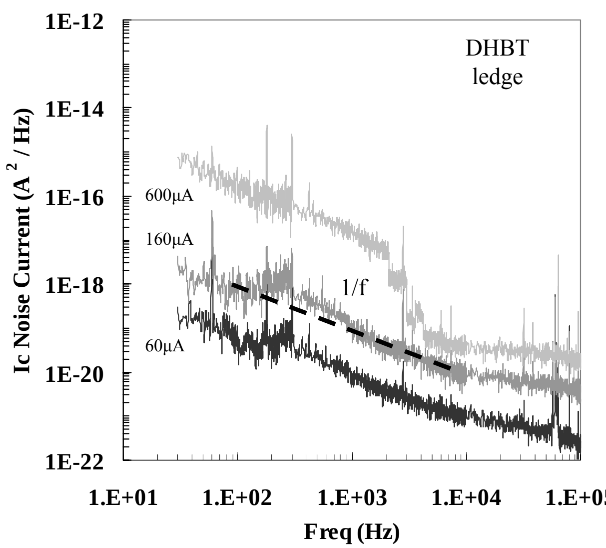

Figure 5: DHBT with ledge low frequency noise with I_E = 60, 160, 600uA

All measured curves exhibit slight deviation from an ideal 1/f slope, however, the DHBT in figure 5 shows the most deviation with a 1/f trend at lower frequencies, a period of leveling off, and then a steep drop at higher frequencies.

This fits the so-called burst noise effect that has been seen in active solid state devices before. [5]. Typically in a burst type event the steeper slope falls off at a rate of $1/f^2$ until the spectral curve reaches a 1/f trend again. However, in this case at the edge of the observed burst noise, the slope continues to fall off at steeper and steeper levels. Also, burst noise is dominating the majority of the spectrum. At the higher current densities under which the device would normally be, this burst effect would be buried under 1/f noise and would most likely not be seen. In Figure 5, the DHBT with ledge is showing a much lower level of noise.

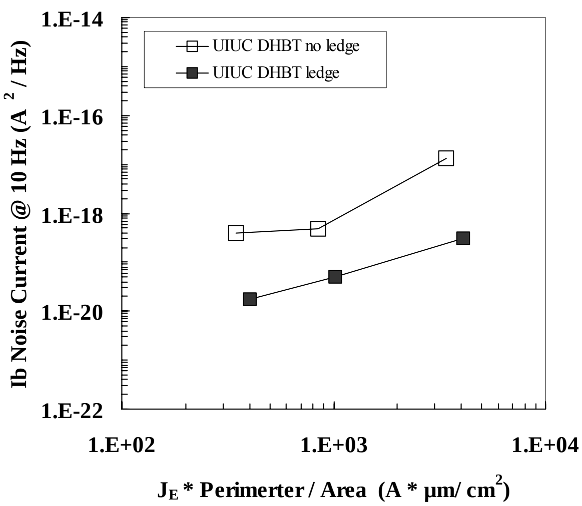

Figure 6: Comparison of effective base noise current at 10 Hz vs. Emitter current density times perimeter over area ratio

Figure 6 shows the results of converting I_C noise current to I_B noise current. The DHBT without a ledge shows the higher level of low frequency noise and is the only device to display a strong burst effect. These findings indicate that for an InP SHBT, the effect of a ledge is negligible due to the small recombination velocity, but for an InP DHBT the effect of a ledge not only lowers the noise current output by the device, but also prevents the burst effect.

CONCLUSION

This work reported experimental data comparing the low frequency noise spectrum of InP based HBTs. Double heterojunction were examined with and without surface passivation ledges. The data showed that only the DHBT devices without surface passivation ledges displayed burst noise.

ACKNOWLEDGEMENTS

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ACRONYMS

HBT: Heterojunction Bipolar Transistor
DHBT: Double Heterojunction Bipolar Transistor
DESL: Double Etch Stop Ledge
MBE: Molecular Beam Epitaxy