Low-Frequency Noise in GaAs and InP Schottky Diodes

K.F. Sato[1], C.W. Chan[1], K. Najita[1], M.P. DeLisio[1]
Y.H. Chung[2], J. Cowles[2], P.C. Grossman[2], R. Lai[2], A.K. Oki[2], D.C. Streit[2], H. Wang[3]

[1]University of Hawaii at Manoa, Department of Electrical Engineering, Honolulu, HI
[2]TRW, Space and Electronics Group, Redondo Beach, CA
[3]National Taiwan University, Department of Electrical Engineering, Taipei, Taiwan

Abstract

This paper examines the low-frequency noise properties of millimeter-wave GaAs and InP Schottky diodes. Measurements of diodes fabricated using both HEMT and HBT epitaxy will be presented. These noise measurements should enable the development of accurate models useful in the analysis and design of MMIC components.

Introduction

The noise performance of many MMIC components will often be dominated by the low-frequency noise behavior of the semiconductor devices. This is especially true for nonlinear components such as mixers and detectors, which downconvert millimeter-wave signals to much lower frequencies. In addition, the phase noise of millimeter-wave oscillators will depend on the active device's low-frequency noise behavior due to frequency upconversion. Any complete analysis of these components must include reliable low-frequency modeling. Unfortunately, low-frequency noise is often overlooked in MMIC design. The analysis presented in this paper can be used to supplement existing small-signal and nonlinear Schottky-diode models, providing more comprehensive models.

Low-Frequency Noise Sources

Flicker noise is the most common source of excess low-frequency noise. It is generally linked to generation and recombination in surface states [1,2]. The noise current spectral density is given by:

$$\overline{i_f^2} = k_f \cdot \frac{I^{a_f}}{f^{b_f}} \qquad (1)$$

where I is the dc bias current and f is the frequency. The k_f, a_f and b_f are constants that are device dependent. Generally, b_f is near unity, giving flicker noise its characteristic *1/f* behavior.

Another source of low-frequency noise is burst noise. It is suspected that burst noise is related to heavy-metal ion contamination, carrier generation and recombination within the semiconductor bulk [1,2], and DX (deep trap) centers [3]. The noise current

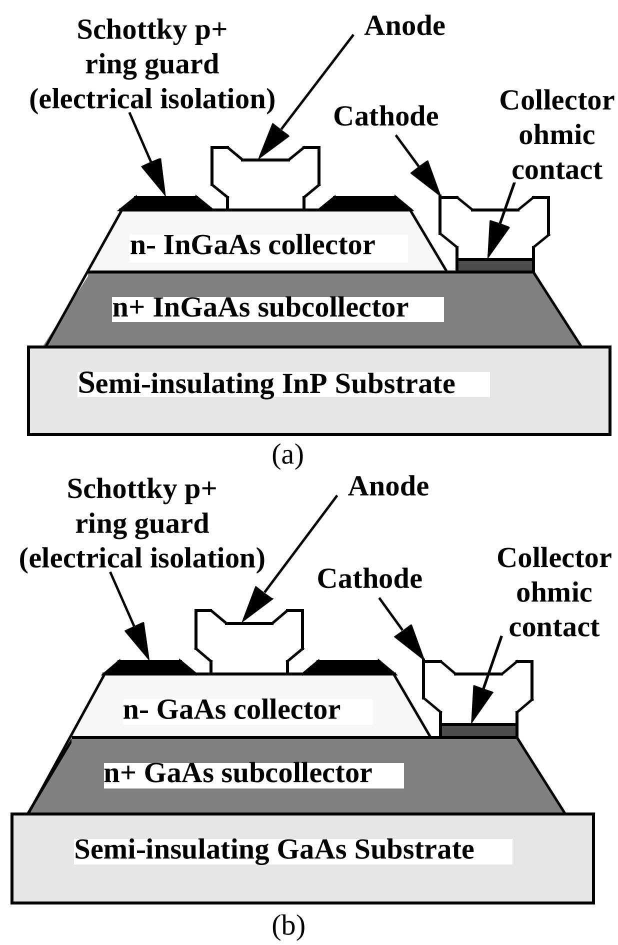
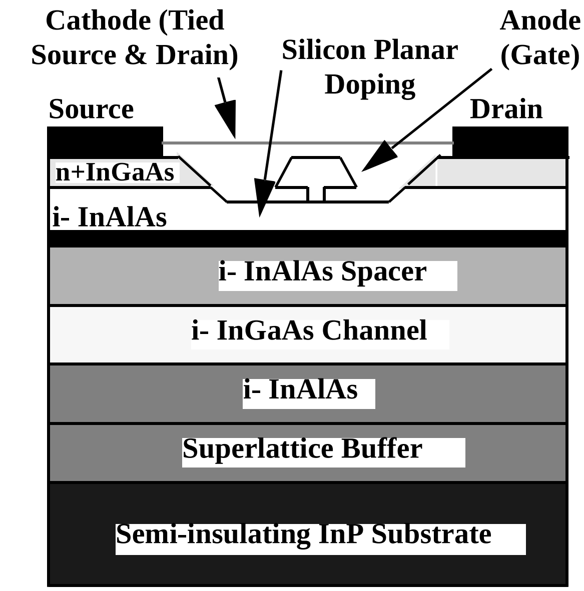
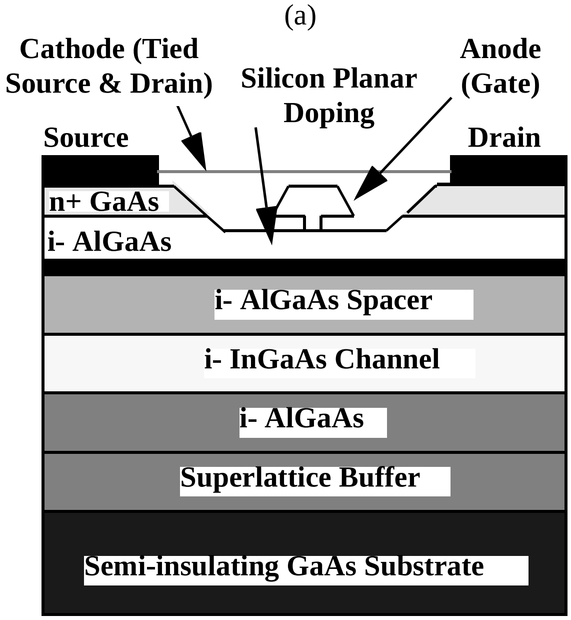


Figure 1: (a) InP and (b) GaAs HBT-based Schottky diode cross-sections.



(a)



(b)

Figure 2: (a) InP and (b) GaAs HEMT-based Schottky diode cross-section.

spectral density has the form:

$$\overline{i_b^2} = k_b \cdot \frac{I^{a_b}}{1 + \left(\frac{f}{f_c}\right)^{b_b}} \qquad (2)$$

where I is the dc bias current, f is the frequency, and f_c is the burst corner frequency. Constants k_b, a_b, and b_b are also device dependent. Generally, b_b has a value near two, giving burst noise its characteristic Lorentzian spectrum.

Assuming the noise sources are uncorrelated, a general low-frequency noise equation is given by:

$$\overline{i_n^2} = \overline{i_f^2} + \overline{i_b^2} + \overline{i_w^2} \qquad (3)$$

where $\overline{i_w^2}$ is broadband white noise due to shot and thermal contributions.

Device Descriptions.

The Schottky diodes presented in this paper are fabricated using the GaAs and InP HBT [4,5] and HEMT [6,7] processes developed by TRW. Figure 1 shows the GaAs and InP HBT Schottky diode structures. The Schottky barrier is formed in the collector region, with a Schottky p+ ring guard to provide electrical isolation. The diodes have a contact area of 7 µm x 7 µm. Figure 2 shows the cross-section of the HEMT-based diodes. The Schottky contact is formed at the 0.1-µm T-gate. The source and drain ohmic contacts are connected together to form the cathode. The HEMT Schottky diodes presented here consist of four-fingered gates with a total gate width of 40 µm.

Measured Results

The diode's low-frequency noise properties were measured using a custom-made probe card. Figure 3 shows a simplified schematic of the noise measurement system. Rechargable lead-acid batteries were used to provide a low-noise bias to the diodes. This system was used to measure the diode noise from 100 Hz to 500 kHz. The noise floor of the system prevents measuring noise currents below 1×10^{-22} A^2/Hz.

Figure 4 shows a typical low-frequency noise measurement for GaAs and InP HBT-based Schottky diodes. Three bias conditions are shown. From the

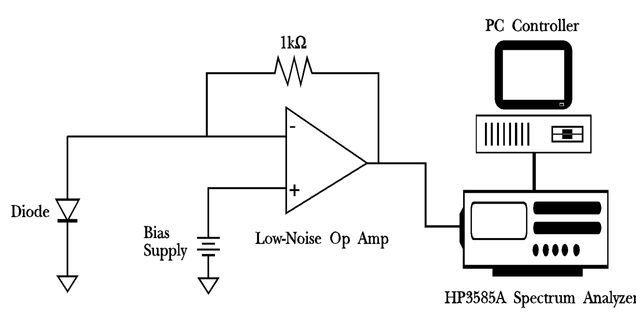
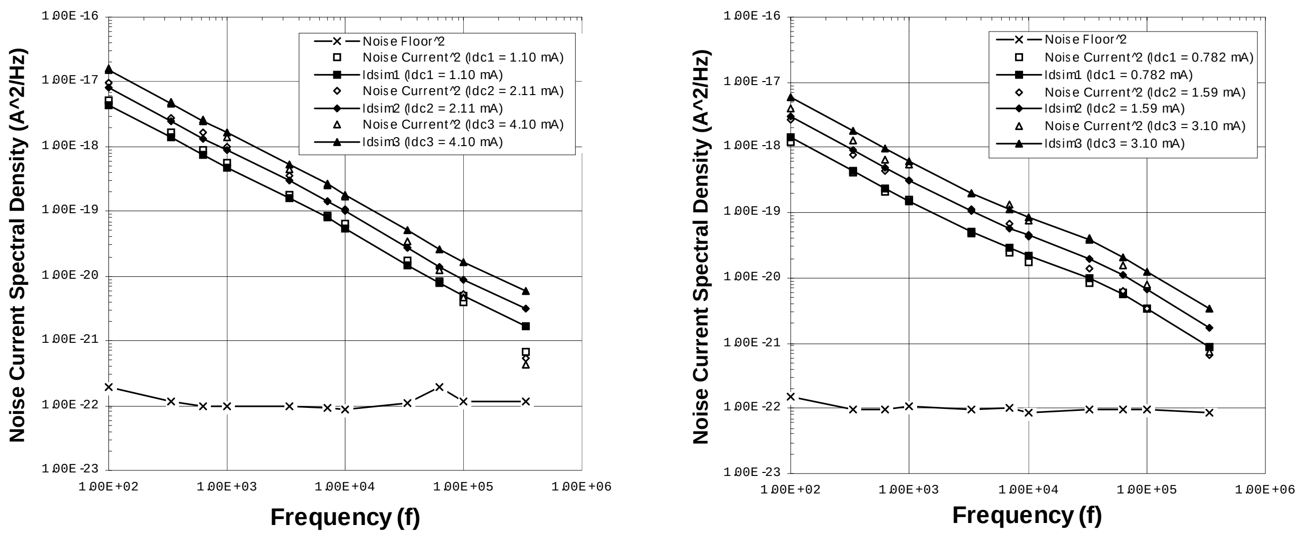


Figure 3: Simplified schematic of the low-frequency noise measurement system.

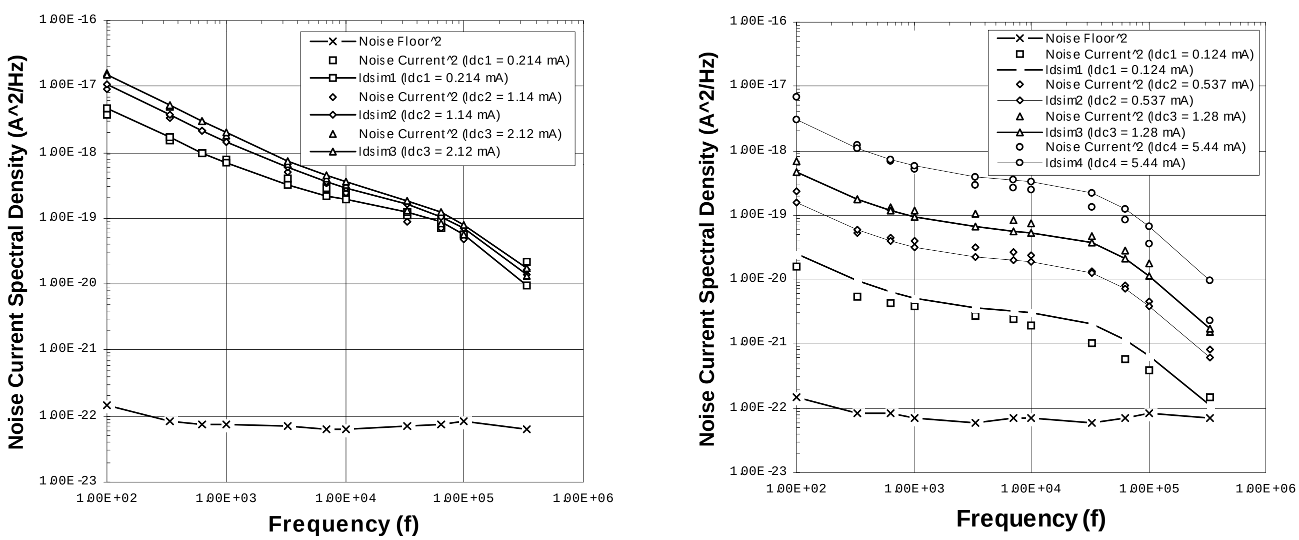
measurements, both HBT-based diodes demonstrate a noise behavior dominated by a flicker component. At comparable bias current, the GaAs diodes have slightly lower noise levels. This may be due to the relative immaturity of the InP process, especially in surface passivation. We suspect that the InP diode's low-frequency noise will improve as the process matures.

The measured low-frequency noise of GaAs and InP HEMT-based Schottky diodes are depicted in Figure 5. Several bias conditions are shown. The GaAs diodes show a pronounced burst component with a corner frequency of 50 kHz. We suspect that this is due to the high aluminum content in the GaAs HEMT epitaxy which behaves as DX centers. Again, the InP diodes show higher noise at similar bias currents for the similar sized devices. An interesting observation to be noted is the invariant burst noise present near 80 kHz regardless of bias current for the InP HEMT-based Schottky diode. The DX center associated with



(a) (b)

Figure 4: (a) InP and (b) GaAs HBT-based Schottky diode measured and modeled noise current spectral density.



(a) (b)

Figure 5: (a) InP and (b) GaAs HEMT-based Schottky diode measured and modeled noise current spectral density.

this phenomenon is suspected to be a low-energy-activated deep-level trap.

Table 1 lists the noise parameters used to curve fit the measured data for the four different diodes. From Figures 4 and 5, the simulated noise models (Idsim curves) display good agreement with the measured data.

	flicker		burst		
	kf	**af**	**kb**	**ab**	**fc (kHz)**
GaAs HBT diode	**2.0e-13**	**1.01**	**5.0e-18**	**0.90**	**50**
InP HBT diode	**2.5e-13**	**0.93**	**-**	**-**	**-**
GaAs HEMT diode	**2.0e-13**	**1.27**	**2.0e-16**	**1.24**	**50**
InP HEMT diode	**2.0e-14**	**0.50**	**1.4e-19**	**0.02**	**80**

Table 1: GaAs and InP Diode Noise modeling parameters.

A direct comparison of the HEMT- and HBT-based Schottky diodes is difficult since the operation mechanisms and size of the devices are very different. A possible premise is to compare devices with similar diode junction capacitance. The InP HBT diodes exhibit lower noise than the InP HEMT-based diodes at similar bias currents. This may be attributed to the fact that the vertical HBT structure is well-shielded from surface and deep level traps, as opposed to the lateral HEMT structure. The GaAs HBT-based diode proved to have the lowest noise performance of all, due to its vertical structure and process maturity.

Conclusion

We have presented and compared the low-frequency noise data measured from GaAs and InP Schottky diodes constructed using HBT and HEMT epitaxy. Incorporation of these device models into existing models should enable a more complete analysis of the behavior of many MMIC components. This modeling approach has been applied to a W-band MMIC mixer using HBT-based InP Schottky diodes with considerable success [8].

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