X-BAND NOISE PARAMETERS OF HEMT DEVICES AT 300K AND 12.5K

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ABSTRACT

The four noise parameters of room-temperature and cryogenically-cooled HEMT's have been investigated. Two previously described structures, the quantum-well HEMT [1] and the high-transconductance HEMT [2] have been tested and compared with noise parameters of a MESFET (NE67383). It was demonstrated that the cryogenic noise performance of a HEMT is dependent on light illumination and may be or may not be better than that of a MESFET, depending on the device structure. The minimum noise temperature of T_{min} = 10.5 ± 1.5K of the quantum-well HEMT, illuminated with light, measured at f = 8.4 GHz and T_a = 12.5K is the best yet published for field effect transistors.

INTRODUCTION

High-electron-mobility transistors employing modulation doped AlGaAs/GaAs heterostructures have been demonstrated to show superior noise performance to that of conventional MESFET's [3], [4], [5]. The published studies are concerned mostly with the minimum noise figure, which is only one of four noise parameters determining the circuit performance of the transistor. This paper discusses the noise performance of the HEMT in terms of four noise parameters: T_{min} - minimum noise temperature; $Z_{gopt} = R_{gopt} + j X_{gopt}$ - optimum generator impedance; and g_n - noise conductance. It is shown that at room temperature the performance of a HEMT may be superior to a MESFET not necessarily because of a lower T_{min}, but because of a much lower value of noise conductance g_n and Q of the optimum generator impedance. At cryogenic temperatures the noise temperature may be substantially lower than that of a MESFET. It is, however, dramatically different for different structures and in our case of a quantum-well HEMT is strongly light sensitive. This seems to be related to the charge trapping mechanism, which has been suggested as the cause of the collapse of the I-V characteristic at cryogenic temperatures [6], [7].

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DEVICE DESCRIPTION

The HEMT devices used for our measurements were fabricated by Camnitz and co-workers in the Semiconductor Device Group headed by Prof. L. Eastman at Cornell University. Two types of devices, termed the quantum-well HEMT and high-g_m HEMT, were tested; the structure, material growth, and room-temperature signal parameters of the two devices are described in references (1) and (2), respectively. The cross-sections of the devices are shown in Figures 1 and 2. It should be noted that the quantum-well device has an undoped AlGaAs spacer layer between the doped AlGaAs layer and undoped GaAs channel while the high-g_m device does not. The planar pattern of both HEMT devices was similar to the NE67383 MESFET (all 300 µm gate width and approximately 0.3 µm gate length) which was also measured for comparison.

METHOD OF MEASUREMENT

The noise parameters of the packaged devices were determined by the noise temperature measurement of a single-stage amplifier with simplified schematic and photograph as shown in Figures 3 and 4.

The quarter-wave transformers are realized as movable slugs on a 50 Ω transmission line. The measurements of the amplifier noise temperature were performed for five different values of the characteristic impedance of the input transformer, both at room and cryogenic temperatures. From these measurements, noise parameters of the device itself have been determined. The details of the measurement method, its accuracy, and the computational techniques employed are discussed in (8).

MEASUREMENT AT 300K

The room temperature measurement of the quantum-well HEMT, high-g_m HEMT, and for comparison the noise parameters of the NE67383 FET, all measured in the same mount, are given in Table I. The values of the minimum noise temperature T_{min} and the DC measured transconductance g_m as a function of a drain current are plotted in Figures 5 and 6 for the quantum-well HEMT and the high-g_m HEMT, respectively. The characteristics for both HEMT's can be at least qualitatively explained by the extention of the Pucel

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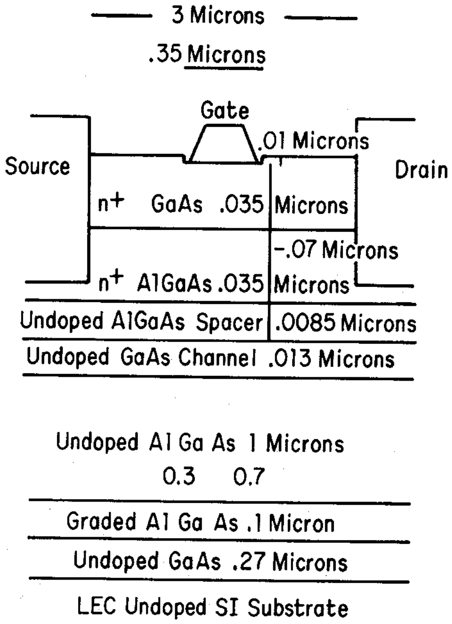

Fig. 1. Quantum-well device structure (reprinted from [1] with permission of author).

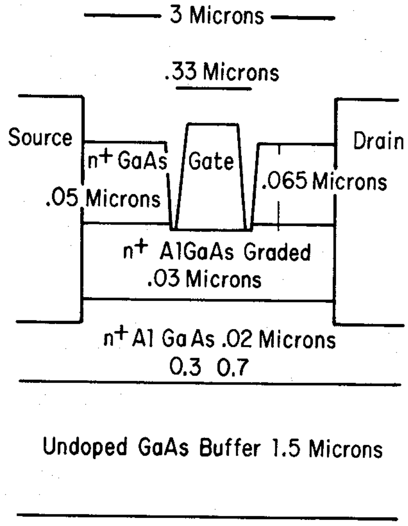

Fig. 2. High-g_m device structure (reprinted from [2] with permission of author).

theory of noise in MESFET's [9] modified for HEMT's by Brookes [10]. The minimum noise temperatures of the three devices are nearly equal. Higher than expected values of noise temperature for HEMT's are due to the relatively large gate and source parasitic resistances [1], [2]. However, it should be noted that the optimum bias conditions, ratio of X_{gopt}/R_{gopt}, and g_n are very different. In particular, the factor of 3 lower values of X_{gopt}/R_{gopt} and g_n for the high-g_m HEMT would allow low noise over a much wider bandwidth than the NE67383.

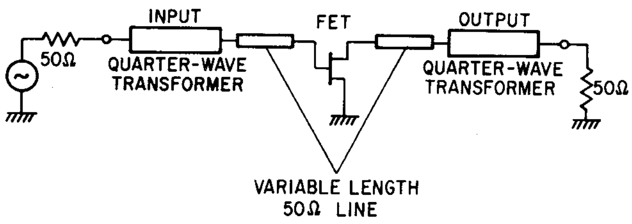

Fig. 3. Simplified schematic of a single-stage amplifier used as measurement mount.

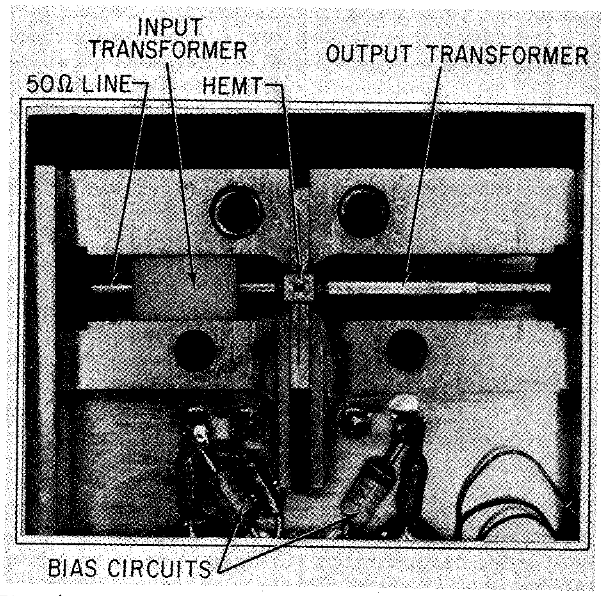

Fig. 4. Photograph of the single-stage amplifier with cover plate removed. Light illumination is provided by LED mounted in the cover.

MEASUREMENTS AT 12.5K

The measured noise paramters of the same devices at the temperature of 12.5K are summarized in Table II. The data for HEMT's are with illumination with light. The quantum-well HEMT exhibits the lowest minimum noise temperature yet published for a three-terminal device at this frequency, while high-g_m exhibits a minimum noise temperature which is typical for conventional FET's at cryogenic temperatures [8]. The values of the minimum noise temperature T_{min} and the DC measured transconductance g_m as a function of drain current are compared with 300K values in Figures 5 and 6 for the quantum-well HEMT and high-g_m HEMT, respectively. Very little influence of the illumination with light on the noise performance of the high-g_m HEMT has been observed. In contrast the influence of light illumination on the noise performance of the quantum-well HEMT was dramatic. Constant illumination with light was needed to keep the performance of the amplifier time-invariant. If the illumination is removed the

TABLE I. Noise Parameters of HEMT's and MESFET at Room Temperature and 8.4 GHz.

FET	I_{ds} (mA)	V_{ds} (V)	T_{min} (K)	R_{gopt} (Ω)	X_{gopt} (Ω)	g_n (mS)	Assoc. Gain (dB)
QUANTUM WELL HEMT	1	2	140	6.9	56	21.5	5.6
	2	2	113	8.7	55	15.5	7.2
	5	2	104	10.8	54	12.0	8.4
	10	2	122	12.0	54	12.3	8.6
HIGH-gm HEMT	5	1	192	14.4	31	14.3	6.5
	10	1	142	19.5	30	8.0	8.5
	15	1	125	22.5	30	5.7	8.5
	20	1	119	24.0	30	5.4	9.3
	25	1	116	25.3	30	4.8	9.6
NE 67383	5	3.5	124	6.5	37	21.2	9.2
	10	3.0	113	8.3	35	12.8	9.9
	15	2.5	116	9.5	34	13.5	10.9

TABLE II. Noise Parameters of HEMT's and MESFET at 12.5K and 8.4 GHz.

FET	I_{ds} (mA)	V_{ds} (V)	T_{min} (K)	R_{gopt} (Ω)	X_{gopt} (Ω)	g_n (mS)	Assoc. Gain (dB)
QUANTUM WELL HEMT	1	1.2	11.7	5.9	55	2.1	9.0
	2	1.2	10.5	7.8	55	1.5	10.5
	5	1.2	12.2	11.2	54	1.2	11.8
HIGH-gm HEMT	5	0.8	23.6	5.5	31	5.2	11.4
	10	0.8	20.7	6.7	30.5	3.5	11.6
	15	0.8	21.2	8.2	30	3.2	11.8
	20	0.8	23.9	8.6	30	3.3	12.5
NE 67383	5	3.5	22.0	1.9	38	10.2	10.7
	10	3	21.7	3.2	36	7.1	12.2
	15	2.5	23.3	3.6	35	6.3	12.7

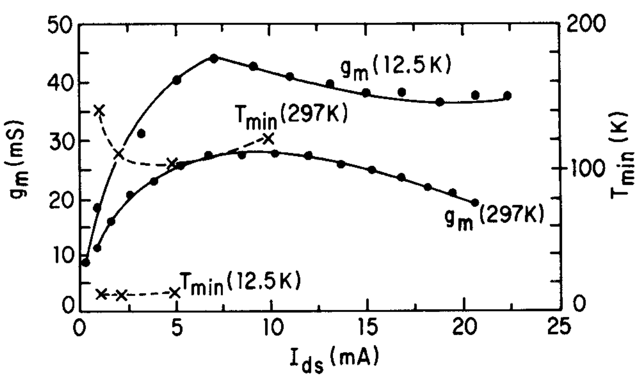

Fig. 5. Minimum noise temperature T_{min} and DC measured transconductance g_m for the quantum-well HEMT at 297K and 12.5K.

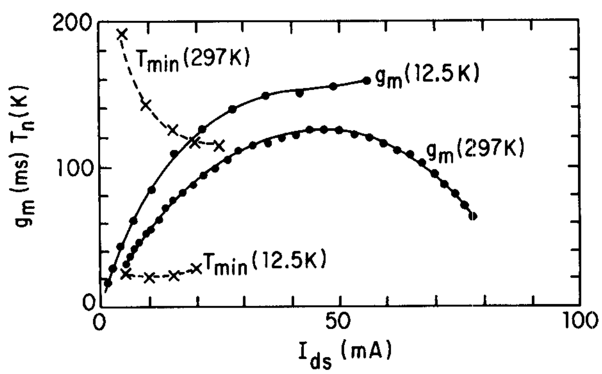

Fig. 6. Minimum noise temperature T_{min} and DC measured transconductance g_m for the high-g_m HEMT at 297K and 12.5K.

noise temperature of the amplifier will increase with time as shown in Figure 7. During the same time interval, the gain of the amplifier varied very little (by about .2 dB at 9.5 dB level), indicating no significant change in the device signal parameters. This observation points to the direct influence of the light illumination on noise generating mechanism in the quantum-well HEMT. Light sensitivity of the noise performance of the HEMT is most likely connected with the existence of traps in the highly doped AlGaAs layer. The effect of these traps on the DC characteristic of HEMT's has been studied recently [6], [7]. Though trap-generated noise has been known to be of importance at the frequencies below 3 GHz, the results of our measurements suggest traps may also be of importance at higher frequencies for HEMT's cooled to cryogenic temperatures.

The cryogenic noise performance of the quantum-well HEMT is not only superior to the high-g_m HEMT and NE67383 by a factor of 2 in noise temperature, but also exhibits much lower X_{gopt}/R_{gopt} and g_n values to facilitate lower noise over a wider bandwidth. It should also be noted that a DC bias power of < 2.4 mW is required as compared to 17 mW for the NE67383; this is of importance to the design of the cryogenic cooling mechanism.

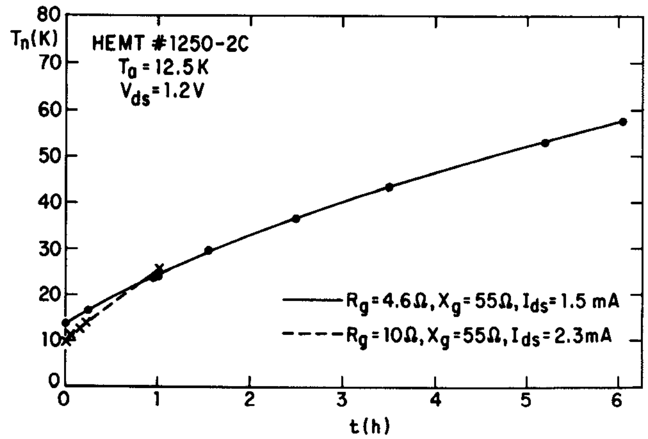

Fig. 7. Examples of deterioration of noise temperature of a quantum-well HEMT amplifier with time elapsed after removal of light.

CONCLUSIONS

The noise temperature at room temperature of the three tested devices is similar but much wider noise bandwidth is achievable with the high-g_m HEMT. Excellent noise performance of a quantum-well HEMT device at cryogenic temperatures has been obtained. The cryogenic performance is strongly dependent on the light illumination of the device. Charge trapping mechanism appears to be a strong factor in the noise performance of cryogenic HEMT's even at frequencies as high as 8.4 GHz.

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