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NOISE MEASUREMENTS AND NOISE MECHANISMS IN MICROWAVE MIXER DIODES

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ABSTRACT

Classic work on optimized heterodyne receivers has been concentrated on the network aspects of mixers with limited emphasis on device properties. We present an in depth analysis of the best possible mixer diode and of mechanisms limiting its performance.

INTRODUCTION

Work on Schottky diode receivers has reached a plateau in recent years because possible improvements in circuit and diode realizations seemed to be exhausted. What will be needed to advance the state of the art is to take a closer look at the mechanisms limiting the diode performance. This paper will investigate the transport mechanisms which affect the non-linear current-voltage characteristics and the noise properties of the mixer diode. Some of these studies are also applicable to FETs and HEMTs. Preliminary work in this area has been already reported by Maracas[1] and Pinsard[2].

CURRENT-VOLTAGE AND NOISE CHARACTERISTICS

The current-voltage characteristics of an ideal and a real Schottky diode are shown schematically in Fig. 1 and the corresponding noise temperature at microwave frequencies is displayed in Fig. 2. The i-v characteristic is given by[3]

$$i = J_S \exp\{(qv - iR_S)/(k\theta)\} \qquad (1)$$

where J_S is the saturation current, R_S the series resistance, and θ an effective junction temperature which depends on the physical temperature T_O of the junction and the electron transport mechanism across the barrier. The effective junction temperatures for the three possible means of electron transport are listed in Fig. 3. The equivalent noise temperature of the diode, T_n, is given by[4]

$$T_n = \frac{R_j\theta/2 + R_S T_O}{R_j + R_S} \qquad (2)$$

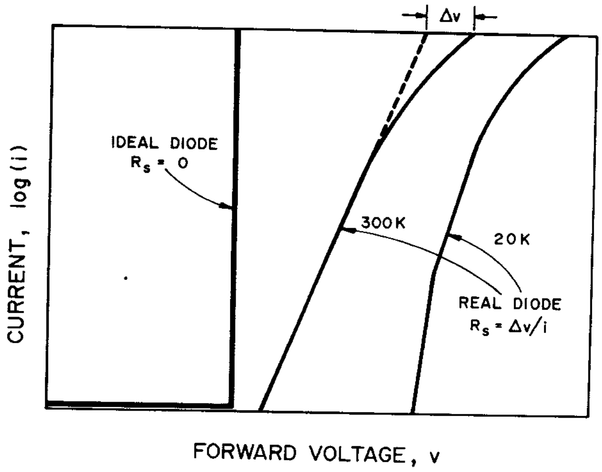

Fig. 1 Current versus voltage characteristics.

where R_j is the junction resistance, i.e. the inverse of the device conductance at a specified bias current. The first term in the nominator of Eq.(2) is caused by shot noise while the second term is the thermal noise of the series resistance R_S. This second term should become dominant at large forward currents. However, the decrease of T_n with increasing current at low temperatures was never observed. Instead, the measurements showed a sharp increase of the diode noise temperature, T_n, above a critical forward current. Thus

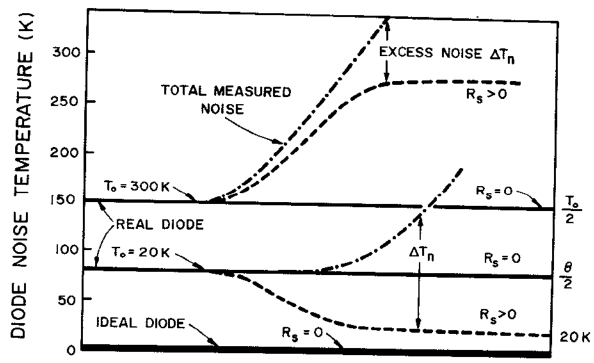

Fig. 2 Equivalent diode noise temperature

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the total measured noise shown by the dash-dot curves in Fig. 2 for T_o = 300 K and 20 K was substantially larger at high currents than the value predicted from Eq. (2).

The noise mechanisms which cause the observed excess noise, ΔT_n, shown in Fig. 2 are related to excess fluctuations of the number and velocities of electrons traversing the barrier. The principal mechanisms producing the excess velocity fluctuations are:

1) Generation of hot electrons. These hot carriers appear if the high electric field in the undepleted epilayer will accelerate the electrons to energies which exceed significantly the energy of the thermal equilibrum.
2) Local heating of the junction caused by high current densities[5].

The excess fluctuations of the number of electrons (electron density fluctuations) are attributed to:

1) Intervalley scattering, i.e. the hot-test electrons are injected into a different regime of the conduction band where they become nearly immobile because of their apparent higher effective mass.
2) Trapping of electrons in the undepleted epilayer and in the vicinity of the metal-semiconductor interface.

There are additional mechanisms in metal-semiconductor junctions which affect the vollage-current characteristics and the noise performance of the devices. Two mechanisms which have been recently investigated are the formation of microclusters at the metal-semiconductor interface[6] and the graininess of the junction[7] caused by the relatively small number of dopants in the thin epitaxial layer. The clusters are formed by different chemical phases at the interface. Metal films deposited on compound semiconductors form different phases at the interface, such as areas which have an excessive concentration of Ga, As or traces of oxides which remain after processing. Thus a single GaAs diode is an agglomorate of paralleled microjunctions with different barrier heights and saturation currents. The current-voltage characteristic at low temperatures of such a cluster deviates from a straight line as shown schematically in Fig. 1.

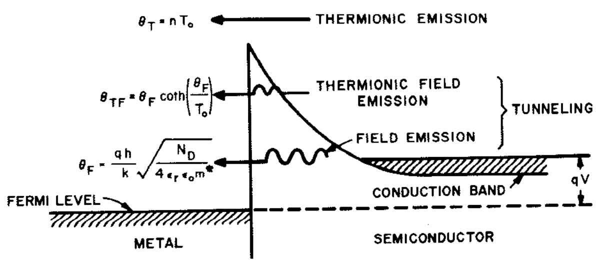
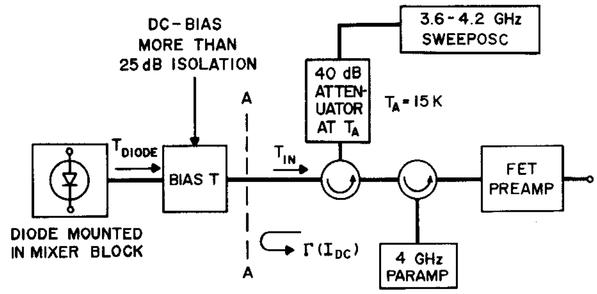


Fig. 3 Electron transport mechanisms.



$$T_{IN} = T_{DIODE}\,(1-|\Gamma_D(I_{DC})|^2) + T_A\,|\Gamma_D(I_{DC})|^2 + T_{PARAMP} + T_{FET}/G_{PARAMP}$$

Fig. 4 Schematic view of test apparatus for performing noise measurements at 4 GHz.

EXPERIMENTAL RESULTS

A number of GaAs diodes fabricated by both university laboratories and industry were tested at frequencies from 0.45 to 17.5 GHz and at temperatures from 20 to 300 K. The junctions were electroplated Pt-GaAs Schottky diodes and single-crystal Al-GaAs devices fabricated on vapor-phase epitaxial and MBE material. The epitaxial layers had a thickness of 0.05 to 0.50 μm, doping concentrations of 1 x 10^{16} to 2 x $10^{17} cm^{-3}$, and the junctions had a diameter of 1 to 3 μm.

A schematic view of the test apparatus for performing the noise measurements at 4 GHz is shown in Fig. 4. A similar arrangement was used at higher and lower

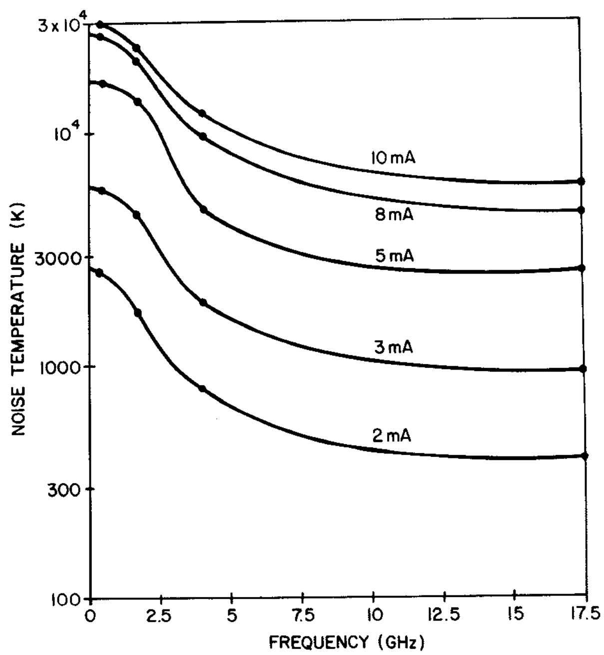


Fig. 5 Frequency dependence of equivalent diode noise temperature.

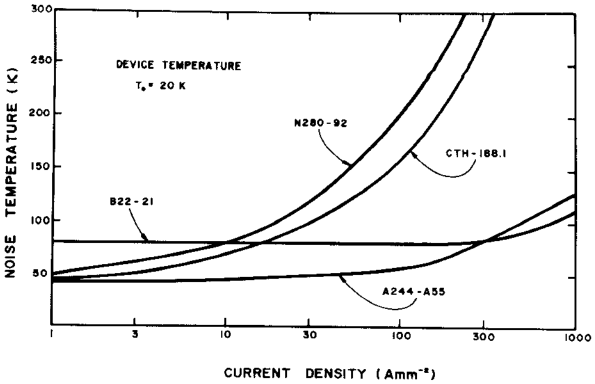


Fig. 6 Equivalent diode noise temperatures as a function of current density for different device structures and fabrication techniques.

frequencies. The equivalent noise temperature of a typical diode as a function of frequency for bias currents of 2 to 10 mA is displayed in Fig. 5. The measurements which were taken at a device temperature of 300 K show a relatively high noise below 5 GHz, which is caused by shallow electron traps at the interface of the metal-semiconductor junction. The lifetime of these traps determined from the curves in Fig. 5 is 66 picoseconds. At higher frequencies the trap noise disappears, and the two remaining sources of excess noise, i.e. intervalley scattering and hot electron noise, can be clearly distinguished. At a current of 10 mA intervalley scattering noise is predominant, while at currents of 2 mA and lower only hot electron noise and the classic shot noise are observed.

Figure 6 shows measurements of the equivalent noise temperature of different diodes at 4 GHz as a function of current density. The comparison of the various devices shows that the excess noise can be reduced by a combination of proper diode design and fabrication technology. The best performance at low and medium current densities is achieved with MBE-fabricated single-crystal Al-GaAs devices (batch A244-A55).

We can conclude from these experiments that the classic trap noise[8] can be reduced by using advanced growth and processing techniques for fabricating the epitaxial layer and metal-semiconductor contact. The intervalley scattering noise can be decreased by operating the junction at relatively low current densities or by choosing materials with higher intervalley energy gaps[9]. Both intervalley scattering noise and hot electron noise[10] will be lowered if materials with higher electron mobilities at the operating point of the device can be found.

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