LOW NOISE MILLIMETER WAVE SCHOTTKY BARRIER DIODES WITH EXTREMELY LOW LOCAL OSCILLATOR POWER REQUIREMENTS

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ABSTRACT

Low capacitance Schottky barrier diodes have been fabricated which yield extremely low noise performance and require exceptionally low local oscillator power. Measurements made at 111 GHz and 170 GHz are presented.

Introduction

One of the major impediments to the realization of low conversion loss, low noise mixers in the 1 to 2 mm wavelength region has been the lack of suitable sources of L.O. power. At these wavelengths L.O. requirements for GaAs Schottky barrier diode mixers are normally of the order of milli-watts. As the wavelength decreases the problem gets worse because of a rise in the irreducible parasitic conversion loss of the diode itself[1].

This paper reports measurements on a new Schottky barrier diode of very low capacitance made on material with an abrupt transition between epi-layer and substrate which yields extremely low noise performance and requires exceptionally low L.O. power. The diode noise and L.O. requirements are further reduced by cooling to 16K.

Diode

The diodes were fabricated at the European Diode Laboratory, University College, Cork. The VPE epitaxial material was supplied by Thomson - C.S.F., Corbeville, and was prepared by organometallic cracking at low pressures[2]. Diode characteristics are summarized in Table 1. The diodes were easy to mount and contact, and d.c. and r.f. characteristics were highly repeatable from anode to anode.

C-V measurements on these diodes indicated a relatively small variation in capacitance with applied voltage. This is shown in Figure 1 which plots $(C_o/C)^2$ against bias, where C_o is the zero bias capacitance. For a typical Schottky diode this graph would be a straight line, with slope inversely proportional to epilayer carrier concentration, until it bends over when the depletion region extends into the substrate transition region. For a GaAs Schottky diode $(C_o/C_{-3V})^2$ would be typically[3] about 3, for an ideal Mott diode it would be 1, and for the diodes being discussed here it is 1.6.

Schottky contact	:	Pt - GaAs
Epi-thickness	:	Approx. 1200 Å
Transition thickness	:	200 - 300 Å
Epi-doping	:	1.7×10^{17} cm^{-3} (Ge)
Substrate doping	:	6×10^{18} cm^{-3} (Te)
Anode diameter	:	1.0 μm
R_S	:	10.5 Ω
C_{JO}	:	4.8 fF
$\eta_{295\ K}$	:	1.12
$\eta_{16\ K}$	:	10
$V_{B.10\mu A}$	:	-7.5 v.

Table 1: Diode Characteristics.

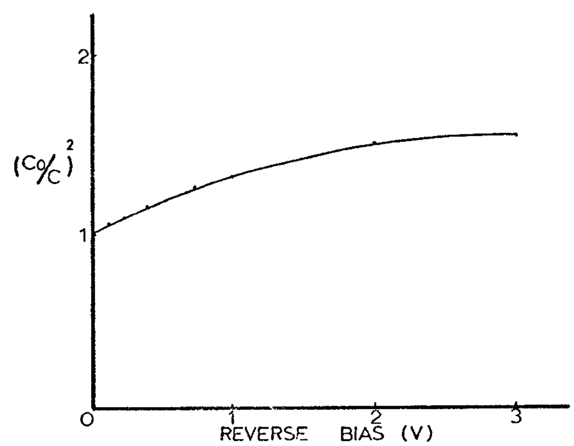

Fig.1. $(C_o/C)^2$ plotted as a function of applied reverse bias for the diodes discussed in the text.

From these capacitance measurements the zero bias depletion edge is estimated to be in the epilayer/substrate transition at the 10^{18}/cc level, as in Figure 2.

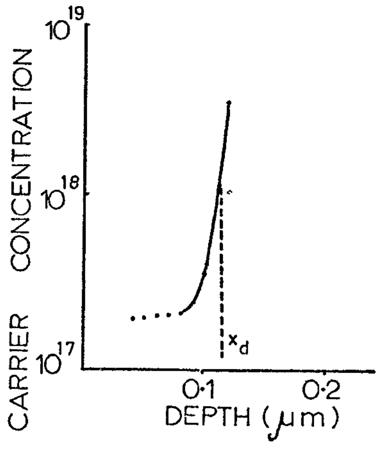

Fig. 2. Carrier profile (Hg - probe) showing the zero bias depletion edge x_d.

111 GHz Measurements

These measurements were carried out at the Max-Planck-Institut für Radioastronomie. The mixer and test receiver are identical to those used by Keen, Haas and Perchtold[4]. Measurements of single side-band noise temperature as a function of local oscillator power are shown in Figure 3 for the mixer

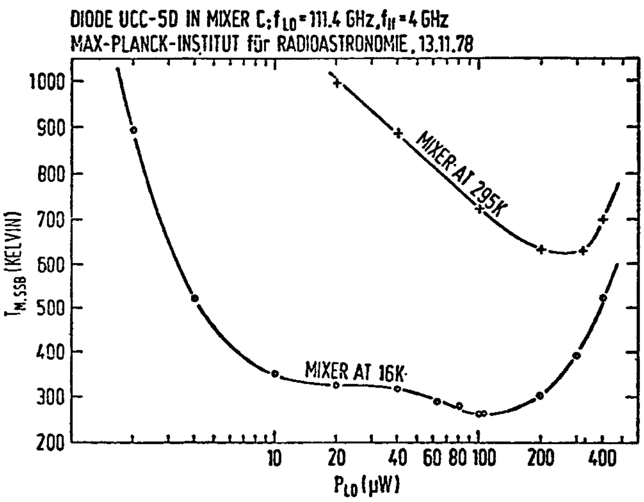

Fig. 3. Single-sideband mixer noise measurements as a function of local oscillator power: Max-Planck-Institut für Radioastronomie mixer with f_{LO} = 111.4 GHz, at ambient mixer temperatures of 16 K and 295 K.

at 295 K and 16 K. The diodes were forward-biased for minimum noise: conditions were 0.75 V, 0.45 mA at 16 K and 0.5 V, 1 mA at 295 K.

Power measurements were performed with a Hughes thermistor head, and were confirmed using a specially designed calorimeter[5]. The measurements indicate that for lowest noise the diodes must be lightly pumped, and that cooling reduces the local oscillator requirement for minimum noise by a factor 3 to 4. This approximates the reduction in l.o. power of $1/a^2$ by cooling, as predicted by Weinreb and Kerr[6], where $a = \eta T/\eta' T'$.

Noteworthy is the 15 dB L.O. power range within which the cooled mixer noise temperature remains within 100 K of the minimum. The lowest noise temperatures obtained with these diodes at 111 GHz (not shown on Figure 3) was 250 K.

170 GHz Measurements

These measurements were carried out at Appleton Laboratory. The mixer which was used is designed for the frequency band 140-220 GHz and is similar to that described by Kerr[7]. A waveguide height reduction of 4:1 is used to facilitate input matching, and was realized in both a linear taper and a four step transformer for comparison purposes. At 170 GHz both transformers gave identical results.

Mixer noise and conversion loss were measured by conventional hot and cold load techniques with a test receiver operating at a 4 GHz I.F. Power measurements were made with an Anritsu thermocouple mount designed for the frequency range 170 - 260 GHz.

Figure 4 shows the single sideband noise

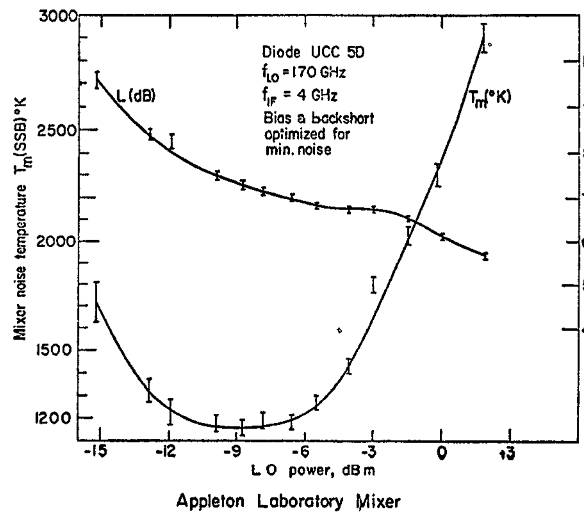

Fig. 4. Single-sideband uncooled mixer noise and conversion-loss **measurements as a function** of local oscillator power:
Appleton Laboratory mixer at f_{LO} = 170 GHz.

temperature and conversion loss of the uncooled mixer as a function of local oscillator power. The best noise performance is obtained with only 125μW of pump power, and the mixer noise is $\lesssim 1200^{o}$K for powers between 50 μW and 250 μW. The average conversion loss under these conditions is 7.5 dB. The diode was forward-biased at 0.8 V and 0.6 mA for minimum noise. Noteworthy is the > 6dB range of l.o. power over which the noise temperature increases by < 100 K.

These noise measurements have not been corrected for any contributions from local oscillator noise sidebands. No L.O. filter was available but estimates of the klystron noise through the insertion of an E-H tuner into the L.O. arm gave values between 50^{o}K and 150^{o}K; this estimate appears to be confirmed by using a frequency meter to deteriorate klystron carrier-to-noise ratio by a known amount.

2.2 μm diameter diodes made on molecular beam epitaxy (MBE) material were also tested in this mixer at 170 GHz. The l.o. power requirement for minimum noise (T_M = 1420 K) was not significantly more, although the conversion loss was about 1dB higher. These diodes were also fabricated at the European Diode Laboratory.

Conclusions

Schottky barrier diodes eminently suitable for shorter millimeter wavelengths have been fabricated and tested. Despite their relatively high spreading resistance, low noise performance is obtained at low local oscillator power levels. Further tests on different doping levels and profiles are proceeding in an attempt to understand and possibly further reduce the low power requirements of these mixers. In view of the capacitance data quoted above and taking into account the excellent results reported recently[3] for devices with similar C-V characteristics (T_m < 250 K with 50μW LO power at 111 GHz), it appears that capacitance variation may play an important role in diode noise behaviour.and local oscillator power requirements. This appears to open up possibilities of replacing klystrons by a combination of solid-state source plus frequency multiplier.

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