MILLIMETRE WAVE LOW NOISE E-PLANE BALANCED MIXERS INCORPORATING PLANAR MBE GaAs MIXER DIODES

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Summary

Planar GaAs Mott mixer diodes have been made for use in novel E-plane balanced mixers at 35 and 85 GHz. Single sideband noise figures of 6 dB at 35 GHz and 7.5 dB at 85 GHz (including 1 dB I.F. contribution) have been achieved. Both devices and circuits are suitable for low cost, high volume applications.

Introduction

Increasing interest in mm-wave systems in the frequency range 30 - 100 GHz has led to a requirement for low cost high performance mixers. E-plane circuits have been shown[1] to be suitable for constructing mixers in this frequency range. The circuits are made on thin, low dielectric constant substrates and mounted in the E-plane of a rectangular waveguide and incorporate finline, microstrip and coplanar line. For low noise performance it is essential that the mixer diodes have low device parasitics. In order to minimise stray bonding capacitance and inductance, we have made GaAs coplanar mixer diodes[2] which are mounted directly into the E-plane circuit. The diodes are low resistance Mott devices on thin lightly doped ($n \sim 5 \times 10^{16}$ cm^{-3}) gallium arsenide layers with a thicker heavily doped layer of low resistivity underneath. The interface between the two layers must be sharp for the minimum resistance and minimum variation in capacitance. This is achieved with layers grown by Molecular Beam Epitaxy[3] on semi insulating substrates. A typical doping profile near the surface is shown in Figure 1. The diodes have been mounted in E-plane mixers and state-of-the-art performance has been achieved.

Device Technology

Planar devices have been made using either proton bombardment or mesa etching to ensure that the material under the Schottky barrier bonding pad is semi-insulating. The mesa etched device is illustrated schematically in Figure 2. The edge of the mesa is coated with sputtered SiO_2 in order to prevent the metal contacting the n^+ layer. Currently Ti/Au is used for the Schottky barrier metal and Ni/Au/Ge is used for the alloyed ohmic contact. The specific contact resistance, an important parameter for this planar geometry, is consistently $10^{-6}\Omega$ cm² or less as measured by the Shockley transfer length method. Some devices have been successfully made using non alloyed ohmic contacts on to a heavily doped surface layer ($n > 10^{19}$ cm^{-3}) produced by ion implantation and laser annealing[4]. With all of these device fabrication techniques an important feature is that the bonding pads are supported completely by the GaAs chip and are therefore extremely robust.

Diodes may be mounted using any of the conventional bonding techniques. On the Duroid substrates, used in the fabrication of our finline circuits, the most successful mounting methods to date have utilised silver loaded epoxy resin; either on chips recessed into the Duroid, or using flip chip techniques. Diodes mounted in the latter way have withstood acceleration tests at 2000 g for 0.5 msec in three axes in both directions without any degradation in DC or microwave performance.

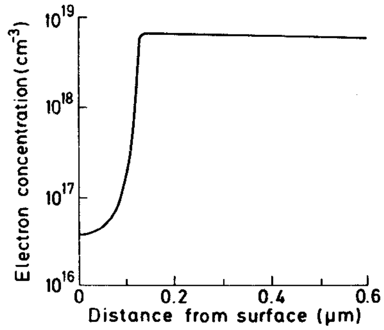

Fig. 1 Doping Profile of Surface of MBE Layer

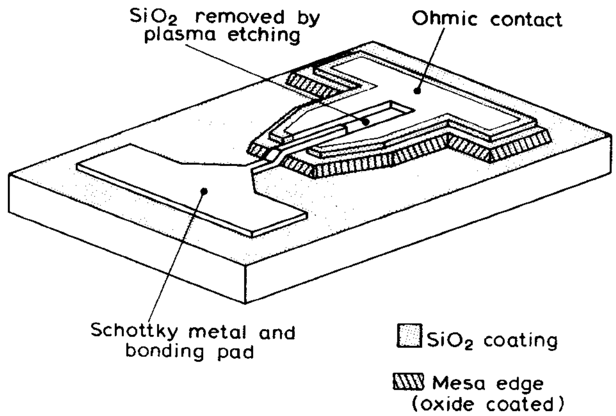

Fig. 2 Oxide Mesa Mixer Diode

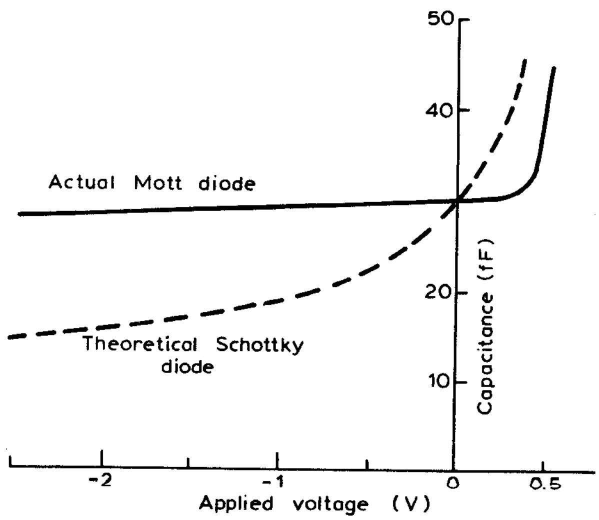

Fig. 3 Capacitance-Voltage Characteristics of 85 GHz Mixer Diodes

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Diode Characteristics

Mott diodes have been fabricated for Ka band and E-band with capacitances of 0.05 pF and 0.03 pF respectively which remain constant under all bias conditions up to ~ 0.5V in the forward direction (Figure 3).

Low series resistances are achieved by optimising the thickness and doping levels of the n^+ epitaxial layers. Typical resistivities of these layers are 0.7 m Ω cm. A model, based on conformal mapping[5] of the diode structure and treating the ohmic contact as a lossy transmission line, has been used to optimise the device structure, both in terms of device thickness and the separation between the ohmic contact and Schottky barrier. In practice, the fabrication process is simplified, and the yield improved, if the depth of the mesa is limited to 3 - 4 μm and the ohmic/Schottky separation increased to about 4 μm.

Both Ni and Ti Schottky barrier metals have resulted in ideality factors of less than 1.1 over at least four decades of current, and we consider this to be a useful criteria for assessing the quality of the barriers formed.

Alternative metals are being reviewed in order to obtain high burn-out performance. Preliminary burn-out measurements are encouraging and indicate that burn-out levels in excess of 3W are achieved at 35 GHz, with a triangular pulse 200 nsecs long and a p.r.f. of 4.5 kHz using diodes with Ti/Au Schottky metallisation.

The E-plane Balanced Mixer

The mixer circuits are made using E-plane circuitry[1]. Figure 4 shows the external appearance of an E-band (60 - 90 GHz) balanced mixer. Figure 5 shows three units, one of which has a cover removed to reveal the location of a constant current bias circuit and another has been opened to reveal the E-plane circuit mounted in the waveguide cavity. Figure 6 shows a close-up view of the E-plane circuit. The signal input uses isolated unilateral finline to couple to the mixer diodes. The local oscillator input to the mixer is coupled to the diodes via a waveguide to microstrip transition and a microstrip to coplanar line transition. The I.F. output is coupled out of the circuit via a stripline low pass filter. The I.F. bandwidth is 6 GHz for the Ka-band mixer and 12 GHz for the E-band mixer. The input impedance of the mixer diodes has been measured using a network analyser for the Ka-band unit and a slotted line for the E-band unit. A matching transformer was designed in finline using the results obtained from a spectral domain analysis of various E-plane circuits.[6] A single section transformer positioned the appropriate distance from the mixer diodes was sufficient to obtain a bandwidth of 5 GHz. Figure 7 shows the measured conversion loss as a function of frequency from 80 to 90 GHz. The conversion loss is less than 6.5 dB from 82 to 87 GHz. The performance degrades above 87 GHz due to the finite matching bandwidth of the matching transformer, however the transformer can be centred on any frequency in the band as required. The noise figure of the mixer was measured using a gas discharge tube. The noise figure as a function of local oscillator frequency is also shown in figure 7. The I.F. noise figure has been subtracted in order to give a direct comparison between the conversion loss and noise figure. The curves are typically within 0.5 dB over the range and this discrepancy is within the accuracy of the measurement equipment. An overall s.s.b. noise figure of 7.5 dB has been measured at 85 GHz including an I.F. contribution of 1 dB and using a Mullard 833CL1 85 GHz Gunn oscillator for the local

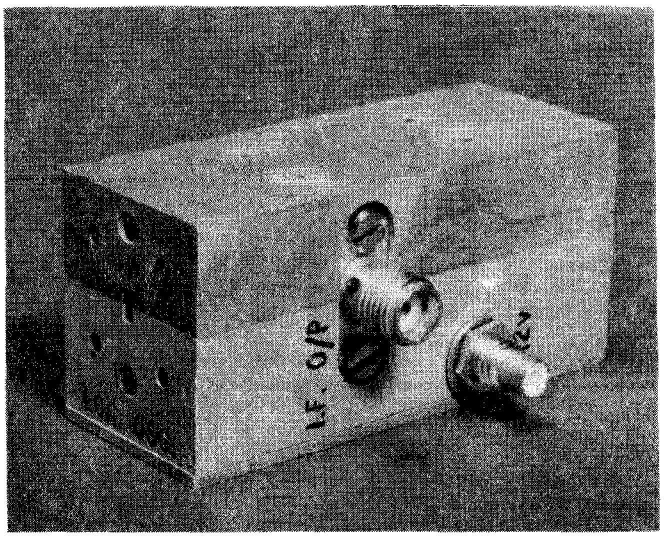

Fig. 4 E-band Balanced Mixer

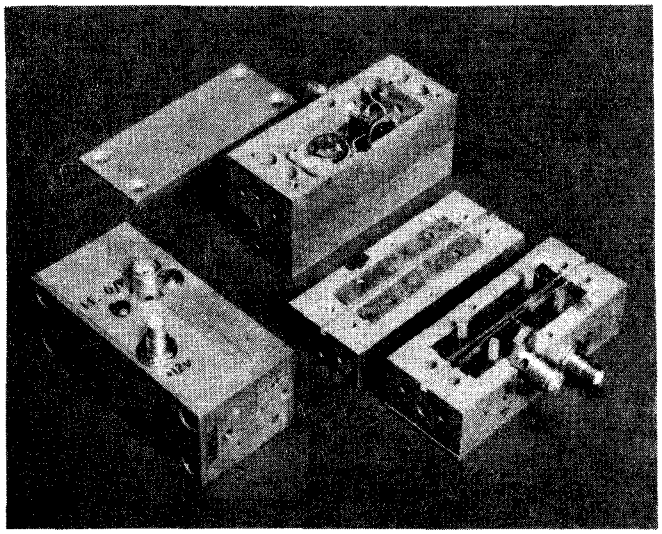

Fig. 5 E-band Balanced Mixer Construction

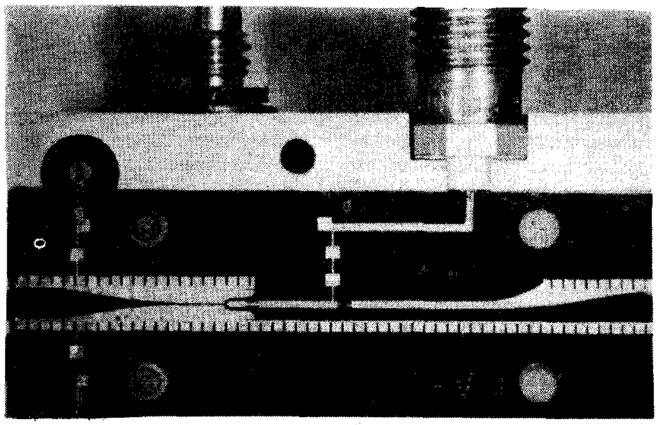

Fig. 6 The E-plane Mixer Circuit

oscillator.

At 35 GHz a conversion loss of 5 dB has been achieved with an overall s.s.b. noise figure of 6 dB (including 1 dB I.F. contribution). Due to the invariance of capacitance with voltage of the Mott diode, a significant improvement in the performance at low local oscillator powers is observed, as shown in Figure 8.

Conclusions

Reproducible state-of-the-art mm-wave performance has been achieved at 35 GHz and 85 GHz using several novel concepts in low noise mixer, device and circuit design. The coplanar diodes are made by low cost GaAs planar technology which is suitable also for the realization of monolithic GaAs mixers. A high cut-off frequency is obtained from a robust Mott diode in which the variation of noise figure with local oscillator power is significantly less than a conventional Schottky. It has been demonstrated also that several circuit functions can be integrated on to E-plane circuits to obtain balanced mixers from Ka to E band.

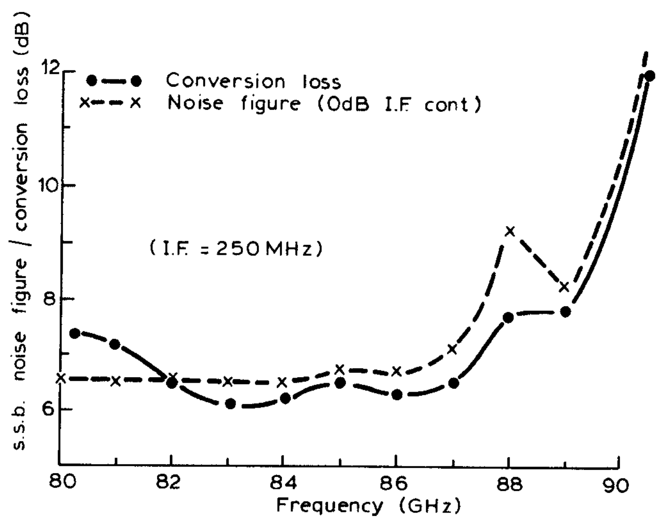

Fig. 7 E-band Mixer Conversion Loss and Noise Figure Versus Frequency

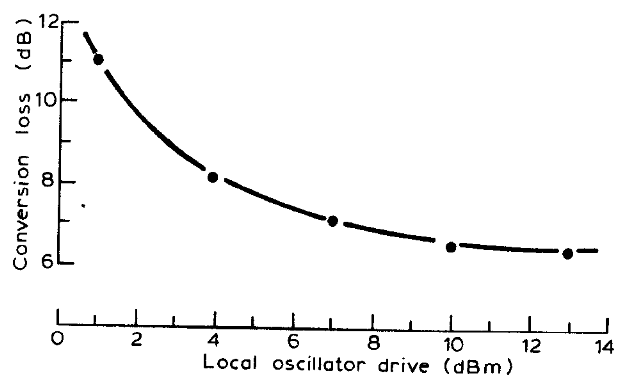

Fig. 8 Conversion Loss Vs. L.O. drive (85 GHz)

Acknowledgements

This work has been supported in part by the Procurement Executive, Ministry of Defence, sponsored by DCVD.

The authors wish to thank M.A. Ayling for device fabrication, M.D. Coleman for microwave burn-out measurements, J.J. Harris for MBE material and R.S. Watts for assembling the mixers.

References

1. Bates, R.N., Coleman, M.D. "Millimetre Wave Finline Balanced Mixers", Proc. 9th European Microwave Conference, pp.721-735, 1979.

2. Surridge, R.K., Summers, J.G. and Woodcock, J.M. "Planar GaAs Mott Low Noise mm-wave (35 and 85 GHz) Mixer Diodes", Proc. 11th European Microwave Conference, 1981, pp.871-875.

3. Harris, J.J. "Dopant Profiles in MBE GaAs for Microwave Diode Applications", 1st European Molecular Beam Epitaxial Workshop, Stuttgart, 1981.

4. Woodcock, J.M. "Non Alloyed Ohmic Contacts for GaAs Coplanar Mixer Diodes". Laser and Electron Beam Interactions with Solids (ed. B.R. Appleton and G.K. Celler), Proc. Symposium A of Materials Research Society Annual Meeting, Boston, 1981.

5. Berger, H.H. "Models for Contacts to Planar Devices", Solid State Electronics, P.145, 1972.

6. Mirshekar-Syahkal, D. and Davies, J.B. "An Accurate, Unified Solution to Various Finline Structures, of Phase Constant, Characteristic Impedance and Attenuation". Submitted for publication to IEEE Trans. MTT.