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MICROSTRIP DEVICES FOR MILLIMETRIC FREQUENCIES

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SUMMARY

A new generation of glass reinforced low capacitance beam lead mixer and PIN diodes has been developed for use at millimetric frequencies. In microstrip circuitry the gallium arsenide mixer diodes display typical conversion losses of 6.5 dB (single ended) and 7.0 dB (balanced) at 94 GHz, and 7.5 dB (single ended) at 140 GHz. A microstrip PIN switch produces greater than 30 dB isolation at 90 GHz with an insertion loss of 1 dB per diode pair.

INTRODUCTION

Much of the current effort towards millimetric wave integration has been concerned with circuits based on suspended strip line or fin line. Open microstrip is however considered to be a valuable alternative[1] and is particularly suitable for the realisation of fully integrated radar front ends for instance in the 80-100 GHz frequency band. In this laboratory a programme to develop the devices for use in microstrip receivers has been proceeding with particular emphasis on the functions of mixing and switching for frequencies in the region of 90 and 140 GHz. This paper describes the development of a new low capacitance format beam lead structure which is applicable to both mixer and PIN diodes. The performances of the diodes are described for microstrip circuits operating near 94 and 140 GHz.

BEAM LEAD DIODES

Mixer diodes

The principle of construction of the beam lead mixer diode[2] is illustrated in Figure 1. It is essentially a gallium arsenide Schottky barrier diode in which the gallium arsenide chip is surrounded by a thick dielectric wall of glass. The purpose of the glass is to provide a low capacitance support for the beam leads and to give adequate mechanical strength to the device. Because the beams are attached to the top of the glass there is no leverage on the rectifying and ohmic contacts.

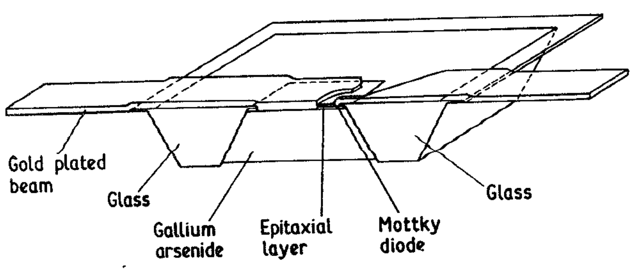

Figure 1 : Millimetre wave beam lead mixer diode

The glass is selected to have a good expansion match to gallium arsenide and also a low melting point to prevent dissociation of the semiconductor. A thin epitaxial layer is provided on top of the gallium arsenide to reduce series resistance, the specification being doping level 2×10^{17} cm^{-3} and thickness 0.1 μm. At zero bias the epitaxial layer is fully depleted so that the diodes have the characteristics of Mott barriers rather than pure Schottky barrier diodes. Most of the layers processed have been grown by metal organic vapour phase epitaxy although similar results have been achieved with hydride vapour phase and molecular beam epitaxial layers. In some cases a low resistivity buffer layer was included between active layer and substrate but this did not significantly reduce the series resistance. The essential steps in the construction are

a) etch a deep trough (~30 μm) into the gallium arsenide

b) fill the trough with glass

c) define the ohmic and rectifying contacts

d) electroplate the beam leads

e) separate the devices by back etching

The aim of the exercise has been to increase the cut off frequency of previously available beam lead diodes by reducing the R_s C_{jo} product. The results of processing several batches of diodes indicate that the total capacitance at zero bias is typically 30 fF which includes a junction capacitance, C_{jo} of 10 fF . The series resistance measured at a forward bias current of 20 mA is in the region of 5-7 Ω. Thus the cut off frequency ($= 1/2\pi R_s C_{jo}$) is about 2500 GHz. Although it is conventional to quote the DC measured value of series resistance it is necessary to consider the influence of skin effect at shorter millimetre wave frequencies. The beam lead structure is particularly favourable from the point of view of mimimising this effect and it has been calculated that R_s would only be increased by about 0.7 Ω at 90 GHz or 0.8 Ω at 140 GHz.

The mechanical strength of the diodes was one of the most important considerations in designing the new diode. If a diode is thermocompression bonded into the circuit then a force of 4.5g is required to fracture the beams.

PIN diodes

For fast switching applications it has been decided to opt for the mesa type of PIN diode rather than the planar PIN which is inherently limited by the long 'tail' in the recovery time characteristic. A construction based on the same principle as for the mixer diode has been developed but in this case a small subsidiary glass trough is included in order to isolate the PIN mesa as is shown in Figure 2. A 2 μm thick low doped epitaxial layer is grown by the silane method on top of an arsenic doped silicon substrate of resistivity 3 mΩcm. The sharpness of the interface region is improved by the incorporation of a hold time in the growth schedule. The PIN structure is completed with a shallow boron diffusion and the mesa is subsequently etched to a diameter of 15 μm.

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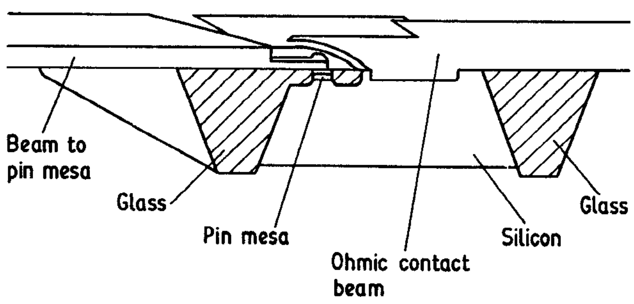


Figure 2 : Detail of beam lead PIN diode

The total capacitance of typical diodes is approximately 30 fF which includes a stray capacitance contribution of 15 fF. The series resistance has been measured at 400 MHz to be about 5 Ω and the reverse breakdown voltage at 10 μA is about 45V.

MICROSTRIP TEST CIRCUITS

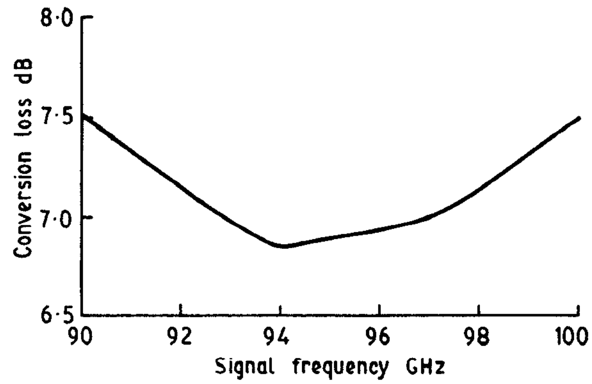
The most suitable low loss, low dispersion substrate material for the shorter millimetre waves is single crystal z-cut quartz. For the manufacture of millimetre MICs it has the major advantage of being thermally compatible with the other materials required such as inserted ferrites as used for cirulators and the conductors copper, brass and nickel. The quartz can be bonded directly to the latter materials using conventional AgSn soldering techniques. The circuit patterns are defined easily by photolithography and the beam lead diodes attached readily by thermocompression bonding. Access to the 50 Ω microstrip lines from waveguide is by means of low loss, broadband stepped ridge transitions developed to cover the 60-90 GHz, 75-110 GHz and 110-170 GHz frequency bands.

94 GHz mixers

Both single ended and balanced mixer circuits have been developed for operation in the 80-100 GHz band, the latter incorporating a conventional hybrid ring coupler. Using typical mixer diodes the conversion losses of a number of single ended mixer circuits were in the range 6.0 to 6.5 dB at 94 GHz. These mixers were developed to establish the matching required for the diode and led to the design of balanced mixers optimised for broadband operation. The performance of a typical balanced mixer is shown in Figure 3 which shows conversion loss against frequency for the band 90 to 100 GHz. The mixer was driven by a 10 mW local oscillator 70 MHz away from the signal and the diodes were each forward biased by 0.4V.

140 GHz mixers

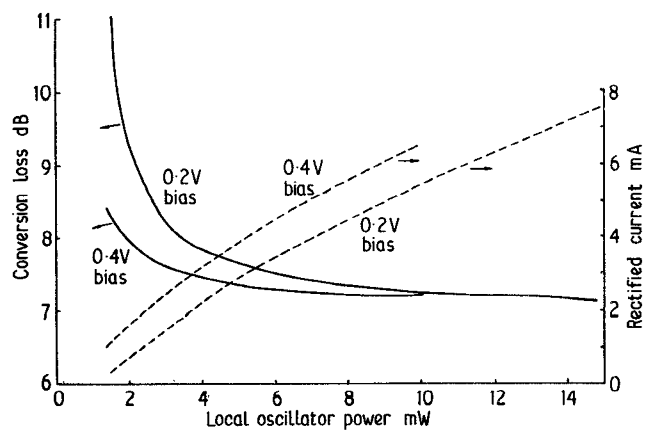
The development of a single ended mixer for 140 GHz commenced with an assessment of the inherent loss in the microstrip[3]. The single crystal quartz substrates were thinned to 100 μm and the transmission loss for different lengths of 50 Ω line terminated at each end with a transition to waveguide was assessed and found to be 0.1 dB per millimetre. The feasibility of using microstrip at 140 GHz then led to an optimisation of the microstrip elements required for a mixer including the RF short circuit and filter sections. The mixer was assembled with a diode of total capacitance of 25-30 fF and the conversion loss of the mixer was assessed by direct measurement of the signal and IF power for an IF of 4 GHz. The results are given in Figure 4 and show that a conversion loss of 7.5 dB can be achieved with a forward bias of 0.4V and local oscillator drive at 140 GHz of 10 mW. Figure 4 also shows the rectified current generated by the diode at two different DC line levels. The conversion loss has also been found to be almost independent of IF in the range 2 to 4 GHz.



LO drive +10 dBm
forward bias 0.4V
IF 70 MHz

Diode characteristics
C_{to} 0.035 pF
R_s 6 Ω

Figure 3 : Microstrip balanced mixer conversion loss versus frequency



Signal frequency 136 GHz
LO frequency 140 GHz

Diode capacitance 0.34 pF
Series resistance 7 Ω

Figure 4 : Performance of 140 GHz microstrip mixer

94 GHz PIN switch

The PIN diode test circuit includes a pair of $\lambda_g/4$ spaced diodes in shunt connection and incoporates RF shorting and inductive tuning stubs. The diodes are biased via low pass filters on the circuit. Using the new PIN diodes the switch has produced an isolation of over 35 dB at 87 GHz and greater than 20 dB for the band 80 to 97 GHz. By adjusting the lengths of the tuning elements the centre frequency can be adjusted through the band 82 to 95 GHz. The diodes were each forward biased to 10 mA for the test. The insertion loss for the switch excluding transitions is about 1 dB per diode pair.

CONCLUSIONS

The performance of the new glass wall beam lead diodes represents a significant improvement on previously available types particularly with respect to total capacitance and mechanical strength. The diodes are ideally suited to microstrip circuits and their development has enabled advances to be made in mixer performance at the shorter millimetre wavelengths. The low capacitance mixer diode has for instance produced a much broader bandwidth capability than was previously available and combined with low series resistance given state-of-the-art conversion losses at 94 GHz. The possibility of improved switching performance has also been demonstrated with silicon PIN diodes.

At 140 GHz a single ended microstrip mixer has been shown to be feasible and gives an acceptable conversion loss of 7.5 dB. Although the diodes were primarily designed for microstrip circuits their structure is equally applicable to other transmission media such as suspended strip line of fin line.

ACKNOWLEDGEMENT

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