A MONOLITHIC 60 GHZ DIODE MIXER IN FET COMPATIBLE TECHNOLOGY

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Abstract

A technology has been developed with which MeSFETs with an f_{max} of 70 GHz and Schottky diodes with $f_T \approx 2300$ GHz can be fabricated on the same chip. This allows the production of mm wave mixers with integrated LO and IF amplifier. A 60 GHz mixer chip has been designed and fabricated using this technology and shows a conversion loss of 6.0 dB and a noise figure (DSB) of 3.3 dB.

Introduction

The feasibility of millimeter wave systems in large quantities depends on the availability of millimeter-wave MMICs. Frequencies of interest are at approximately 35, and 90 GHz for seeker heads and intelligent fuses and 60 GHz for short range covert communication. On the basis of earlier results /1, 2/, a new technology has been developed which allows the integration of Schottky diodes ($f_t \approx$ 2300 GHz) and MeSFETs (f_{max} = 70 GHz) on the same chip. With this technology it is possible to integrate diode mixer, IF amplifier and mixer LO on one chip. The paper describes the design and fabrication of a first 60 GHz mixer, having a conversion loss of 6.0 dB and an minimum noise figure $N_{F(DSB)}$ of 3.3 dB.

Technology

Because Schottky diodes and MeSFETs are to be fabricated simultaneously, a new and unusual technology has been developed. Fig. 1 shows a schematic cross section of the active devices. A deep selective n^+ implantation was used for a buried n^+ zone under the mixer diode and MOCVD was used for the growth of the active n layer and an n^+ surface

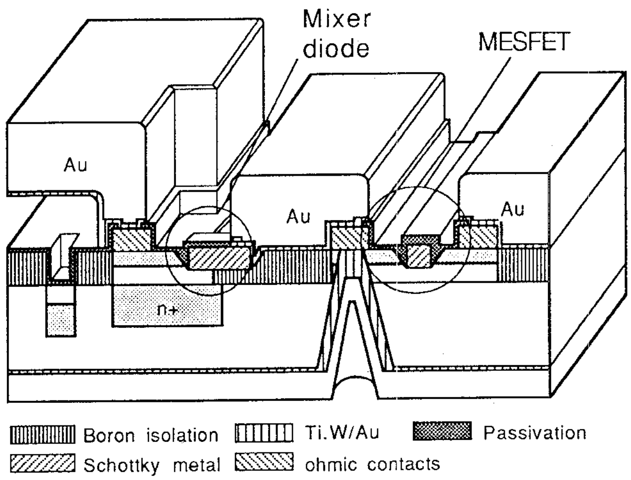

Fig.1: Schematic cross section of the active devices

contact layer. The n^+ surface contact layer facilitated the fabrication of recessed gate MeSFETs. The multiple implantation of Si followed by transient annealing leads to a very high carrier concentration and the sheet resistance of the n^+ buried layer was routinely lower then 20 Ohm/□ . The high conductivity of the n^+ buried layer plus the small geometry of the Schottky fingers were important contributions to the achievement of very high diode cutoff frequencies. MOCVD of the n layer and n^+ surface contact layer was carried out in a horizontal reactor at atmospheric pressure. Diode fingers and FET gates were directly exposed using e-beam lithography allowing a minimum structure size of 0.3 um.

The MeSFETS and the diodes were both fabricated with a recessed Schottky contact structure using Ti Pt Au metalisation. The ohmic contacts were Au/Ge and the devices were passivated by a combination of pyrolytically deposited SiO_2 and plasma deposited Si_3N_4 which is also used for the overlay capacitors. The devices were isolated by Boron implantation into the epitaxial layer. The technology includes both airbridges and via holes.

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Diodes and MeSFETs

Arrays of 30 different diodes and 55 different MeSFETs have been fabricated to study the process technology and to get optimum devices for a receiver chip containing a diode balanced mixer plus a low noise IF amplifier. Conversion loss and noise figure of the diodes have been measured and compared with those obtained from computer simulations, which included both large and small signal analysis. The computer simulation was used to calculate the impedances which have to be seen by the mixer diodes to obtain optimum performance. Fig. 2 shows, for example, the comparison of measured and calculated conversion loss of a single diode. This diode has three fingers each 0.3 x 4 um^2 and is shown in Fig. 3. The measured values C_j = 11fF and R_S = 6.1 Ohm result in an f_T = 2370 GHz. The fabricated MeSFETs have gate lengths between 0.3 and 1.0 um and different gatewidths in π - and multi finger configuration to satisfy the different requirements of the different parts of the receiver circuit. The short gatelength transistors, for example Fig. 4, will be used for an integrated LO, consisting of a 27,7 GHz FET oscillator and a 27,7 GHz amplifier. Together with the Schottky mixer diodes varactor diodes are with this technology under development to realize a varactor diode doubler to get 55,4 GHz LO. S-parameter measure-

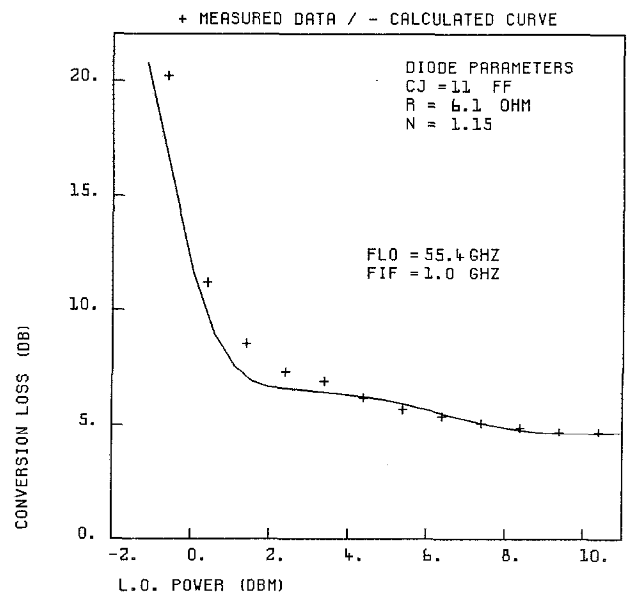

Fig.2: Measured and calculated transmission loss of a Schottky mixer diode

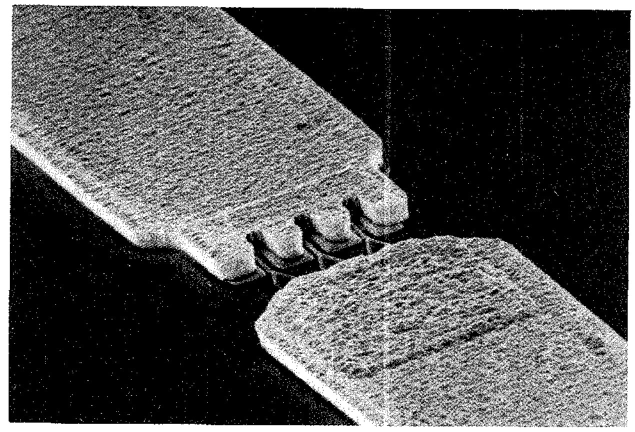

Fig.3: Three finger Schottky diode

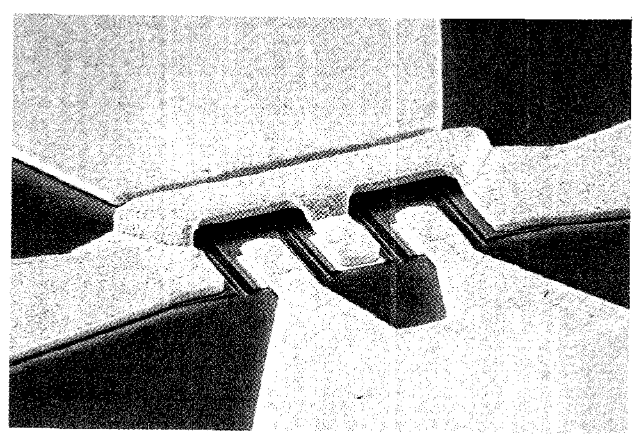

Fig.4: Four finger MeSFET

ments of the transistors showed an extrapolated f_{max} = 70 GHz and a MAG = 7 dB at 30 GHz (Fig. 5). The transistors with longer gatelengths (0.75 um) were used for the design of an integrated low noise IF amplifier with 2 stages for an IF bandwith from 4 to 5 GHz. Noise figures of 0.8 dB at 4.5 GHz with an associated gain of 11 dB have been measured.

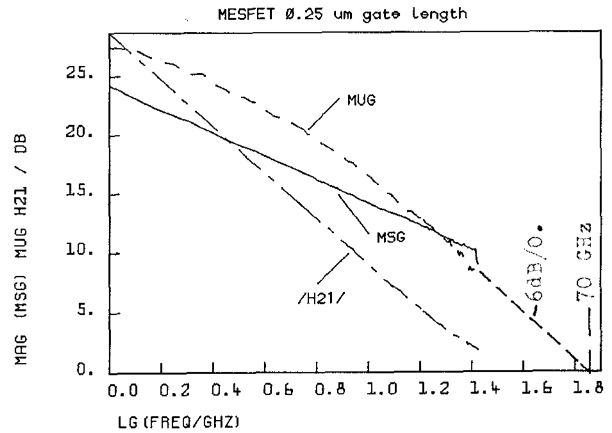

Fig.5: Gain vs. frequency of a MeSFET

for the mm-wave frequency range /3/. LO at 55.4 GHz and signal frequencies at 60 GHz are fed to the diodes through a branchline coupler which has been designed using this software taking into account improved models of the MSL-Tee junction and coupling between the lines of the coupler. An improved bandwith of 15 % was achieved by adding 4 open ended stubs to the coupler /4/.

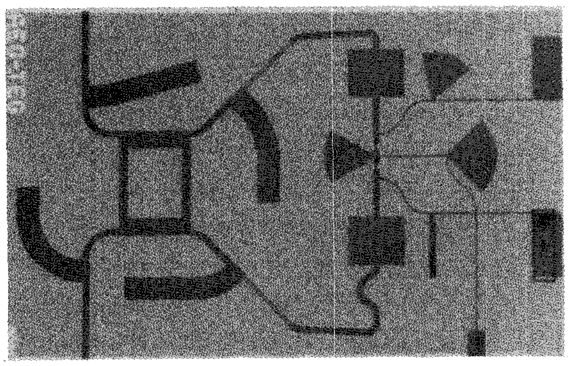

Fig.6: 60 GHz mixer chip

60 GHz mixer

The developed single balanced mixer chip is shown in fig. 6. The chip thickness was chosen to be 150 um. To avoid problems with coupling effects and microstrip (MSL) discontinuities and to get optimum design possibilities (Fig. 7), an impedance level of 70 Ohm was used. The in house software to calculate MSL-discontinuities and radial stubs on basis of the magnetic wave guide model has been improved

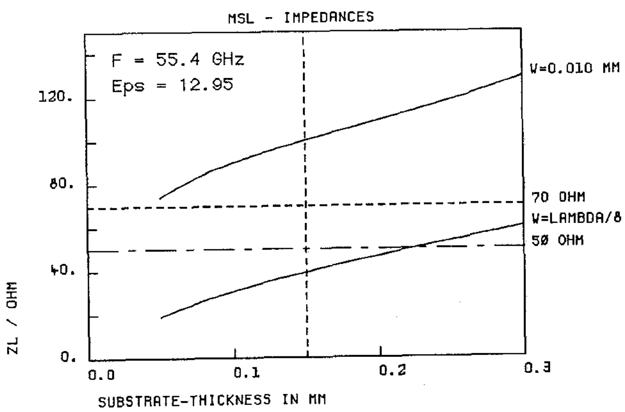

Fig.7: MSL impedance range vs. substrate thickness

Fig. 8 shows the characteristic of a separately fabricated coupler measured in a V-band test fixture. Because the coupler has a 90° phase difference between its two output ports, a line length of a quarter of a wavelength was added to one port to get a phase difference of 180° at the center frequency of the mixer. Calculation show, that the phase error due to the MSL dispersion within the

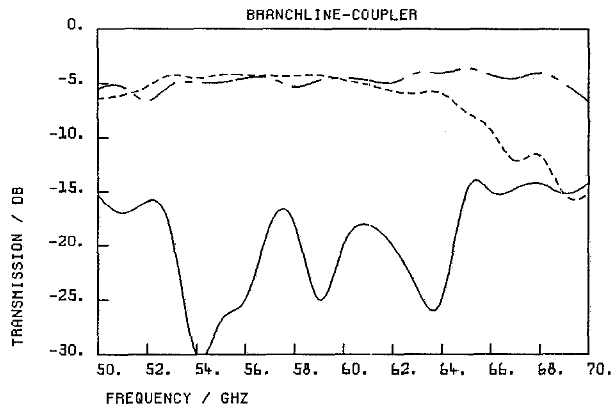

Fig.8: Measured characteristic of the branchline coupler

band of operation of the mixer is less than $\pm 10^{o}$. The RF-short between the diodes is realized by a radial stub.

Two side coupled DC stops allow DC bias of the diodes through two band stop filters for optimum performance. For self bias operation the two bias pads are connected. The measured transmission loss of seperately fabricated DC stops is better than 0.6 dB between 50 and 60 GHz compared to 0.5 dB calculated.

The IF output is also realized as a bandstop filter with a radial stub to reject LO and Signal. Fig. 9 shows the measured conversion loss and noise figure of a mixer chip versus LO power in self bias operation. We achieved a DSB-noise figure of N_F = 3.3 dB combined with 6 dB conversion loss. The LO-power was P_{LO} = 6.5 dBm at 55.4 GHz. IF was 4.1 GHz in this case.

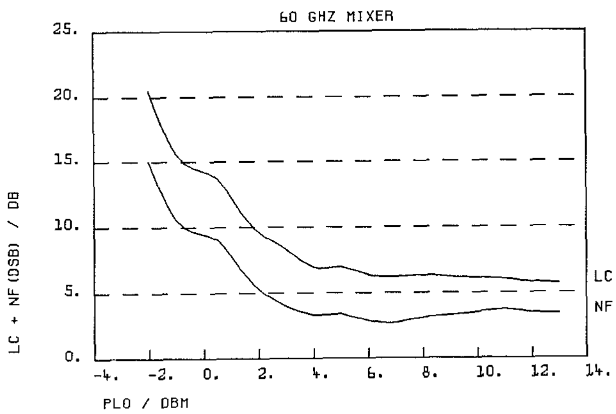

Fig. 9: Conversion loss and noise figure of the mixer chip

Conclusion

A GaAs-technology using a combination of implantation and MOCVD has been developed and allows the fabrication of Schottky mixer diodes ($f_T \approx$ 2300 GHz), varactor diodes and MeSFETs (f_{max} = 70 GHz) on the same chip. Using this technology a 60 GHz single balanced mixer has been developed with a conversion loss of 6.0 dB and a minimum noise figure (DSB) of 3.3. dB.

References

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