30 GHZ MONOLITHIC BALANCED MIXERS USING AN ION-IMPLANTED FET-COMPATIBLE 3-INCH GAAS WAFER PROCESS TECHNOLOGY*

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ABSTRACT

An all ion-implanted Schottky barrier mixer diode which has a cutoff frequency greater than 1000 GHz has been developed. This new device is planar and FET-compatible and employs a projection lithography 3-inch wafer process. A Ka-band monolithic balanced mixer based on this device has been designed, fabricated and tested. A conversion loss of 8 dB has been measured with a LO drive of 10 dBm at 30 GHz.

I. INTRODUCTION

Planar gallium arsenide Schottky barrier mixer diodes have shown very good performance for millimeter wave frequencies. [1] These devices usually employ a thick (2-5 microns) n^+ layer between the thin active n layer and the semi-insulating substrate to minimize the diode series resistance. This buried n^+-layer diode structure is not very compatible with GaAs MESFET-based integrated circuit processing where a high resistivity layer is required under the FET channel. Earlier attempts to demonstrate diode/FET integration have used a complex selective epitaxial growth approach which is not easily reproduced. Recently, the use of a selective ion implantation technique to enable the separate optimization of the diode and FET layers for monolithic integration has been demonstrated.(3) In this paper, we report the use of selective ion implantation for a structure with significantly reduced diode spreading resistance. A cutoff frequency over 1000 GHz has been achieved using this structure.

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II. FABRICATION PROCESS

The fabrication process that has been developed for the ion-implanted 30 GHz mixer is based on projection photolithography using 3-inch GaAs wafers. The optical lithography is performed using a Censor SRA-100, direct-step-on-wafer (DSW), 10:1 projection alignment/exposure system. This optical system is capable of high resolution (<0.7-micron structure resolved), high alignment accuracy(<0.2-micron layer-to-layer misalignment), and high throughput (>45 wafers per hour) photolithography on 3-inch GaAs wafers.

An advanced IC process developed for the ion implanted 30 GHz mixer using 3-inch GaAs wafers and projection lithography includes the following key steps. After the formation of alignment marks, a high energy, heavy dose implant forms the active and low resistance contact regions in one step. The implant is capped and annealed to activate the implants followed by formation of the ohmic contacts. The final step in topside processing is formation of the Schottky contacts and circuit metal pattern. After thinning, via contacts providing the IF ground return are etched and backside metallization is deposited. The wafers are then ready for scribing, breaking and packaging prior to final testing.

III. MIXER DIODE

To achieve a high-cutoff frequency with an ion-implanted mixer diode, a unique micro-dot diode structure has been developed. The design is shown in Figure 1. It consists of twenty-four, one-micron diameter Schottky diodes on an active layer implanted with a relatively heavy Si dose ($4x10^{13}cm^{-2}$) at high energies (300 KeV). The result is low surface doping and decreased sheet resistance. The low surface doping will reduce the diode capacitance while the multiple diodes and decreased sheet resistance imply low series resistance. The RF series resistance of a single diode with diameter, D can be calculated from the following formula:(4)

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$$R_S = 4\frac{\rho t}{\pi D^2} + \frac{r_s}{2\pi} \ln \frac{(2b)}{D} + \frac{r_s d}{\pi D} \tan^{-1} \frac{(2b)}{D} + R_C$$

where ρ and t are, respectively, the resistivity and thickness of the surface layer, r_s is the sheet resistance of the implanted region and d is its thickness. The mean distance to the ohmic contacts is denoted by b, and R_C is the ohmic contact line resistance. The resistance of the diode is estimated using the following parameters:

D = 1 micron
ρ = 2×10^{-2} ohm-cm
t = 0.07 microns
r_s = 100 ohms/square
d = .5 microns
b = 3 microns
R_C = .2 ohm-mm

Using these relatively conservative parameters, a one micron diode series resistance of 96 ohms is calculated. The corresponding junction capacitance is 1.3 fF. This gives a cutoff frequency over 1200 GHz which is high enough that diode parasitics are not a significant factor in the conversion loss.

Fabrication of the micro-dot mixer diode based on the above design has been successfully completed. A photograph of the diode is shown in Figure 2. The measured characteristics of the diode are:

- o Series resistance from 2-6 ohms
- o Total capacitance between .068 and .076 pF (includes parasitic "pad" capacitance
- o Ideality between 1.1 and 1.4

These parameters cover a few extreme cases but the diodes with the lowest series resistance appear to have the highest ideality. Diode cutoff frequencies have ranged from a low of approximately 400 to more than 1000 GHz.

IV. MONOLITHIC BALANCED MIXER

Based on the planar, ion-implanted diode design described above, a broadband balanced mixer has been designed, fabricated and tested. A conversion loss of 8 dB with a LO drive of 10 dBm at 22 GHz has been measured over the 27.5 - 30 GHz frequency range.

Figure 3 shows the layout of the balanced mixer circuit. The circuit consists of a modified rat race hybrid, two mixer diodes, filters and signal ports. The modified rat race hybrid nominally provides balanced local oscillator and signal amplitudes to the two diodes over a wide bandwidth. At the same time, the sum of the local oscillator and signal frequencies is rejected for lowest conversion loss.

A photograph of the completed 30 GHz ion-implanted mixer is shown in Figure 4. A test fixture has been designed for the broadband mixer. Figures 5 and 6 show the 30 GHz ion-implanted mixer chip mounted in its test fixture. The signal port of the fixture uses a fin-line transition with the local oscillator connected by means of a SMA coaxial connector.

The measured conversion loss at reduced LO drive (6 dBm) for two mixer chips in two test fixtures is shown in Figure 7. It includes test fixture and transition losses. Much of the performance degradation is related to the high VSWR at the signal and local oscillator ports due to mismatch at the diode junction. This mismatch should be corrected in a new circuit design which is being fabricated.

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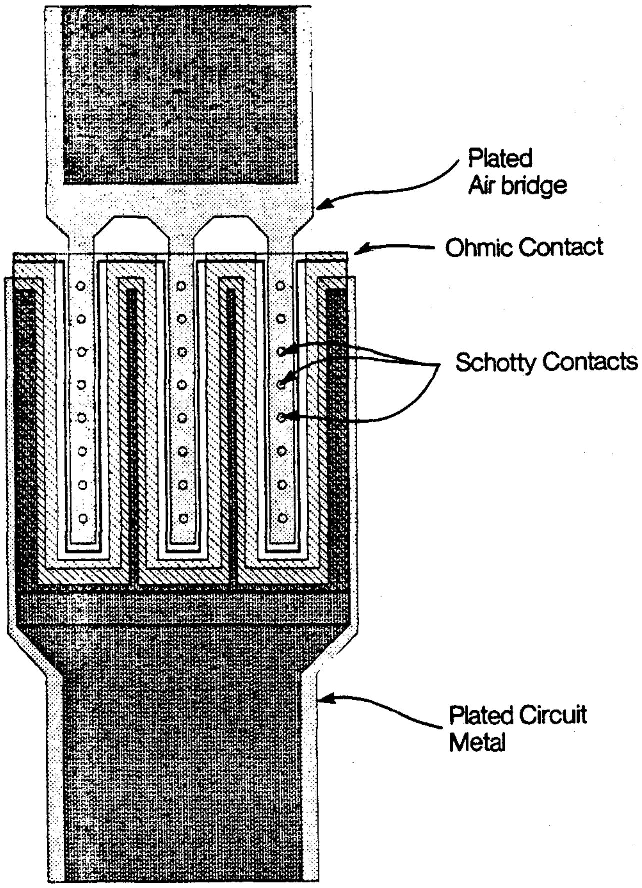

Figure 1. CALMA Layout of Ion-Implanted Mixer Diode Showing 1-Micron Schottky Contacts Used to Reduce Spreading Resistance

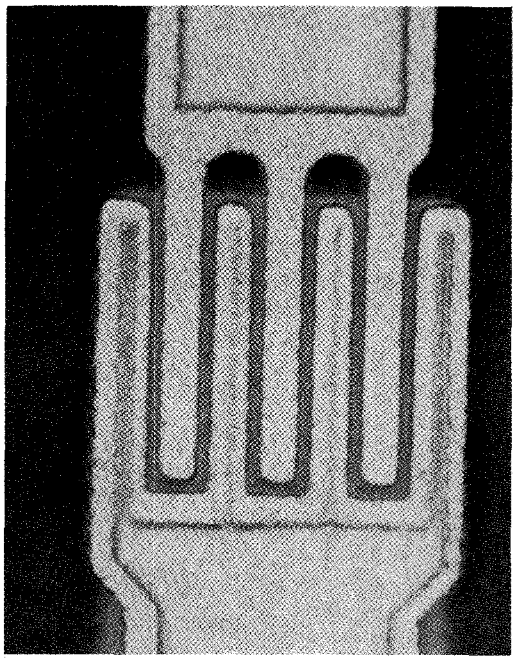

Figure 2. Photograph of the Ion-Implanted Mixer Diode

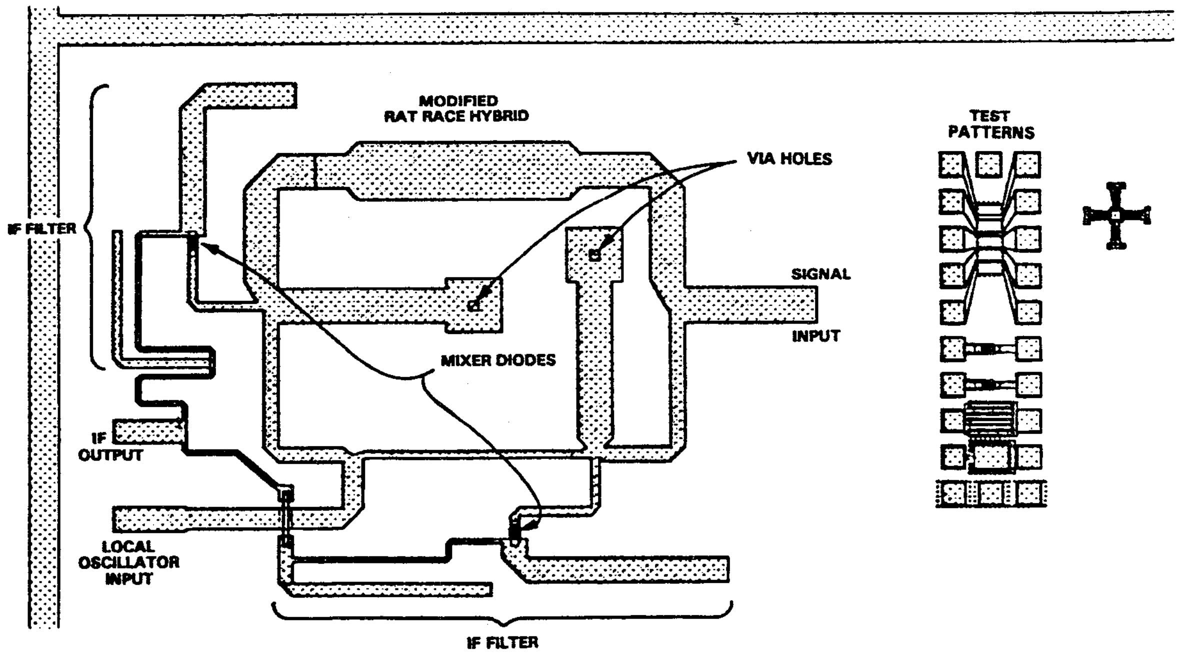

Figure 3 CALMA Layout of 30-GHz Mixer with Rat-Race Hybrid Modified for Wide Bandwidth

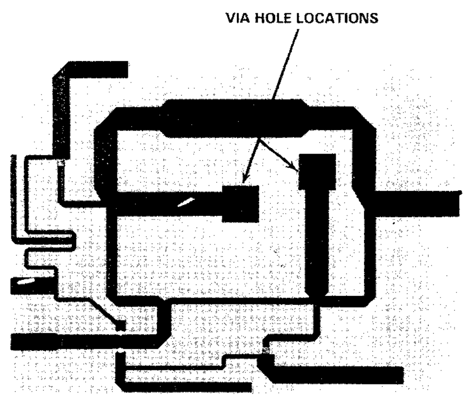

Figure 4. 30-GHz Ion-Implanted Mixer

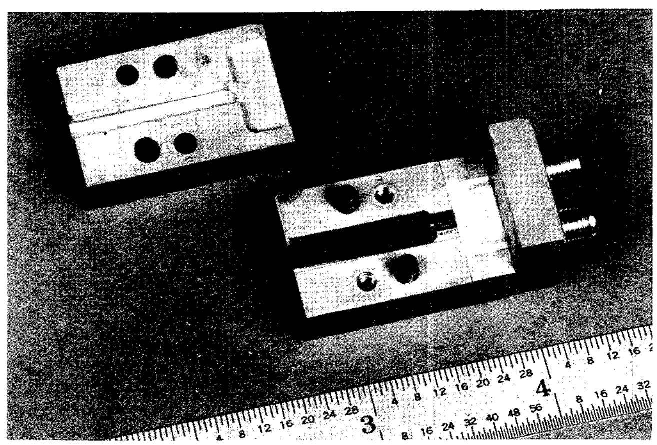

Figure 5. 30-GHz Ion-Implanted Mixer Mounted in Its Test Fixture

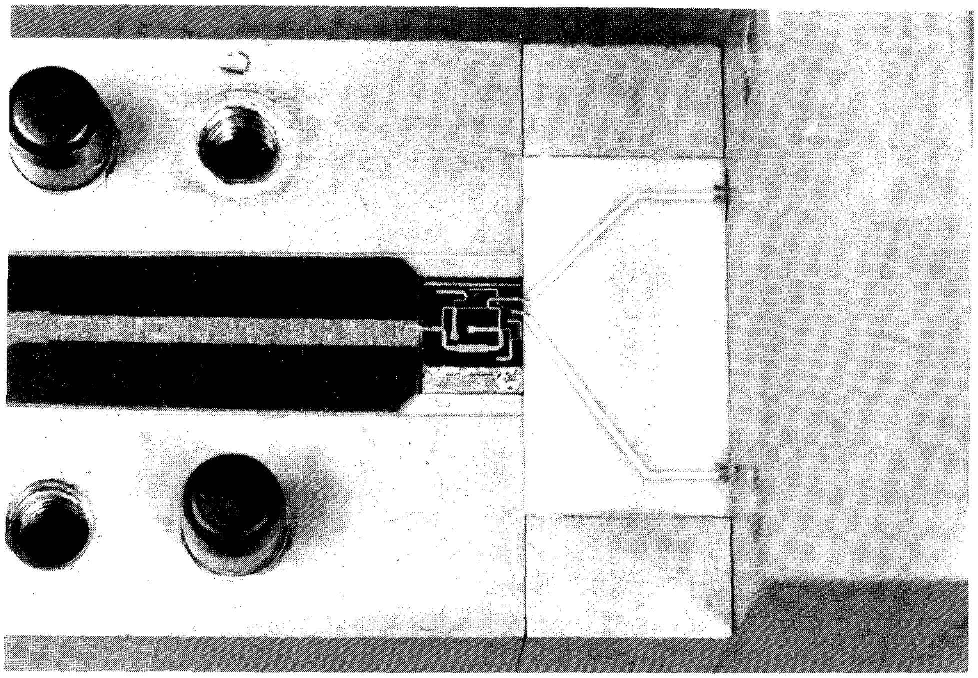

Figure 6. Detailed View of Mounted 30-GHz Mixer

Conversion Loss vs. Frequency for Two Different Mixer Chips

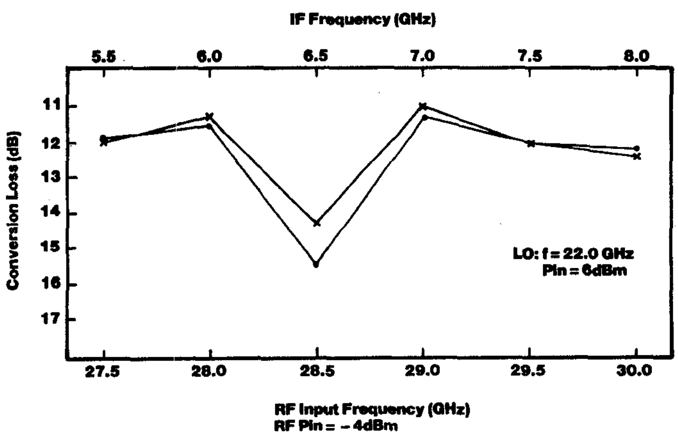

Figure 7. Ion-Implanted Mixer Measured Conversion Loss