ION IMPLANTED W-BAND MONOLITHIC BALANCED MIXERS FOR BROADBAND APPLICATIONS*

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ABSTRACT

An all ion-implanted monolithic broadband balanced mixer fabricated on a GaAs substrate for operation at W-band frequencies is described. A deep implanted buried n^+ layer was used to minimize the diode series resistance. Ohmic contacts were formed by standard alloying of planar eutectic AuGe metallization into the n^+ layer. The mixer diode structure is completely compatible with GaAs MESFET-based monolithic integrated circuit processing techniques. A conversion loss from 6.8 to 10 dB has been measured over an RF range of 75 to 88 GHz, with a LO drive of 10 dBm at 92 GHz.

INTRODUCTION

W-band monolithic GaAs mixers fabricated in a crossbar configuration have been reported previously.[1] Although good results have been obtained, this mixer configuration is not suitable for monolithic millimeter-wave integrated circuits (MMWICs). Another planar monolithic balanced mixer configuration utilizes a combination of microstrips, slotlines, and coplanar striplines.[2] This circuit configuration is suitable for MMWICs and produces respectable performance; however, careful grounding must be taken into consideration to obtain proper excitation conditions. In both cases, the in situ Schottky barrier mixer diode structure was based on the use of a thick (2-5 μm) n^+ layer and a thin active n layer, on which the Schottky contacts are formed (VPE growth material). This buried n^+ layer diode structure is not very compatible with GaAs MESFET-based integrated circuit processing. Earlier attempts to demonstrate diode/FET integration relied on selective MBE or epitaxial growth, which is not easily reproduced.[3] Recently, the use of a selective ion implantation technique to optimize mixer diodes and FET profiles has been demonstrated.[4,5] This paper describes an all ion-implanted monolithic broadband balanced mixer for operation at W-band frequencies. Broadband performance is realized by the use of a monolithic Lange coupler and radial-line stubs (see Figure 1). IF ground and dc returns are provided by a pair of monolithic via holes. A conversion loss of less than 10 dB has been measured over an RF frequency range from 75 to 88 GHz, with a LO drive of 10 dBm at 92 GHz.

MIXER CIRCUIT CONFIGURATION

A balanced mixer configuration, utilizing a pair of in situ Schottky barrier diodes and a quadrature 3 dB coupler, has been used in the design of the W-band monolithic mixer, as shown in Figure 1. The circuit integrates a broadband Lange coupler, a radial line stub for RF short, a pair of ion implanted Schottky barrier diodes, monolithic via holes, and a microstrip low-pass filter. The overall dimensions of the mixer chip are 1.6 x 2.4 mm.

A Lange coupler was used to improve the bandwidth of the mixer. The coupler also provides a better RF to LO isolation than conventional branch line or ratrace couplers. The basic coupler design is based on published theory.[6] We did not take the effect of the monolithic airbridges into account. The odd and even mode impedances and effective dielectric constant values were obtained by using the spectrum domain approach for a pair of coupled microstrip lines.[7] At the mixer diode junction, a broadband quarter-wave radial line provides the RF short. IF ground and dc returns are provided by monolithic via holes. A combination of a high impedance quarterwave section and an open-circuit radial line prevents the RF from leaking through, while it allows the IF and dc to pass. Two small square pads were plated to 5 μm to provide a strong footing for the via holes. A low-pass filter is placed approximately a half-wavelength away from the diode junction and allows only the IF signal to pass. LO and RF signals are fed at the two input ports of the Lange coupler. No dc bias was provided for this mixer circuit.

CIRCUIT FABRICATIONS

The monolithic mixer circuit was fabricated on a 0.1 mm (0.004 inch) semi-insulating GaAs substrate. Ion

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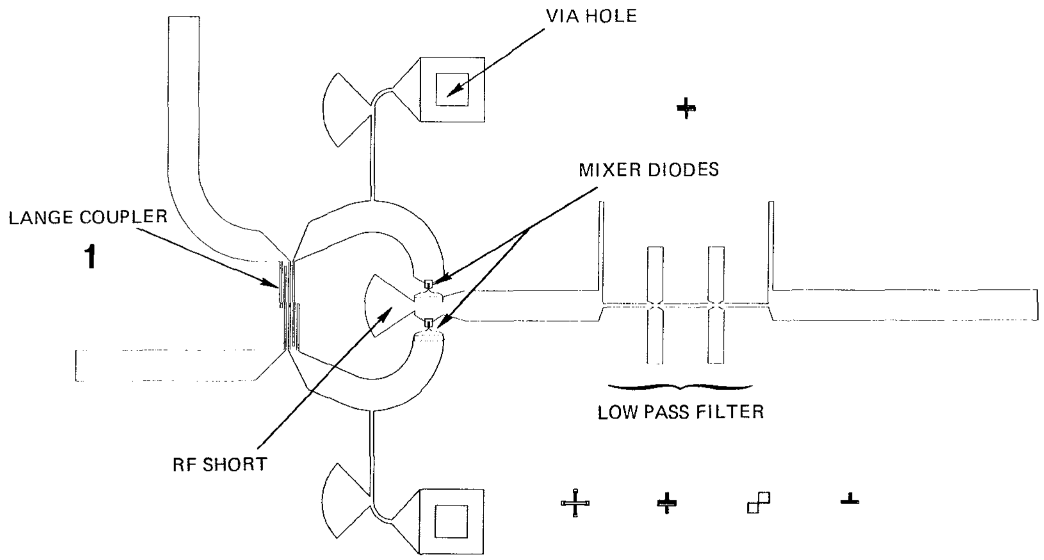

Fig. 1 CAD layout of the monolithic balanced mixer.

implanted GaAs wafers are compatible for fully monolithic integrated circuits, which are multiple device-types. Therefore, for future monolithic integration with our ion implanted FET amplifier, we fabricated the Schottky mixer diode structure using the selective ion implantation technique. Figure 2 shows the LSS (Lindhard, Scharf, and Schiott) ion implantation model used for the simulation of the n-on-n^+ mixer diode profile. We used three different ion implantation schedules to obtain the composite profile. After selected areas of the wafer were ion implanted, the species were activated by CAT anneal at 890°C for 30 minutes. An ohmic mask was aligned over the implanted area, and the ohmic contact was formed by standard AuGe-Ni-Au metallization lift-off and alloying. No etching to the n^+ region was necessary. To ensure absolute device isolation, a proton bombardment technique was used, with proton energy up to 400 KeV. Next, a 1 x 10 μm Schottky contact was formed inside the 5 μm wide active area on the ohmic contact by using a standard photolithographic technique.

I-V characteristics of the Schottky diode thus formed were evaluated on a separate test wafer and showed a typical series resistance of 6 to 8 ohms, an ideality of 1.19, a diode capacitance of 43 pF, and cut-off frequencies from 450 to 560 GHz, which are quite remarkable for mixer diodes formed by the ion implantation technique. After the individual Schottky diodes were established, we integrated the transmission line circuit patterns. Figure 3 summarizes the processing sequence. The monolithic airbridges on the Lange coupler were formed by a two-step photoresist process and selective gold electroplating. The wafer was then lapped to 0.1 mm thick, and backside via holes were formed by chemical etching. The backside ground metal was Ti-Au. Individual monolithic mixer chips were separated by automatic sawing. Figure 4 shows the fabricated mixer chip.

RF PERFORMANCE

The W-band monolithic mixer chip was mounted on a test fixture, as shown in Figure 5. In the test fixture, waveguide-to-coax-to-microstrip transitions (utilizing special miniature semirigid coaxes, UT-13) are provided for the RF and LO inputs. Typical transition loss of these coaxial transitions at W-band is about 2 dB for a pair connected back-to-back. The IF output of the mixer is taken out of an SMA connector via a semirigid UT-34 coax. The ion-implanted Schottky barrier diodes on the monolithic mixer chip had typical dc characteristics as follows: diode series resistance R_S = 8.2 ohms, ideality factor n = 1.19, and diode junction capacitance C_j = 47 pF. The conversion loss of the mixer circuit is shown in Figure 6. For a 13 GHz bandwidth covering from

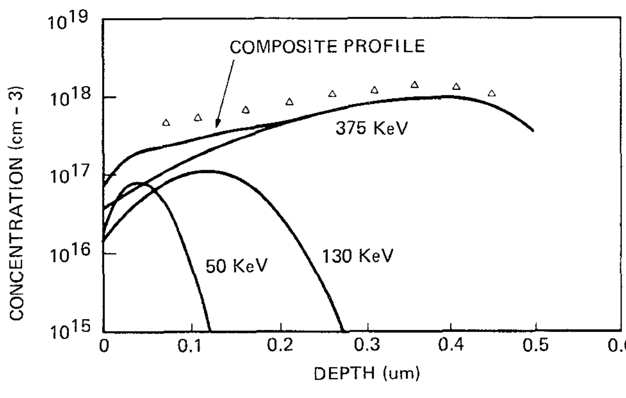

Fig. 2 Composite profile of n-on-n^+ prepared by ion implantation technique.

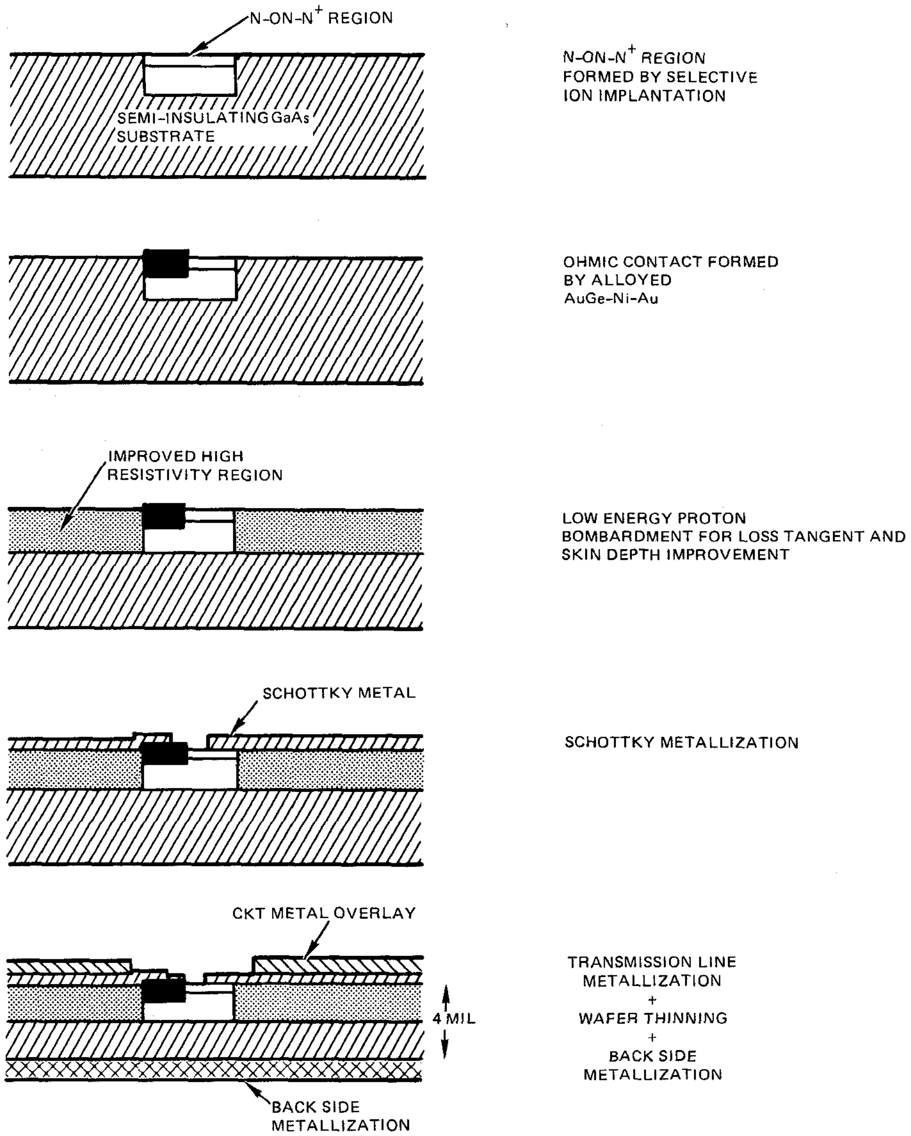

Fig. 3 Planar mixer MMIC processing sequence.

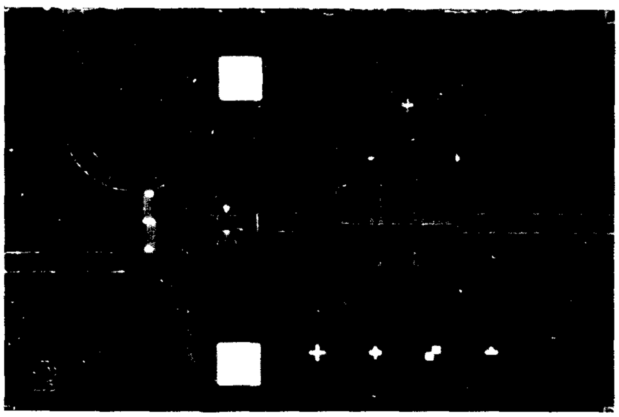

Fig. 4 Actual layout of the fabricated monolithic mixer.

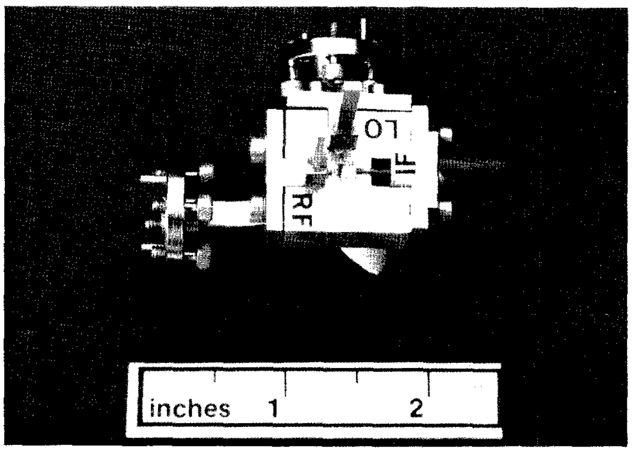

Fig. 5 Test fixture for the monolithic mixer chip.

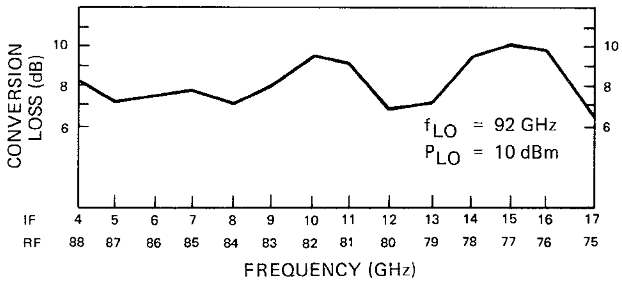

Fig. 6 Performance of the ion implanted W-Band monolithic mixer.

75 to 88 GHz, a conversion loss from 6.8 to 10 dB has been measured. The LO drive level for this mixer was set at +10 dBm and at 92 GHz. When the same mixer was tuned over a narrower bandwidth of 5 GHz, the conversion loss was less than 8 dB, with a minimum of 6 dB.

CONCLUSIONS

A planar ion implanted W-band monolithic mixer circuit compatible with GaAs MESFET-based integrated circuit fabrication has been developed. The deep Si implantation into a semi-insulating substrate can provide an adequate n^+ contact layer to minimize diode series resistance. The entire mixer chip measures only 1.6 x 2.4 mm. The conversion loss of less than 10 dB over a broad IF bandwidth from 4 to 17 GHz was achieved with 10 dBm LO power drive. The truly planar ion implanted mixer diode design offers a potentially low cost, high yield millimeter-wave monolithic integrated circuit.

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