200 GHz Submillimeter-Wave Emitter Mixers with L-Ge- and L-He Angles in Planar Schottky Diodes

Acknowledgement and Performance of Planar Schottky Diodes

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packages in place on millimeter-wave circuits and at the same time allow the implementation of GaAs devices on substrates (quartz, silicon, sapphire etc.) with dielectric properties more suitable for submillimeter-wave operation.

Most high frequency diodes use a circular anode with an air-bridge type finger that connects the anode to the ohmic contact. As the anode diameter is reduced for higher frequency operation and the finger width becomes larger than the anode diameter, this structure induces a strong parasitic capacitance between the finger tip and the region surrounding the anode. This parasitic capacitance is difficult to tune out and results in deteriorating the circuit performance at high frequencies.

In this letter, we report on the design and performance of a 'T'-gate-like structure in which the anodes are shaped like a “T” and the finger or air-bridge between the anode and the ohmic contact is made in the same step as the anodes. This structure is readily scaled to frequencies above 1 THz and also suits lower parasitics than conventional circular air-bridge type diodes. Antiparallel pair 'T'-anode devices monolithically integrated on quartz microstrip circuits using the <111> process [5] have been fabricated and tested in a room-temperature subharmonically-pumped mixer operating at 200 GHz. The measured mixer noise temperature and conversion loss are 600° KDSB and 4.7 dB respectively, which is believed to be the best performance ever obtained in this configuration at this frequency.

II. DEVICE DESIGN AND FABRICATION

The T-anodes are formed using a process reported by Muller et. al [6] which was developed for very high frequency resonant tunneling diode structures by Allen et. al [7]. The process uses multiple e-beam scans at
different doses and a trilevel ΙΜMA coating to enable one to separately define the footprint and the side-beadis of the T-anode structure. Moreover, the finger that becomes the air-bridge after the surface channel etch is also formed in the same step. A layer of 496 K molecular weight PMMA, with 4% solids content, is spun on the wafer at 4000 RPM. The resulting film is then cured at 170 degrees to form a 300 nm thick layer. A middle layer (actually two layers of a copolymer of PMMA and methacrylic acid) is deposited, next and cured. Each layer after cure is about 400 nm. Finally, the top layer, 2300 K molecular weight PMMA with 10/0 solids content, is spun cm, resulting in a 100 nm thick layer after cure. The c-beam exposure is performed with a JEOL JBX 5111 electron beam lithography system in the high resolution mode.

After exposure the chip is immersion developed at room temperature using three different solutions. The top layer is developed in chlorobenzene, which aggressively dissolves the exposed ΙΜMA but does not affect the copolymer layer. A one to one mixture of isopropanol and methanol opens the copolymer layer. Since PMMA is insoluble in this solution, the copolymer can be overdeveloped enough to undercut the PMMA and provide a good lift-off profile. Finally, the footprint is defined by developing the bottom layer in a one-to-one mixture of MIBK and isopropanol. This solution provides enough contrast to define tenth micron lines.

Fig. 1 shows a close up of one of the T-anodes. Once the surface channel is etched to isolate the devices the process schematically depicted in Fig. 7 (QU11) process) is followed in order to obtain structures that can easily be tested in a waveguide block. 101200 GHz operation the top epilayer is doped 2.0x10^18 cm^-3 and is 1000 Å thick. The heavily doped layer is about 2.5 microns thick. Shrinking the anode area for use at higher frequencies involves no change to the fabrication process. Also, since no oxide etching is involved, and the anode footprint is defined by the c-beam, anodes made with this technique are extremely uniform. If surface passivation is desired, a thin layer of oxide can be deposited after the anodes have been put down.
The major advantages of the T-anode diode structure are reduced parasitic capacitance and resistance and extremely small realizable anode areas. Both of these characteristics are critical for increasing the sensitivity of millimeter and submillimeter-wave mixers. DC characteristics for the T-anode QU11 Schottky diode pair (diode A/diode B) used in the measurements reported in this letter are: ideality factor 1.16/1.20, reverse saturation current $6.8 \times 10^{-16}/1.8 \times 10^{-15}$ A, series resistance 9.7/8.7 $\Omega$. The process has not been fully optimized yet and it is expected that diode performance and uniformity will improve in the future. The total device capacitance, measured before the chip was flipped up-side-down and without the filter structures, is 9-11 $\text{ff}$. Each anode is calculated to have about 3 $\text{ff}$ of capacitance and thus the parasitic capacitance of the diode pair is calculated to be 3-4 $\text{ff}$. The total capacitance of the structure after QU11 processing and dicing was measured to be 17 $\text{ff}$. The extra capacitance is due to the microstrip filter structure, which contributes about 3-4 $\text{ff}$, and the higher dielectric constant of the bonding adhesive.

III. MIXER MEASUREMENTS

The completed structure, consisting of a pair of antiparallel diodes, two quartz microstrip filters and a waveguide coupling probe was tested in a subharmonically-pumped mixer block at 200 GHz. A detailed description of the waveguide block and the measurement procedure has been described in [4]. Figure 3 shows the measured double sideband noise temperature and conversion 10$\text{dB}$s optimized over a band centered at 200 GHz, optimized at each RF frequency, with an IF of 1.5 GHz. The required LO power at the optimum noise temperature was excessively high, about 30 mW, due to a resonance in the filter design, but drops to 8 mW at 102.5 GHz where the noise temperature is about 15 0/0 worse. At 115 GHz the required LO power is only 1.5 mW. The output impedance at the optimum noise temperature is about 200 $\Omega$. It is noteworthy to point out that these results are 30 0/0 lower than the best reported whisker-contact diode mixers and somewhat lower than the best GaAs discrete chip
type diode mixers (measured with the same circuit under identical conditions) at this frequency [4].

IV. CONCLUSION

Schottky diodes with '1'-anodes have been fabricated and tested. These devices are easily scaled to THz frequencies and have lower parasitic than comparable air-bridge type circular-anode planar Schottky diodes. A waveguide mixer incorporating the new '1'-anode diodes has yielded what is believed to be the best performance for a subharmonic mixer at 200 GHz. Work has already begun on a scaled device for 640 GHz and is planned for implementation at 2.5 THz.

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VI. REFERENCES


Figure Captions

Fig. 1: A close-up SEM of the T-anode structure before the QUILL process. The anode area is nominally 0.25 microns by 4 microns.

Fig. 2: A cut-view schematic representation (not to scale) of the starting point and the end point of the QUILL process. (a) The fabricated chip is bonded up-side-down on the quartz substrate with the help of a heat cured adhesive. (b) After lapping, selective wet chemical etching and removal of the AlGaAs layer the chip is patterned to remove all of the GaAs except for enough material to cover the ohmic and Schottky contacts. This makes sure that there is no excessive GaAs in the waveguide channel.

Fig. 3: Double sideband noise temperature and conversion loss of the tested subharmonic mixer as a function of the signal frequency.
Fig. 2. Schematic of a 150 micron quartz sensor with labeled components.
Fig. 3, mehdi et. al.