600 GHZ PLANAR-SCHOTTKY-DIODE SUBHARMONIC WAVEGUIDE MIXERS

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ABSTRACT

We report on the first planar two-diode subharmonic mixer operating at 600 GHz. The measured mixer noise temperature of 4200 K DSB is only a factor of 2 worse than the best single diode (whisker-contacted or planar) fundamental mixers and a factor 1.5 worse than the best ever single diode (whisker-contacted) harmonic mixer at similar frequencies. The measured conversion loss is ≈12 dB and a noise temperature between 4200-5300 K can be maintained with a fix tuned circuit over a 1-18 GHz IF bandwidth. The anodes are made via a trilayer direct e-beam write process that results in extremely low parasitic devices with high cutoff frequencies. The mixers are being developed for NASA's Mission to Planet Earth.

I. INTRODUCTION

Planar Schottky devices have been under development for a number of years now, with the hope that they will replace the whisker-contacted honeycomb diodes currently being used for most high frequency space-borne applications. Recent results have indicated that the appropriate planar structure can perform as well as whisker contacted diodes at least up to 350 GHz [1-4]. Integrated circuit technology has also enabled the successful implementation of mixers and multipliers that require more than one diode. Currently, we are in the process of developing flight-qualified 240 GHz and 640 GHz subharmonic mixers based on the anti-parallel-pair diode configuration [5] for use in the Earth Observing System Microwave Limb Sounder instrument, an ozone chemistry experiment which is part of NASA's Mission to Planet Earth.

In this paper, we report on the first subharmonic mixer working at 600 GHz which utilizes two planar diodes in an anti-parallel-pair configuration. The main advantages of this particular mixer configuration for Earth remote sensing applications, lie in the simple local oscillator diplexing (the LO is one-half of the signal frequency and can be injected efficiently through waveguide without narrow band filters to suppress LO noise in the signal band), and the broad achievable IF bandwidth, which allows several spectral lines to be measured with a single fixed-frequency LO (the IF output impedance is between 80 and 100 ohms making possible broadband matching to the IF amplifier). Moreover, this particular mixer configuration has a measured LO noise suppression of better than 30 dB due to the anti-parallel-pair configuration [3]. At 200 GHz, using a scaled version of the waveguide mount we report upon here, we have measured an ambient input noise temperature [4] which is about 30 percent lower than that of the best whisker-contacted-diode subharmonic mixers [5] and only a factor of ≈1.5 worse than the best ever fundamental mixer at this frequency [6]. At 614 GHz, currently, we are measuring a noise temperature of 4200 K with a conversion loss of about 12 dB. This is only a factor of 2 worse than the best reported single diode (whisker-contacted or planar) fundamental mixers [7,8,9] and a factor 1.5 worse than the best ever single diode (whisker-contacted) harmonic mixer [10] at similar frequencies. Section II describes the device technology that has been developed for this application and Section III discusses the measured mixer results in more detail.

II. FABRICATION TECHNOLOGY

We have developed two major modifications to current submicron device fabrication technology that enabled us to produce very high frequency planar-Schottky-diode waveguide mixers. First, we have monolithically mated the GaAs diodes with the lower-dielectric-constant lower-loss quartz-based microwave/millimeter-wave circuitry used to couple power in and out of the mixer block. This has been accomplished using a process we refer to as QUID (Quartz Up-side-down Integrated

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Device) [4]. In this process, the completely integrated GaAs device and surrounding circuitry are mounted up-side-down on a quartz carrier with the help of a thermally cured epoxy. The GaAs substrate is then completely etched away everywhere except for a small region around the active devices. A final backside dry mesa etch ensures that all of the unnecessary GaAs is etched away (Figs. 1,2). After the backside process, individual circuits are diced and glued into their supplied microstrip housing in the waveguide block (Fig. 3). Two wire bonds to the circuit metallization provide a DC return on one side of the diodes and an IF output line to a standard K-connector bead on the other. The 600 GHz circuits are fabricated on 2 cm diameter, 50 micron thick crystal quartz and after dicing, each circuit is about 80 microns wide by 2500 microns long.

The second modification we have introduced to the traditional planar-Schottky-diode fabrication process is the technique of using e-beam technology to directly write the anode and the connecting finger in the same step. A trilayer PMMA process was developed for this application which has yielded Schottky diodes with lower-than-average parasitic capacitance and series resistance [4]. This technology is similar to the T-gate technology that has been used for high frequency HEMT structures. An SEM picture of a typical T-anode diode, before the addition of a surface channel for anode-to-cathode isolation, is shown in Figure 1. In addition to the process that has been developed and already described [4,11] for producing 200 GHz diodes, for the 600 GHz devices the horizontal part of the "T" was raised an additional 100-150 nm in order to further decrease the parasitic capacitance. The nominal anode area is $0.8\mu m^2$ ($0.4 \times 2.0\mu m$).

The 600 GHz waveguide mixer mount uses a traditional crossed-guide split-block configuration with the local oscillator waveguide perpendicular to the signal guide and electrically coupled via a shielded quartz microstrip. An external feed horn is used for signal coupling while the LO enters via waveguide. A single quartz substrate contains the LO and IF filters and coupling lines as well as the antiparallel-pair Schottky diodes. Hammerhead filter elements are used for frequency separation and matching. A more detailed description of the block that was used at 215 GHz has been reported elsewhere [3]. The waveguide block used for the 600 GHz work is a scaled version of the 215 GHz design with some minor modifications to the input signal port and LO and IF filter structures. A descriptive schematic of the block is shown in Figure 3.

III. MEASUREMENTS AND DISCUSSION

The diode pair that resulted in the noise temperature reported here has a series resistance of 5.6/5.8 Ohms, an ideality factor of 1.26/1.28 and a reverse saturation current of $4.8\times10^{-14}/5.2\times10^{-14}$ Amps per anode respectively. The total measured capacitance of the diodes (including the microstrip circuit on the quartz substrate) is about 13 fF. From previous measurements, the microstrip contributes about 4 fF of capacitance and the anode capacitance is calculated to be about 1 to 1.5 fF. This leaves a total parasitic capacitance of 6-7 fF. We believe that this capacitance can be further reduced by small variations to the anode finger overlap and T-gate structure.

Figure 4. shows the measured performance of the mixer over an IF frequency band of 1 to 18 GHz with tuners fixed at 8 GHz . The real part of the IF output impedance, as measured on an 8510 network analyzer, is approximately 90 Ohms over the whole band. The best performance was obtained at an IF of 3 GHz with the measured mixer noise temperature of 4180 K DSB and a conversion loss of 11.9 dB. The required LO power for this particular measurement was excessively high (>50 mW), however we have determined that most of the power is being lost in a poorly machined LO waveguide which cannot be corrected in the current mixer block. We have recently (in a newly fabricated mixer block) been able to turn on both devices with only 10 mW of power at the mixer input LO port. We have also determined that there is additional LO power loss in the microstrip coupling circuit between the waveguide probe and the diodes which we attribute to the epoxy that binds the metal of the microstrip line to the quartz substrate. This loss can be reduced by reducing the thickness of the glue layer (currently >10μm). For comparison purposes Table I shows previously published results with room-temperature Schottky-diode mixers around 600 GHz. The present performance is about a factor of two worse than the results obtained from whisker-contacted or planar-diode mixers. We expect our noise numbers to improve as both devices and mount are optimized. The harmonic single-diode mixer results reported in [10] are indeed very impressive and are about a factor of 1.5 better than the results from our subharmonic two-diode mixer. Compared to single-diode harmonic mixers, the main advantage of the two-diode arrangement is a significantly lower output impedance and potentially wider IF bandwidth. Moreover, it should be noted that the harmonic mixer uses a whisker contacted diode which generally has lower parasitics.

IV. CONCLUSION

State-of-the-art mixer performance has been measured with an anti-parallel-pair-diode subharmonic mixer in a waveguide circuit at 600 GHz. The measured noise temperature and conversion loss are only a factor of 2 worse than the best ever fundamental mixers at similar frequencies. To the best of our knowledge, these are the first results from a subharmonic mixer with two diodes at 600 GHz. We are currently improving the quality of the devices and reducing the losses in the waveguide mount and believe that even better results will be forthcoming in the near future.

V. ACKNOWLEDGMENT

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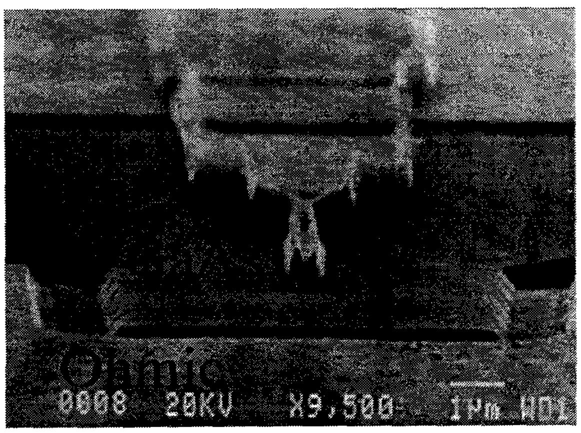

Fig. 1. SEM close-up of T-anode Schottky diode before the channel etch which isolates the anode and cathode.

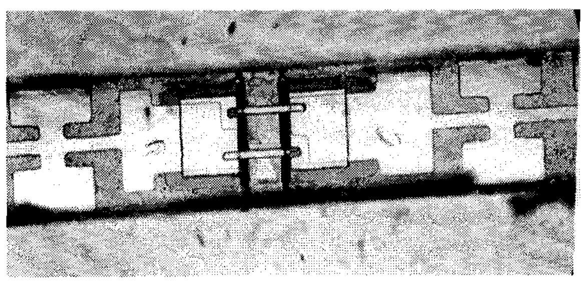

Fig. 2. Photo of the antiparallel-pair diodes and surrounding filter circuitry as seen through the quartz substrate.

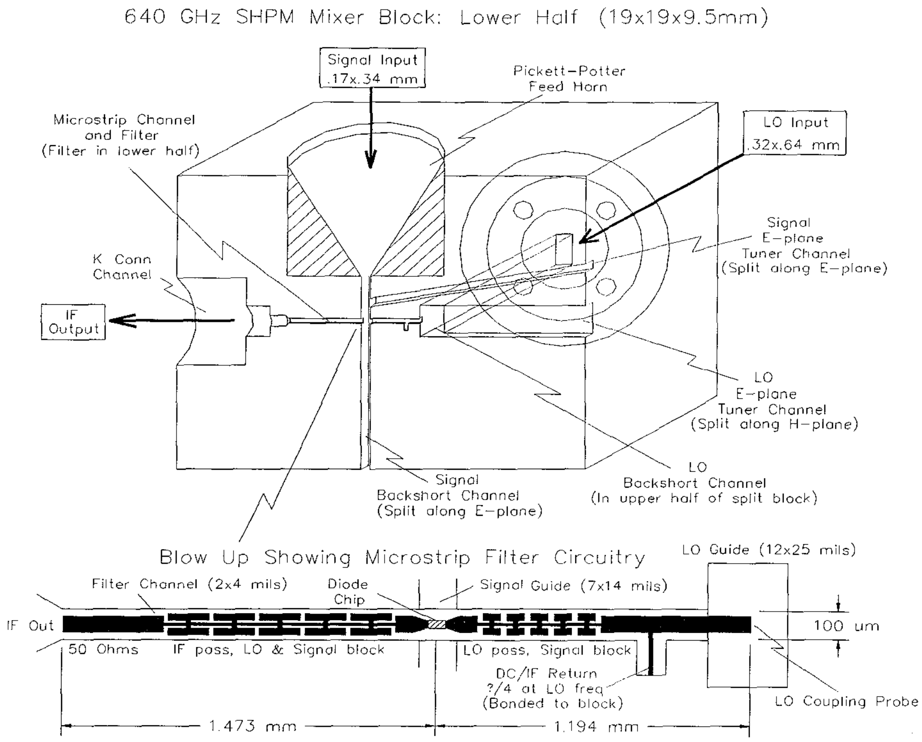

Fig. 3. Schematic of 640 GHz mixer block and filter circuitry.

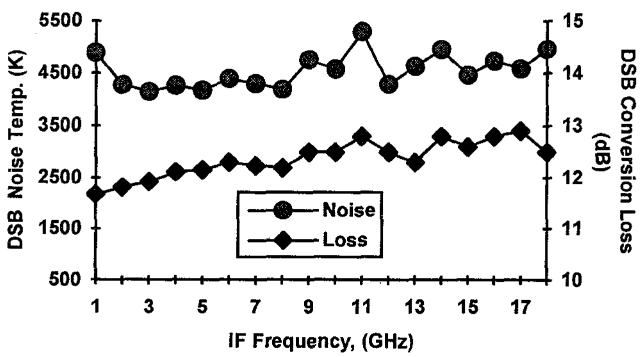

Fig. 4. Measured performance of the subharmonic mixer at 614 GHz over 1-18 GHz IF. The average IF output impedance is 90 Ohms. The RF tuning was optimized at 8 GHz IF.

Freq GHz	Junction Type	Mixer Type	Loss (DSB)	Tm DSB	Ref.
665	whisker	Harmonic Waveguide	~12 dB	2650 K	[10]
649	whisker	Fundamental Waveguide	8.5 dB	1900 K	[7]
760	planar	Fundamental log-periodic	14.9 dB	8900 K	[8]
614	planar	Subharmonic Waveguide	12 dB	4200 K	This work
585	planar	Fundamental Waveguide	8.6 dB	2030 K	[9]

Table I. Comparison of various devices and mixer circuits operating ≈600 GHz.