ANTI-PARALLEL PLANAR SCHOTTKY DIODES FOR SUBHARMONICALLY-PUMPED 220 GHZ MIXER.

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Abstract

Anti-parallel planar Schottky diodes using the Quasi-Vertical Schottky Diode (QVD) geometry, developed by TU Darmstadt, have been fabricated and mounted on subharmonically-pumped waveguide mixers at 220 GHz. The design of the waveguide mixers was done at Helsinki University of Technology. The diode's geometry, an evolution of the substrateless Schottky diode [1] for integration in planar circuits [2], assures intrinsically-vertical current flow and minimizes the volume of the semiconductor diode mesa. This improves heat sink capability and simultaneously reduces diode parasitics, in particular high-frequency series-resistance increase due to skin effect. Furthermore, gold pillars grown on the contact pads confer the diode higher physical strength and protect anode air-bridge contacts, both facilitating soldering to the microstrip filters and allowing a safe flip-chip mounting technique. The QVD shows DC parameters comparable to those of whisker-contacted substrateless diodes. Measured forward I-V characteristics are identical, which contributes to minimize mixer conversion loss. The technology and the electrical characteristics of the Anti-Parallel Quasi-Vertical Schottky Diodes (APQVSD) are presented, as well as the first measurement results obtained with the 220 GHz subharmonic mixer.

Introduction

GaAs-Schottky diodes are used as the non-linear mixer element (varistor) in heterodyne receivers for THz applications because of their high cut-off frequency and low parasitics as compared with other semiconductor devices.

The Quasi-Vertical planar Schottky Diode (QVD), developed by TU Darmstadt, is based on the substrateless, whisker-contacted, Schottky-diode concept. It inherits its extremely reduced diode chip and the correspondingly increased heat-sink capabilities and combines them with the advantages of planar designs, which offer a reliable anode contact and open the door for full integration in MMIC's.

Recently, the Anti-Parallel Quasi-Vertical Schottky Diodes (APQVD) have been developed, fabricated and mounted on 220 GHz subharmonically-pumped waveguide mixers. Figure 1 shows the sketch of the mixer block having two tuners.

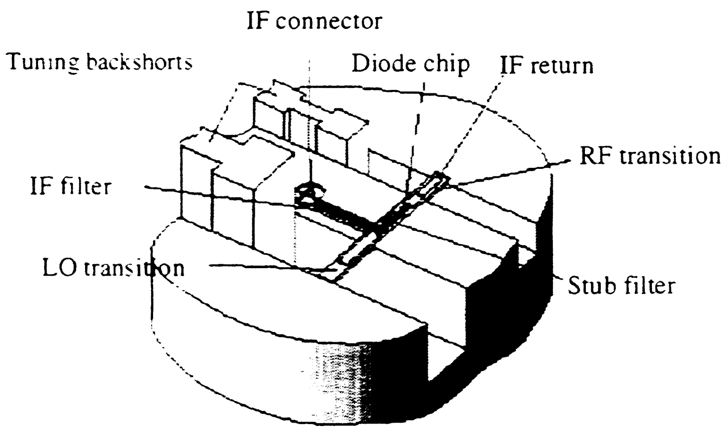

Figure 1: Sketch of the 220 GHz mixer block.

Like the whisker-contacted substrateless diode and the QVD, the APQVD present vertical current flow and low parasitics. The scheme developed to model their predecessors can be applied to them without further modifications [3].

Diode Design and Modeling

The APQVD have a structure similar to that of the single QVD. The complete geometry is presented in Figure 2, which shows some of its advantages with respect to other planar-diode concepts.

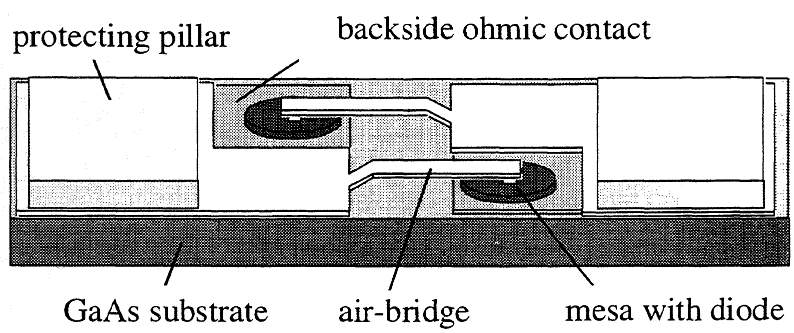

Figure 2: Geometrical structure of an APQVD chip.

The diode mesas, about 2-μm thick, lye directly on top of a gold platform. This improves the diodes' heat-sink capabilities, which in other planar structures is limited to the anode finger and in normal whisker-contacted diodes to the anode whisker. Additionally, dramatically-reduced mesa size eliminates the influence of skin effect on high-frequency series resistance.

Compared with whisker-contacted devices, a general drawback of planar diodes is the pad-to-pad stray capacitance. The need to keep air-bridges short in order to reduce their parasitic inductance sets a limitation to the minimum pad-to-pad capacitance achievable. The APQVD show two major improvements in this respect.

Firstly, a reduced substrate thickness of 10 μm is achieved by means of a novel etch-separation technique in which the diodes are photo-lithographically protected on their front side and the rest of the wafer is etched away. Reduced substrate thickness reduces in turn pad-to-pad stray capacitance. Secondly, high air-bridges have been successfully fabricated. Bridge height above the mesa is about 2 μm, whereas the backside ohmic contact lies 4 μm below the bridges. This reduces their parasitic capacitance to negligible values, which allows bridge widening without significant capacitance increase. This in turn reduces the inductive effect of the air-bridge, and in this way the necessary compromise between bridge inductance and pad-to-pad stray capacitance can be shifted to more convenient values of both.

A further geometrical improvement of the APQVD is the fabrication of gold pillars about 6 μm in height in order to facilitate flip-chip techniques. The pillars, grown on the contact pads, confer the diodes greater physical strength and protect the air-bridge anode contact during device handling. This facilitates soldering to the microstrip filters and allows a safer flip-chip mounting techniques.

According to previous experiences, a doping level of 3×10^{17} cm^{-3} and a thickness of 100 nm is chosen for the active n-layer, while anode diameter is set to be 0.8 μm. The thickness of the n^+-layer is 2 μm, which approximately equals the skin depth of n^+-doped GaAs at 220 GHz, eliminating the high-frequency increase of series resistance due to skin effect.

At millimeter wave lengths, diode dimensions become comparable to the wavelength and, thus, the distributed effects of the passive structure are remarkable. Also, parasitics are introduced due to the associated mounting structure and a microstrip channel surrounding the diode in the mixer block. Therefore, an accurate modeling of the APQVD is crucial for a reliable design of the mixer circuitry.

The diode model has been constructed from the active and passive diode parts. The active part includes the nonlinear junction resistance, nonlinear junction capacitance, series resistance and a series inductance. The passive part including the parasitics due to the diode structure, microstrip channel, and a quartz microstrip substrate has been modeled with help of an electromagnetic high frequency simulator (HFSS) based on the finite element method (FEM) [4]. After the construction of a diode equivalent circuit, the results of the FEM simulations have been fitted into the equivalent circuit. The equivalent circuit of the diode chip is shown in Figure 4. The theoretical modeling work is to be further supported by vector network analyzer (VNA) measurements using CPW on-wafer test structures of single and anti-parallel diodes. The VNA measurements with coplanar probes will take place at the frequency range from 50 MHz possibly up to 110 GHz.

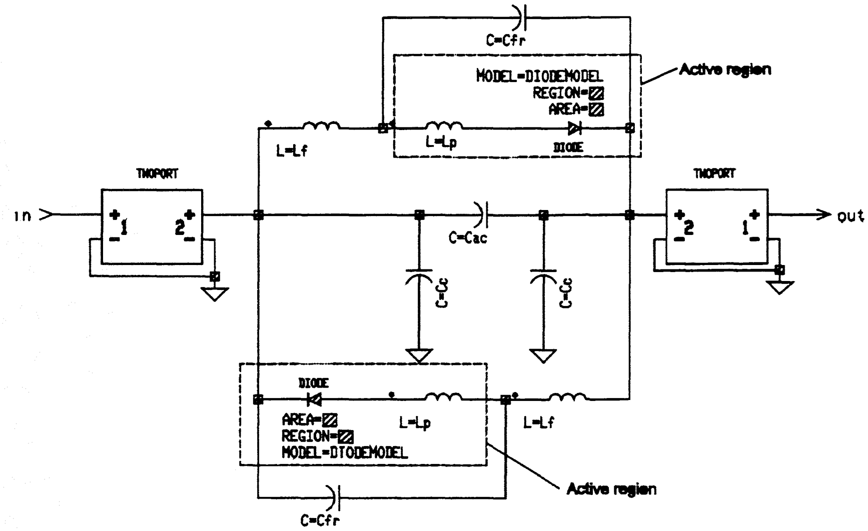

Figure 4: Equivalent circuit of diode chip. Twoports are for soldering pads.

Diode Fabrication and Characterization.

The fabrication process is based on the technologies of single QVD which were developed in the last years. Figure 5 shows a SEM picture of an APQVD chip, where the 4-μm height of the air-bridges as well as the protection gold pillars can be appreciated.

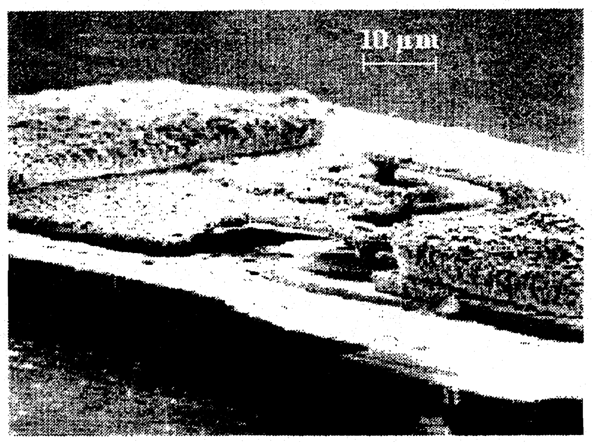

Figure 5: Side view of an APQVD chip (SEM micrograph).

Figure 6 shows an APQVD chip soldered on a quartz-substrate microstrip circuit using a flip-chip technology. The effective protection of the lateral gold pillars can be seen.

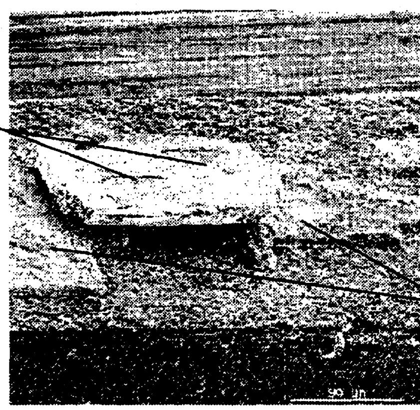

Figure 6: Anti-parallel quasi-vertical Schottky diode after soldering onto a microstrip filter on quartz substrate (SEM micrograph)

Figure ?? shows measured I/V curves of two APQVD. The diodes show an inverse saturation current of 6×10^{-16} A, a series resistance of 25 Ω, an ideality factor of 1.14 and a total capacitance (junction capacitance at zero bias plus parasitic capacitance) of 21 fF. The simultaneous and identical processing of both diodes in an integrated pair achieves practically identical I/V characteristics for all current values above 10 nA. This contributes to reduce mixer conversion loss. Noise temperature measurements at 1.4 GHz have been performed on the diode pairs for different bias currents. At a typical bias of 500 μA, a noise temperature of 350 K is achieved which is comparable to values obtained with whisker-contacted diodes.

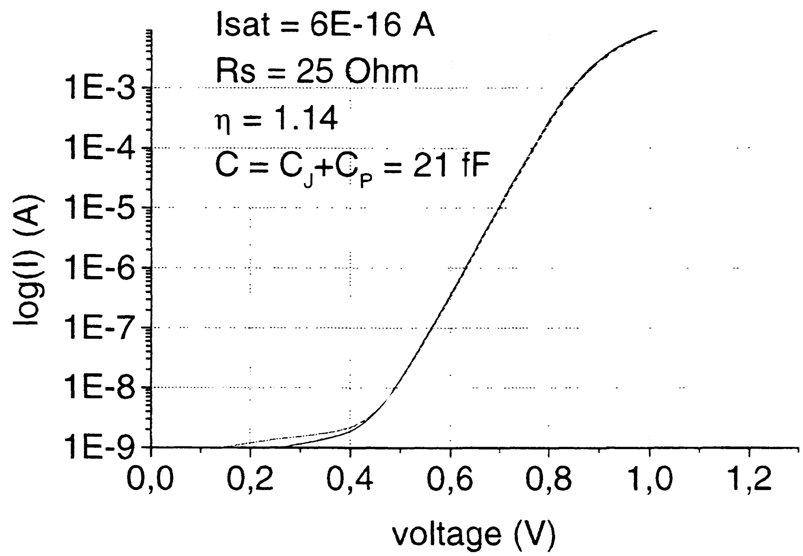

Figure ??: I/V characteristics of two APQVD

Performance of 220 GHz Subharmonic Mixers

The anti-parallel pair of Schottky diodes has been employed in two 220 GHz subharmonic mixers. These mixers are used as scaled models for a 650 GHz mixer. One of the mixers is based on a two-tuner block [5] (Figure 1) and the other one is quite similar but employs four backshort tuners [6] for better tuning possibility. So far, some diode chips have been tested. A 10.5 dB SSB conversion loss has been achieved with The two-tuner mixer design. The measured noise figures are much higher than expected. We believe that this is due to the deterioration of the diode chip during the measurements. The best results have been obtained by using the four-tuner block. The SSB results are a 9.2 dB mixer conversion loss and a 3520 K mixer noise temperature. These figures were obtained at 215 GHz and 107 GHz RF and LO frequencies, respectively. The used LO power was 3.5 mW. The series resistances of the two diodes in the applied chip are 11 Ω and 12.5 Ω and the ideality factors are 1.29 and 1.28, respectively.

The measured conversion loss value is comparable to those of the best published subharmonic planar Schottky diode mixers at this frequency range. On the other hand, the noise temperature is somewhat higher. It should be emphasized that the diode parameters are not optimized for 220 GHz but for 650 GHz. The same diode chip will be used in the 650 subharmonic mixer.

Conclusions

Anti-parallel planar Schottky diodes using quasi-vertical structure have been developed, fabricated and mounted on different 220 GHz sub-harmonic waveguide mixers. To reduce parasitic capacitance of the contact pads, reduced chip thickness of 10 microns and high air-bridges are realized. For a reliable handling of this thin device two flip-chip pillars have been introduced in the fabrication. Several batches of APQVD have been reliably processed.. A wide-band equivalent model has been theoretically developed which includes the passive and active regions of the diode. This model will be further improved by comparison with measured values.

DC characteristics of APQVD prove to be similar to those of whisker-contacted diodes and show that the variation between two diodes of the same pair is negligible. Noise measurements performed on flip-chip-mounted structures show diode noise temperature to be 350 K at a bias current of 500 μA.

The best performance obtained to date with subharmonic mixers using these diodes is 9.2 dB of SSB conversion loss and a corresponding mixer noise temperature of 3520 K. These values were measured at 215 GHz and 107 GHz RF and LO frequencies, respectively, for an LO Power of 3.5 mW.

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