Determination and Reduction of the Capacitance Associated with the Bonding Pads of Planar Millimeter-Wave Mixer Diodes

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Abstract—**A calculation of the capacitance associated with the metal bonding pads of a planar millimeter-wavelength mixer diode is presented. This capacitance is the largest component associated with such a device, contributing a calculated 22 fF toward a total diode capacitance of 30 fF. A demonstration of how the pad capacitance can be almost halved by incorporating an air bridge into the diode structure is included. Computer simulations show that this additional processing step can cause a 1.2-dB drop in mixer conversion loss at 94 GHz.**

I. Introduction

Many laboratories use planar Schottky diodes as the nonlinear element in millimeter-wavelength mixers [1]–[4]. Attempts to theoretically predict the total capacitance of the planar design have met with limited success, as capacitance modeling has always relied on intuitive guesses for values of the capacitance associated with the metal diode bonding pads [5], [6]. This quantity is difficult to calculate due to the complicated geometry of the diode metalisation, yet it is important to know the value of this capacitance component because it can contribute two-third of the total diode capacitance. This letter quantitatively determines the pad capacitance for a planar diode successfully used at 94 GHz [3] and shows how this capacitance is consistent with a measured total diode capacitance of 30 fF. Finally, the reduction in the pad capacitance that would result from the inclusion of an air bridge into the diode structure is determined.

II. Standard Diode Model

The cross section of a typical planar millimeter-wave mixer diode is shown in Fig. 1. Superimposed on the diode cross section is the equivalent circuit associated with different elements of the structure. R_j is the nonlinear Schottky junction resistance that acts in parallel with the diode junction capacitance C_j. The sum of the series resistance associated with the undepleted epitaxial GaAs, the spreading resistance in the lower resistivity n+ layer and the contact resistance of the ohmic contact is denoted by R_s. In parallel with the Schottky junction is the capacitance component C_f representing the capacitance between the anode contact finger and the underlying active GaAs. C_p represents the capacitance between the two diode bonding pads.

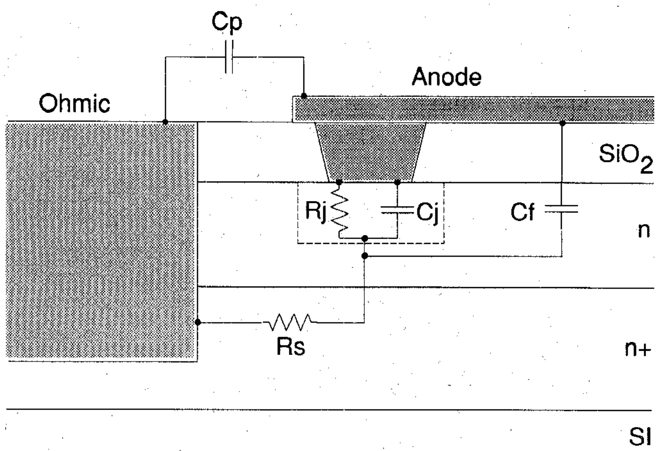

Fig. 1. Cross section of a planar millimeter-wave Schottky mixer diode.

Detailed methods to determine both C_j and C_f, taking account of the anode finger dimensions and the geometry of the Schottky contact, have been published [7]. Applying these methods to our planar diode [3] yields values of 2.6 fF and 7.5 fF, respectively. Previously, values of C_p have only been established by deducting the sum of C_j and C_f from the total measured diode capacitance [5] [6]. Measured on a 1-MHz bridge, the total capacitance of our diode is 30 fF to an accuracy of about 5 fF. Thus, a capacitance associated with the diode bonding pads of between 15 fF and 25 fF would be expected.

III. Diode Simulation and Results

The diode structure is modeled as a three-dimensional grid with increments small enough to allow accurate modeling of the region around the diode finger, as shown in Fig. 2. The diode chip has dimensions of 230 × 200 × 50 μm with 75 × 100 μm contact pads placed 40 μm apart. A 1.5-μm diameter circular Schottky contact is formed beneath a 1.5-μm wide finger that protrudes 4 μm into a 8-μm diameter semicircular recess in the ohmic contact. The finger is connected to a tapered arm, formed as part of the anode contact.

The electric field profile over the three-dimensional structure is calculated using finite-difference algorithms to solve Laplace's equation in the air surrounding the GaAs chip and inside the bulk material. Modified forms of this equation are

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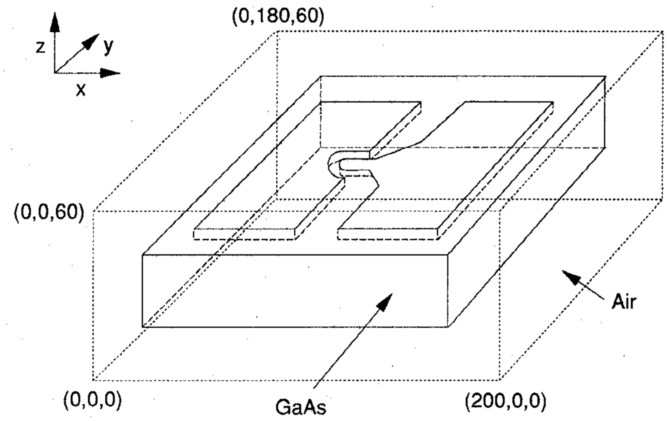

Fig. 2. Three-dimensional grid parameters used to model the planar diode ($\Delta x = \Delta y = \Delta z = 1.5$ μm).

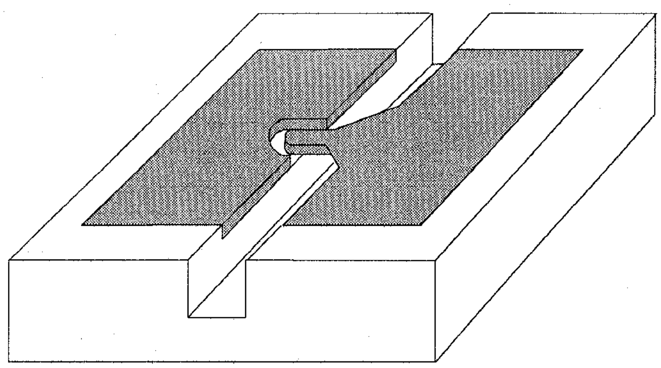

Fig. 3. Planar diode modified by the addition of an air channel between the bonding pads.

employed at the various interfaces between the biased contacts and the edges of the substrate. The total capacitance of the structure is determined by integrating the resulting electric field over all space.

The capacitance analysis program was run on an IBM 320 workstation, requiring 10 hours computer time for convergence. A pad capacitance of 21.9 fF was determined for the single diode.

IV. Reduction of the Diode Capacitance

Several laboratories have used bridging techniques to lower the capacitance of planar diodes [2], [4]–[6]. The insertion of a low-dielectric material between the diode pads, replacing the high-dielectric GaAs, can be incorporated into the model to determine the capacitance reduction associated with such a processing step.

Fig. 3 shows the diode modified by the addition of a 40-μm wide air channel between the two bonding pads. Analysis of this structure yields the variation of pad capacitance with depth of the channel. This is shown in Fig. 4(a), indicating a significant reduction in the diode pad capacitance for even a shallow channel. A complete etch through the 50-μm thick substrate reduces the diode pad capacitance from 21.9 fF to 13.6 fF. The corresponding improvement in mixer conversion loss caused by the reduction in pad capacitance is shown in Fig. 4(b). This data is derived from a harmonic balance mixer analysis program (based on [8]) for a single-ended planar Schottky mixer operating at 94 GHz. A reduction in conversion loss from 7.0 dB to 5.8 dB is shown.

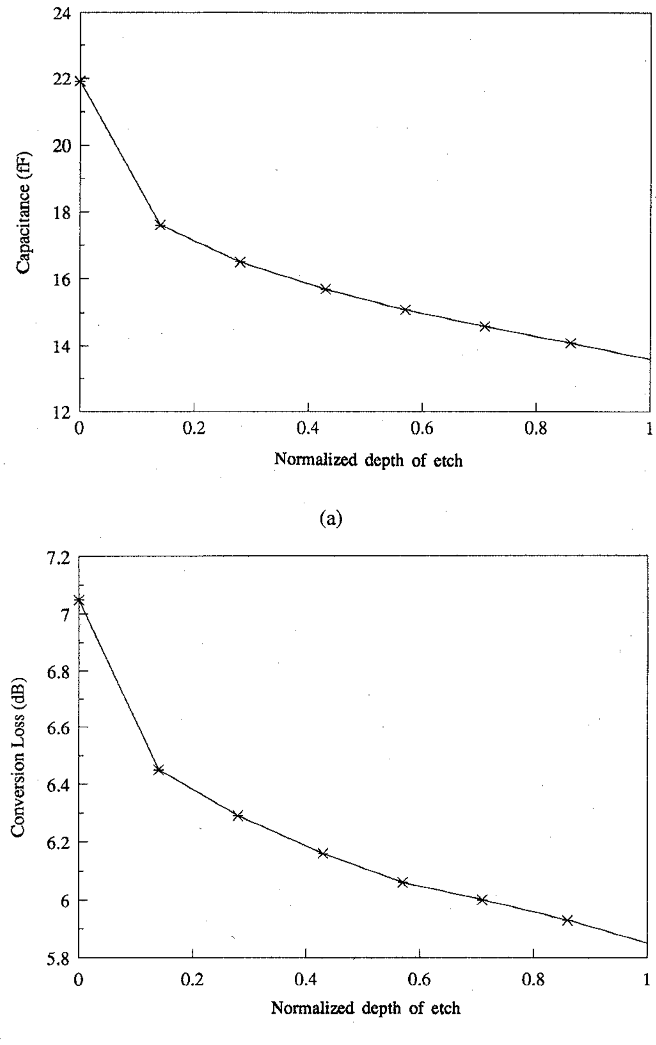

Fig. 4. Computed variation of (a) pad capacitance and (b) corresponding mixer conversion loss with depth of air channel through planar diode.

V. Conclusion

This letter quantifies the capacitance associated with the complicated geometry of the bonding pads of a planar millimeter-wave mixer diode. A value of 21.9 fF is calculated for this capacitance. In parallel with the pad capacitance is a calculated inherent capacitance of 10.1 fF due to the Schottky diode contact and the anode finger. This suggests that the total diode capacitance is 32 fF. This is consistent with the measured value of 30±5 fF.

Further analysis of the diode structure shows that the diode pad capacitance can be further reduced by the inclusion of an air bridge into the diode geometry. Calculations suggest a 40% reduction in pad capacitance by a complete etch beneath the anode contact finger, resulting in a 1.2-dB improvement in mixer conversion loss at 94 GHz. In addition, variations in diode capacitance due to other processing steps, such as reducing the diode substrate thickness by etching the GaAs on the back of the chip, can easily be analyzed.

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