Millimeter Wave Planar Doped Barrier Detector Diodes

Yogi Anand and Jack Hillson
M/A-COM Inc.,
Burlington, Mass. 01803

Abbas Torabi
Georgia Tech Research Institute
Atlanta, Georgia 30332

Jack East
Dept. of Electrical Engineering and Computer Science
The University of Michigan
Ann Arbor, Michigan 48109

Abstract

Planar Doped Barrier (PDB) diodes are semiconductor devices for high frequency detector and mixer applications. In these devices a thin layer of highly p doped GaAs is sandwiched between two layers of lightly n doped material to produce a potential barrier. The height of this potential barrier as well as the device capacitance can be adjusted by varying the doping density and thickness of the various layers. We are developing millimeter wave "zero bias planar doped barriers" for low level detector (zero bias) and low barrier mixer applications in the frequency range of 30 to 140 GHz. These devices exhibit low level signal sensitivity, (TSS) of −58 dBm (bandwidth = 2 MHz) at Ka band frequencies. The PDB detectors are found to be relatively insensitive to electrostatic discharge. The MBE material growth, device fabrication, RF performance and electrostatic burn out characteristics of the PDB detectors will be discussed in this paper.

1. Introduction

The planar doped barrier is a structure that uses intrinsic layers, ohmic contacts and heavily doped spikes or barriers to produce desired terminal current vs. voltage characteristics. The structure first proposed by Malik et. al. [1] used two intrinsic layers with a p^+ doping spike in the middle to produce an anti-symmetric current vs. voltage characteristics. This type of structure can be used as a single diode subharmonically pumped mixer. Experimental results have been obtained at low frequencies [2] and in W [3] and D bands [4]. A summary of the theory and performance of these subharmonic results is given by Lee et. al. [5]. The doping spike can be offset from the center of the intrinsic region to produce a diode like current vs. voltage characteristic. Since the barrier height is controlled by the structure dimensions and sheet doping levels, and not by a metal-semiconductor barrier height, a range of low barrier height mixer and detector characteristics are possible. Initial work on planar doped barrier detectors was described by Dale et. al. [6]. In this paper we will discuss the design and performance of conventional planar doped barrier detector diodes and then point out the potential advantages of using doped spacer layers in place of the conventional intrinsic ones. The next section of this paper will discuss a model for arbitrary doping layer structures. Section 3 will describe the experimental video detector and burnout performance. The results are summarized in section 4.

2. Planar Doped Barrier Detector Characteristics

A range of models for barrier limited current flow are available. The two extremes for analytic models are thermionic emission models and the diffusion theory. A complete review of the possible models and approximations is given in chapter 5 of Sze [7]. The two models both predict an exponential current current vs. applied voltage characteristic, although the internal assumptions and saturation currents are different.

The thermionic emission model is useful when describing current flow over a barrier, and for a variety of other analytic approximations. The diffusion theory theory is easier to implement in a device simulation where charge redistribution effects and space charge effects are possible. A large signal time dependent version of a device simulation has been modified to study the current vs. voltage characteristics of planar doped barrier structures. The simulation solves Poissons' equation and the electron continuity equation self consistently in time to find the total current through the device as a function of time. A simple approximation for the velocity that includes a constant low field mobility region and a saturated high field velocity is used. The Einstein relation is used for the diffusion coefficient. The solution is stepped through a range of bias voltages to obtain the device characteristic.

The purpose of this study is to characterize planar doped barrier devices for low barrier zero bias detector application. The detector properties depend on the curvature of the device current vs. voltage characteristic at the bias point. Since we want a zero bias detector, we need a low barrier height structure, with a low forward resistance and a blocking reverse characteristic. The current vs. voltage characteristic of a planar doped barrier with a p^+ doping spike of $10^{12}/cm^2$ and intrinsic layer widths of 100 and 500 angstroms is shown in figure 1. The doping in the p^+ spike determines the barrier height and the ratio of the lengths of the two intrinsic layers determines the relative resistance in the forward and reverse directions. This figure also shows a potential problem with low doped structures. The low doped regions have a relatively large space charge resistance. The current knee in the forward direction is low, only about 0.1 volts, but the forward characteristic rapidly becomes resistive. This limiting effect caused by the i layers can limit the device performance. One way to reduce this effect is to reduce the thickness of the i layers. This can cause several additional problems. Material growth problems can occur in very thin layers. The thin top i layer combined with a thin top n^+ ohmic cap layer is difficult to process and wire bond.

3.Video Detector Results

The devices discussed in this paper are fabricated from MBE grown GaAs. The devices are fabricated by lapping the semiconductor wafer to 100 microns thickness, depositing ohmic contact metal on both sides, etching a mesa to the final required size and dicing into individual chips. The X and Ka band devices are tested in standard microwave pill packages. The W band results use a whisker contact in a full height waveguide. Typical current vs. voltage characteristics for a zero bias PDB detector are shown in figure 2 and in Table 1. These devices exhibit voltages of 0.11 volt at 10 microamps and 0.20 volts at 100 microamps. The output voltage vs. input power for these detectors at 10 and 35 GHz is shown in figure 3. The power compression point is several milliwatts. Additional detector performance information is shown in Table 2. These devices exhibit a zero bias TSS of −50 to −58 dbm at frequencies between 10 and 35 GHz. The video bandwidth was 2 KHz to 2 MHz and the amplifier noise figure was 2 db. The video impedance varies between 2 and 50 Kohms. A coaxial mounted package with a bias Tee was used between 10 and 20 GHz and a waveguide mount was used at 35 GHz. No matching circuit or tuner was used to optimize the measurement. Broad band low level detector performance was observed in the 75–110 GHz frequency range. These results are shown in Table 3. These initial results were obtained in a broadband waveguide mixer mount. Improvements of 3 to 6 db should be possible.

Electrostatic and RF burnout performance is important in several applications at millimeter wave frequencies. Because of their small active egion planar doped barrier and Schottky barrier diodes are limited in power handling ability. Single junction PDB diodes were subjected to electrostatic pulses. The pulses simulate electrostatic discharge through the human body. The circuit consists of a 100 pf capacitor in parallel with a 1000 ohm resistor and discharges in less than 100 nanoseconds. Table 4 shows the burnout results for PDB detectors along with Schottky barrier results for comparison purposes [8-9]. The Schottky devices withstand 500 to 1500 volts in the forward direction and 300 volts in the reverse direction. The PDB devices survived up to 2500 volts in both directions. The PDB detectors were also tested for CW power handling capability at 10 GHz. A sweeper and TWT amplifier were used along with a precision attenuator to expose the PDB's to gradually increasing amounts of power. High barrier Schottky diodes and PDB's have similar CW power capabilities.

4. Conclusions

This paper gives an overview of zero bias planar doped barrier diodes for video detector applications. The PDB's have excellent video detector performance up to 35 GHz and promising results to W band. They exhibit high resistance to electrostatic burnout and have CW burnout limits similar to high barrier Schottky barrier diodes. These devices should be useful video detectors at microwave and millimeter wave frequencies.

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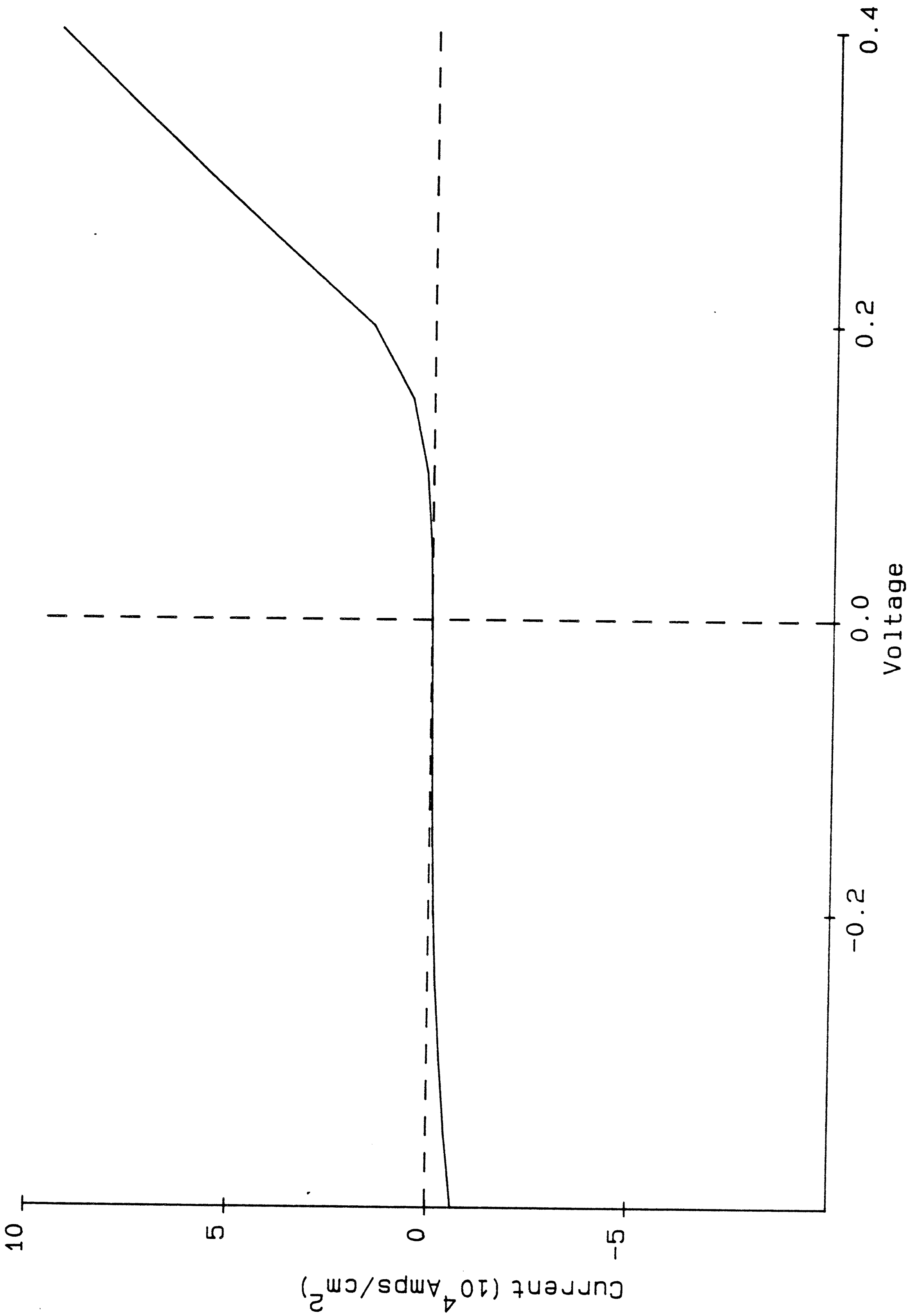

Figure 1. 100 angstrom/500 angstrom intrinsic structure.

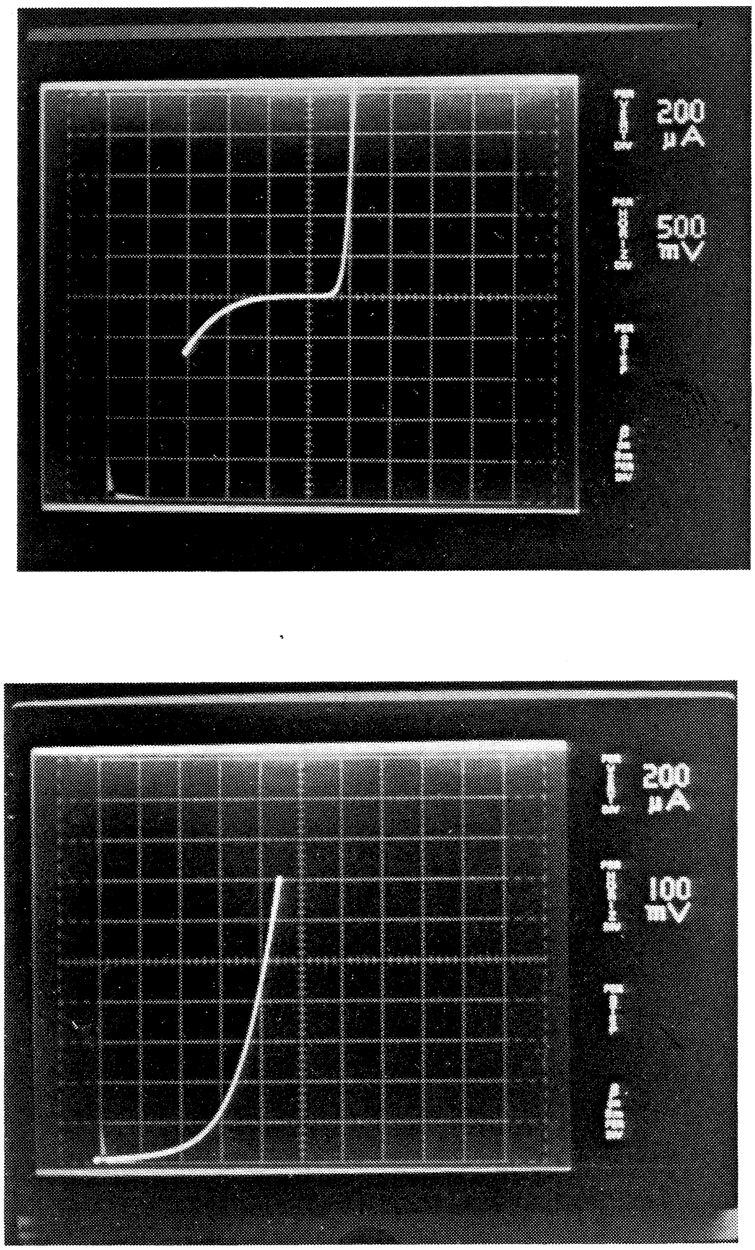

Figure 2. Typical experimental zero bias current vs. voltage results.

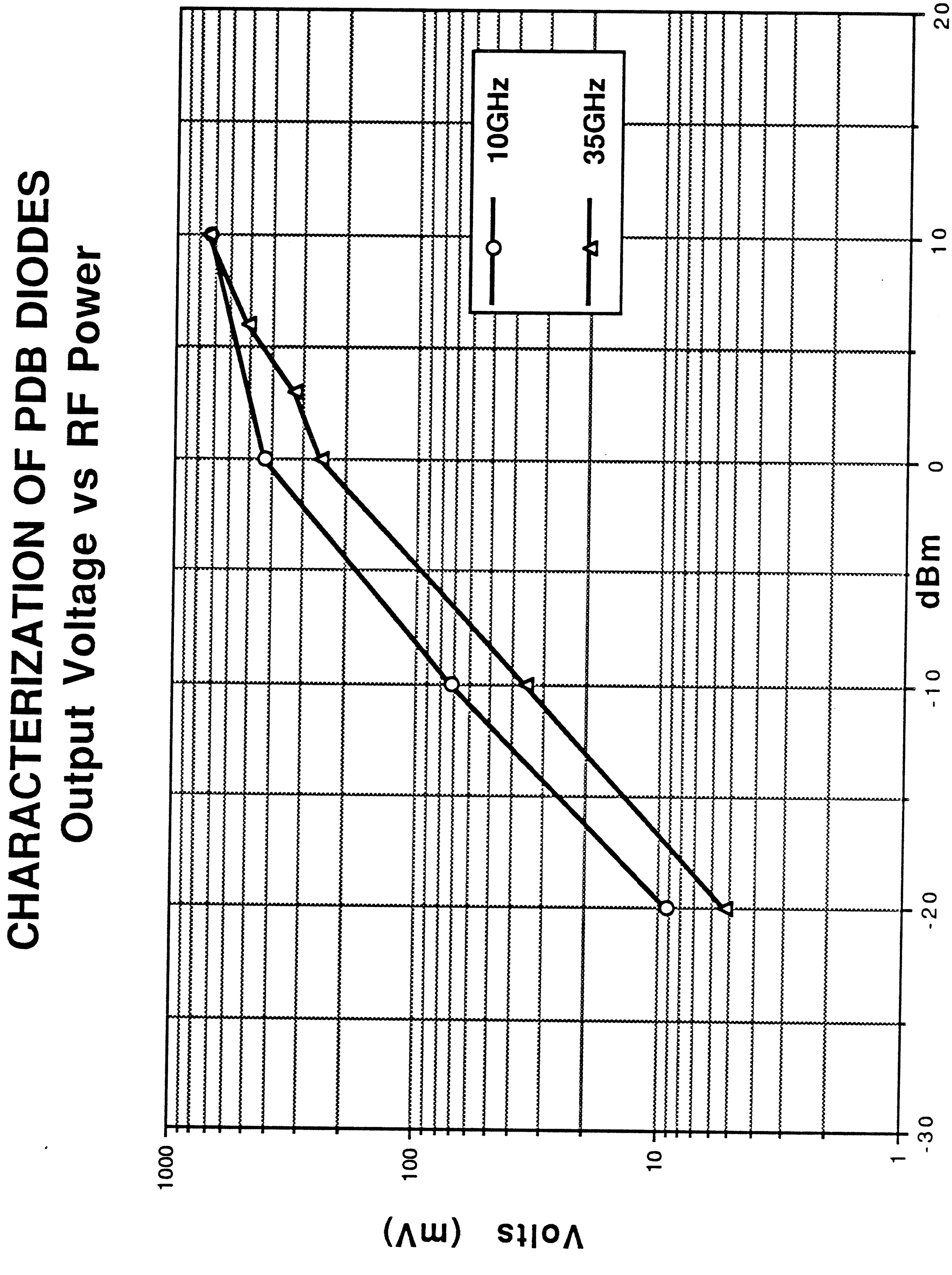

Figure 3. Video detector performance at 10 and 35 GHz.

DC CHARACTERISTICS OF PDB (ZERO BIAS) DIODES

(10 GHz - 40 GHz PILL PACKAGE)

Vf @ 10μA	0.11 Volts
Vf @ 100μA	0.20 Volts
Vb @ 10μA	0.8 Volts
Vb @ 100μA	1.5 Volts
Cj (calculated)	60fF
Rs	20 ohms

TABLE 1

Table 1. Details of low barrier characteristics.

RF PERFORMANCE OF ZERO BIAS PDB DIODES

(10 GHz - 40 GHz PILL PACKAGE)

Detector Performance	10 GHz	35 GHz
Video Impedance; Rv	2-50Kohms	2-50Kohms
Tangential Sensitivity; TSS	-50 to -58dBm	-50 to -58dBm
Voltage Out Put @ -10dBm (RL > 1m ohms)	70mV	40mV

Table 2. Details of video performance at 10 and 35 GHz.

OUTPUT VOLTAGE VS. RF POWER AT W-BAND FREQUENCIES

RF POWER	Vout 92.6 GHz	Vout 94.6 GHz
- 6 dBm	6mV	5mV
- 9 dBm	2mV	1.5mV
-12 dBm	0.7mV	0.6mV
-15 dBm	0.32mV	0.28mV

Table 3. W band detector performance.

ELECTROSTATIC & CW BURNOUT AT 10.0 GHz

	Low Barrier Si-Schottkys	Med. Barrier Si-Schottkys	High Barrier Si-Schottkys	PDB Si-Schottkys
Electrostatic (three pulses)				
Forward	800V	1100V	1500V	2500V
Reverse	300V	300V	300V	2500V
CW Operation	0.2 - 0.4W	0.3 - 0.5W	0.4 - 0.6W	0.4 - 0.6W

Table 4. Video detector burnout performance.