12% EFFICIENCY AND 9.5 DBM OUTPUT POWER FROM INP-BASED HETEROSTRUCTURE BARRIER VARACTOR TRIPLERS AT 250 GHZ

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Abstract

9.5 dBm and 12.3% maximum efficiency were demonstrated for a 250 GHz Heterostructure Barrier Varactor tripler. These state-of-the-art performances can be explained by the highly non linear capacitance-voltage characteristics of InGaAs/InAlAs/AlAs diodes having a zero-bias capacitance of 1fF/μm^2, a capacitance ratio of 6:1 and a breakdown voltage of 12 V for two barriers. Also the potential of non linear transmission lines for harmonic multiplication were investigated for vertically and laterally stacked devices

I. Introduction

The Heterostructure Barrier Varactor (HBV) exhibits a sharp non linearity and a symmetrical Capacitance-Voltage (C-V) characteristic which greatly simplifies the multiplier mount design by opening the way for higher harmonic operating modes. HBV triplers with 2mW and up to 5% have been achieved which operate between 210 and 280 GHz using a whisker contact technology [1]. A 200 GHz tripler using a GaAs single barrier whisker-contacted varactor with an overall efficiency of 2 % was demonstrated at the Jet Propulsion Laboratory [2]. Output power of 3.6mW (2.5% conversion efficiency) was published at 234 GHz using AlGaAs/GaAs heterostructures [3]. Recently, we published 5 % efficiency and 5mW output power at 216 GHz [4]. In the present work, we report on 12.3 % maximum efficiency and 9.8 dBm (9.55 mW) at 247.5 GHz. These results represent the highest performances for HBV multipliers operating at these frequencies.

II Diode design and fabrication

The HBV devices are fabricated at the University of Lille in France using an Indium Phosphide technology which has a number of practical advantages over its GaAs-based counterpart. Pseudomorphic growth of step-like InGaAs/InAlAs/AlAs barrier enables the voltage handling to be dramatically improved (by a factor of 3) due to a more efficient blocking barrier [5]. The apparent barrier height is about 650meV whereas it is ~ 180meV for GaAs/$Al_{0.7}Ga_{0.3}As$/GaAs HBV's. In addition, the narrow gap of the cladding and contact layers is a welcome feature for very high frequency operation notably through a decrease of series resistance. These are the primary reasons of the very good performances reported here with respect to early work using GaAs devices operating in this frequency range.

The devices, with two barriers stacked during the same epitaxy, were planar integrated with coaxial-, coplanar-and strip-type configurations (figure 1). The coaxial-type is used for current-voltage and capacitance-voltage assessments without the requirement of an air bridge technology and of de-embedding techniques [6].

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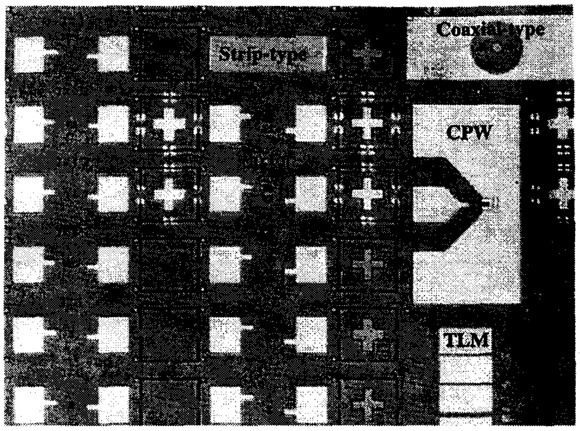

Figure 1: Optical view of the mask set including coaxial, coplanar and microstrip type configurations

The capacitance (C-V) and conductance (G-V) characteristics versus applied voltage are plotted in Figure 2. The C(V) is highly symmetric with a capacitance ratio of 6:1 and a zero bias capacitance of 1fF/μm^2. This high degree of symmetry enables the second harmonic to be readily rejected. The leakage conductance is less than 100 nS/μm^2 (up to 10 V) avoiding the so called self-heating effects [3] when the devices are driven under large signal conditions. In addition, the devices can be planar integrated as illustrated in Figure 3 which shows a SEM view of four air-bridged devices (height barriers).

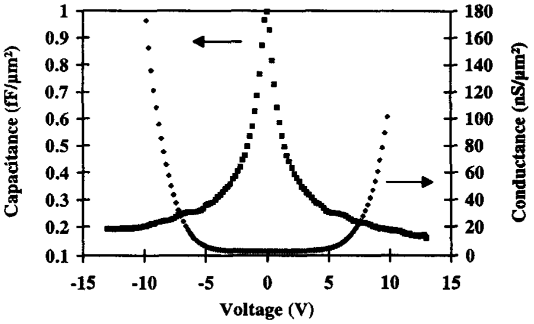

Figure 2: Small signal conductance and capacitance versus voltage for a dual barrier configuration

A coplanar waveguide configuration was employed for the measurement of the diode embedding, in particular the series resistance. By fitting these admittance variations against frequency by means of an equivalent circuit within the broad measurement bandwidth, we found 3.8 Ω for a 30μm^2 (fc= 2.1 THz) 2.5 Ω for a 60 μm^2 (Fc= 1.5 THz) and 2.2 Ω for 121 μm^2 (Fc= 1.2 THz). Measurements in the multiplier block were performed with dual configurations (DHBV's equivalent to 4 barriers) with circular- and finger-shaped contacts.

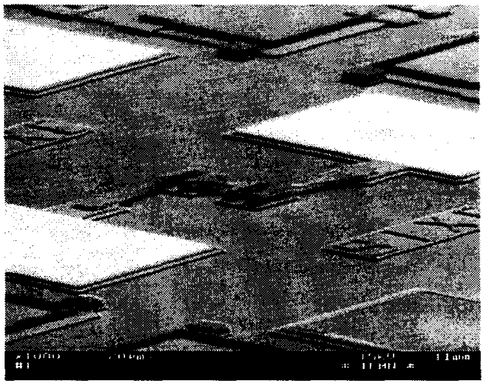

Figure 3 SEM view of laterally stacked devices

III Tripler design and measurement

The multiplier block used for the tripler measurement at 250 GHz (Figure 4) is a crossed wave guide type mount designed and manufactured by Matra Marconi Space (making use of space qualified materials and processes) with a design similar to that proposed by Archer [7]. The pump power incident in the full-height WR-10 wave-guide is fed to the planar integrated diode through a stripline E-plane transition and through a low pass filter implemented on a 75 µm-thick fused silica substrate. Impedance matching at the pump power is achieved using two sliding non contacting backshorts. The output is also equipped with two backshorts. This tuning configuration with two degrees of freedom facilitates the matching of the optimum embedding impedances calculated by harmonic balance analysis.

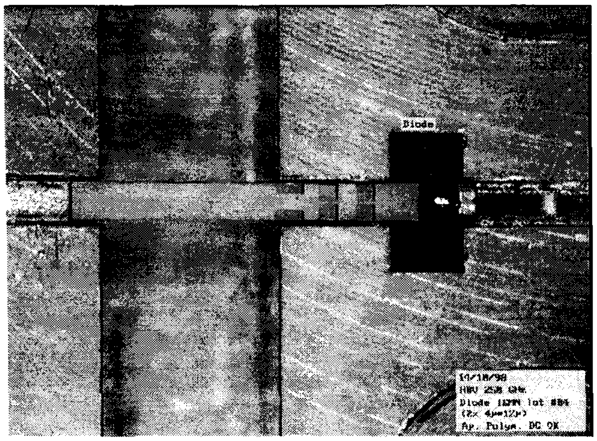

Figure 4 : Multiplier block used for experiment

The strip line low-pass filter is a five section Chebytcheff design implemented by using alternate high-low pass impedance strip line sections printed on the fused silica substrate. The diode chip is mounted in a flip-chip technology after lapping and dicing the wafer into discrete chips which have dimensions of 100 x 220 μm^2 and a thickness of 100 µm.

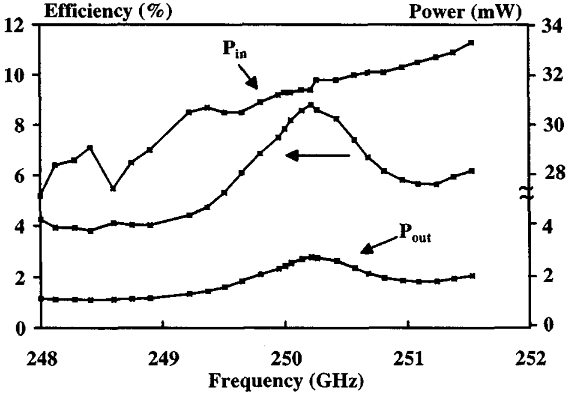

Figure 5: Input and output power along with conversion efficiency versus frequency (2 x6µm-diameter diodes)

In the first experiments, which were performed at a moderate source power, the input power was delivered by a Gunn oscillator which can be mechanically tuned between 248-253 GHz. Input power was measured with a HP power head which was recently calibrated whereas output power was recorded using an Anritsu power head with comparison with a Thomas Keating power meter. Figure 5 shows the variation in the 248-251.5 GHz of input power, output power and efficiency respectively. These measurements were carried out with two planar integrated 6-µm diameter diodes and fixed tuning of backshorts. For experiments at higher power levels notably up to P_{in} = 100 mW, we used a Thomson CSF carcinotron which can deliver a much higher power in the 77-82.25 GHz frequency range. Figure 6 shows the variations of the output power and conversion efficiency as a function of input power for an output frequency of 247.5 GHz.

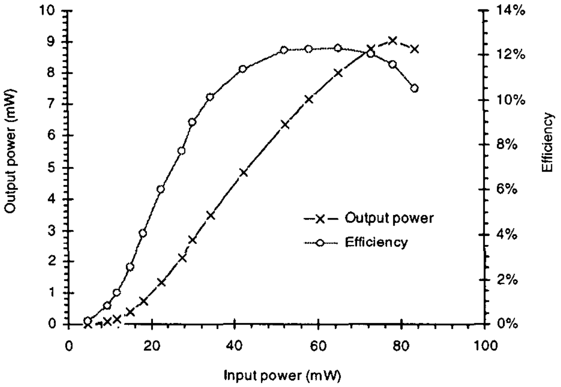

Figure 6 Output power and efficiency as a function of input power for a four-barrier device (diameter 6µm)

Tuning was adjusted for better performance at a pump power of 50 mW. This backshort tuning was maintained at a constant level for recording the variations illustrated in Figure 6. The maximum efficiency typically occurs for pump powers of approximately 60 mW. The maximum output power was 9.5 dBm and was obtained with an efficiency of 10.5 %. On the other hand, second harmonic rejection was measured and found to be -25 dB below the third harmonic which is a consequence of the excellent symmetry in the C-V characteristics.

IV Non LinearTransmission Line simulation

The advantages of symmetrical C-V characteristics can also be demonstrated for designing Non Linear Transmission Line multipliers by using a lumped element model with line inductance (L) and capacitance (C) per section while C_d is the device capacitance. C_d can be modeled by using an experimental $C_d(V)$ curve. Figure 7 shows the variation of the output power at 85 GHz as a function of the number of sections for a Bragg cut-off frequency $f_b= \pi^{-1} [L(C+C_d)]^{1/2}$ of ~110 GHz under large signal conditions. The pump power is 20 dBm in order to meet the requirement of peak-to-peak capacitance modulation of 12 V for a 64 μm^2-area DHBV's. In the ideal case assuming that there are no losses, an optimum basic cell number can be pointed out for which the 5th harmonic content is maximum (conversion efficiency 35%) obtained in the present example for n= 24. Above this threshold, the calculated efficiency starts to saturate.

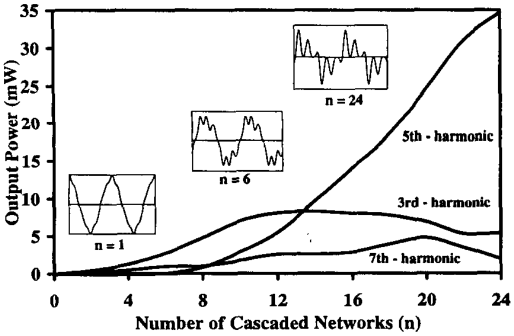

Figure 7 Output power versus basic cell number

Theses results showing good quintupler operation are a direct consequence of the strong non linearity exhibited by the devices. In order to illustrate this point the waveforms at various locations across the line were given in inset. A high harmonic content is evident when M is in excess of 20.

V Conclusion

We have achieved record performances with InP-based HBV's which have been fabricated in stacked and integrated planar configurations. An efficiency in excess of 10 % and around 10 dBm output power have been demonstrated at 250 GHz. We believe that further improvements in these values can be achieved by increasing the integration level. Experiments show voltage handling as high as 40 V with a zero-bias capacitance level C_{J0}=250 aF/μm^2 with eight barriers.

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