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A Broadband Heterostructure Barrier Varactor Tripler Source

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Abstract — **We present the first demonstration of a broadband Heterostructure Barrier Varactor tripler, designed to cover a major part of the WR-8 waveguide band. The source comprises a waveguide housing, a six-barrier InP-HBV diode flip-chip mounted on an AlN microstrip filter circuit. The conversion loss 3-dB bandwidth was measured to 17 % at a center frequency of 112 GHz. The maximum output power was more than 15 mW for an input power of 300 mW. There are no mechanical tuners or DC-bias, which simplifies assembly and allows for ultra-compact design.**

Index Terms — **Frequency conversion, Heterostructure Barrier Varactor (HBV), millimeter wave diodes, III-V semiconductors, varactors, terahertz sources.**

I. INTRODUCTION

There is a need for compact, highly functional and reliable receivers and transmitters at terahertz frequencies [1, 2]. High power and tunable sources are needed as local oscillators for heterodyne receivers (arrays) and transmitters for standoff imaging systems. In this work, the main objective is to demonstrate a broadband and compact varactor multiplier source providing adequate output power for millimeter wave receivers and transmitters in THz-radars [3].

Because of the inherent difficulty to generate power at terahertz frequencies, the output power from a lower frequency source can be multiplied [4] to higher frequencies using a nonlinear device such as the Heterostructure Barrier Varactor (HBV) diode [5]. The HBV has a symmetric capacitance-voltage (C-V) characteristic, operates unbiased and only generates odd harmonics of the pump signal. These specific properties simplify the design of high order multipliers (×3, ×5, ×7, etc.) [6-8]. Moreover, since cascading the epitaxial growth scales the voltage handling capability of the HBV, this device is well suited for high power generation. The progress on HBV multipliers include high power multi diode quasi-optical circuits [9], and single diode HBV triplers (×3) have been shown to provide 0.2 W at 113 GHz [10], 10 mW and at least 10% efficiency has been demonstrated at short millimeter wavelengths [11, 12]. Since the primary focus has been on maximum output power, these reported state-of-the-art HBV multipliers suffer from a relatively poor 3-dB bandwidth (<7%) and very limited efforts have been devoted to expand the bandwidth of HBV sources.

In any varactor type diode multiplier (Schottky, HBV, etc), the challenge is to provide a broadband matching of the pump signal to the capacitive device. Furthermore, the varactor diode is designed to exhibit a high dynamic cut-off frequency, thus high *Q*-value, in order to provide a high conversion efficiency when used for harmonic generation [13, 14]. Adding the requirement to present optimum embedding impedances at the output frequency as well as possible idler frequencies, the design process becomes even more intricate. An alternative solution, is to utilize varactor diodes in a distributed manner such as periodically loaded transmission lines (Non Linear Transmission Lines) [15]. In this work, we take advantage of a single high quality HBV diode and a careful design of the embedding circuitry, in order to make a trade-off between conversion efficiency and bandwidth. We present design, fabrication and test data of a broadband F-band HBV tripler (×3), optimized for a pump power of 0.3 Watt (Q-band).

II. DESIGN AND FABRICATION

A. Basic principles and device design

The HBV is a unipolar and a symmetric device composed of a high-band-gap semiconductor (barrier) that is surrounded by moderately doped low band-gap semiconductors (modulation layers). The barrier region is designed to prevent electron transport through the diode and hence ensure varactor mode, ideal nonlinear reactance, even at large-signal operating conditions [16]. Hence, the barrier should be undoped, high and thick enough to minimize thermionic emission and tunneling of carriers [17]. In this work, the modulation and barrier layers consists of $\mathrm{In_{0,53}GaAs}$ (N_d = 10^{17} $\mathrm{cm^{-3}}$) and $\mathrm{In_{0,52}AlAs/AlAs}$ respectively. Structures with a pseudomorphic (3nm) AlAs layer in the centre of the barrier has a high potential barrier, resulting in a very low leakage current [17-19]. The semiconductor material (MBE1038) was grown on InP by molecular beam epitaxy (EPI930) at the Nanofabrication Laboratory at Chalmers and consists of three epitaxially grown barriers. The design considerations for the device geometry includes both electromagnetic analysis for low parasitics as well as a 3-D thermal heat distribution optimization [10, 20, 21]. The device has 2-mesas in series with a total of 6–barriers and the cross sectional area for the diode used is 500 $\mu\mathrm{m}^2$, see Fig 1. Standard III–V processing techniques were used to fabricate the HBV devices.

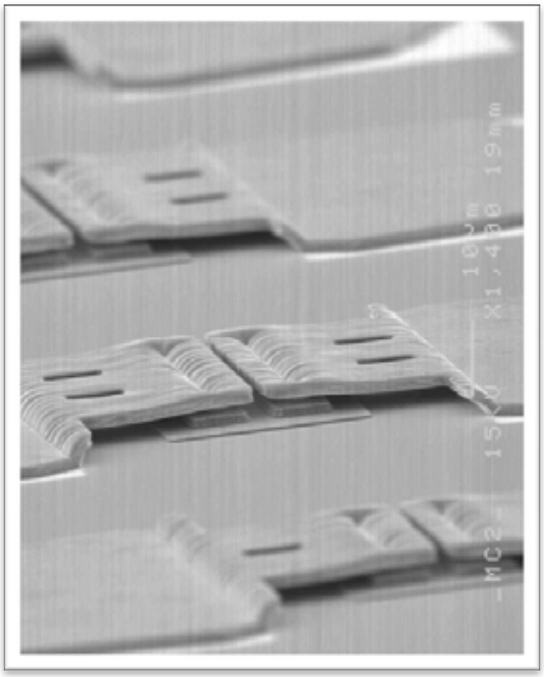

Fig. 1. A SEM photograph showing the two-mesa HBV geometry.

B. Frequency multiplier design

The circuit response was analyzed and designed using harmonic balance simulations. The nonlinear HBV model includes the interdependent electrical and thermal properties of the device [22]. Three-dimensional FEM modeling was applied to calculate the thermal resistance and the electrical series resistance used in the model. The embedding impedances presented to the diode were extracted from 3D electromagnetic analysis of the whole waveguide mount including the chip geometry.

The sacrifice that was done to achieve more broadband operation was to place the matching for the third harmonic close to the diode on the input side. This was accomplished by placing a radial stub for the third harmonic directly at the diode soldering pad. This will give a well-defined ground for the third harmonic while acting as a capacitance for the fundamental frequency. The capacitance will make the impedance matching worse at the fundamental frequency giving lower maximum conversion efficiency, but in total this matching scheme will result in a broadband circuit.

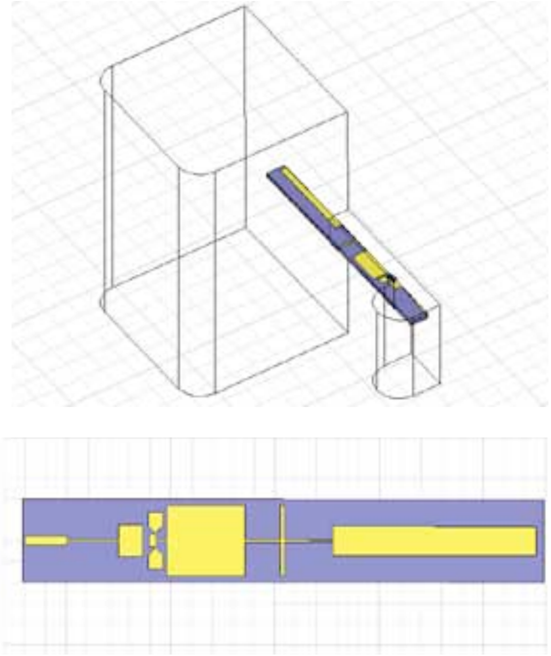

Fig. 2. Top) Schematic CAD model of the complete tripler module (only half the model is shown due to symmetry). Bottom) Circuit layout of the filter/matching network.

The microstrip circuit was fabricated on an AlN substrate and mounted in a waveguide block, see figure 3. The filter circuit includes open waveguide probes for both the input (WR-28) and the output (WR-8) waveguides.

Fig. 3. Photograph of the WR-8 tripler block. The input interface is a WR-28 waveguide.

III. MEASUREMENT RESULTS

The input signal to the multiplier was provided by an Agilent E8257D frequency synthesizer followed by a Spacek power amplifier. A waveguide isolator was used between the power amplifier and the HBV multiplier (DUT). Moreover, a 10 dB directional coupler was used in order to accurately monitor the available input power. The output power was measured using an Erickson PM4 power meter as shown in figure 4.

Fig. 4. The experimental set-up that was used to characterize the HBV WR-8 tripler module.

The output power versus output frequency is shown in figure 5. The 3-dB bandwidth exceeds 17 %, which is the highest value reported for HBV multipliers. The conversion efficiency is still acceptable (~5 %) and the module is still providing enough output power for a wide range of applications.

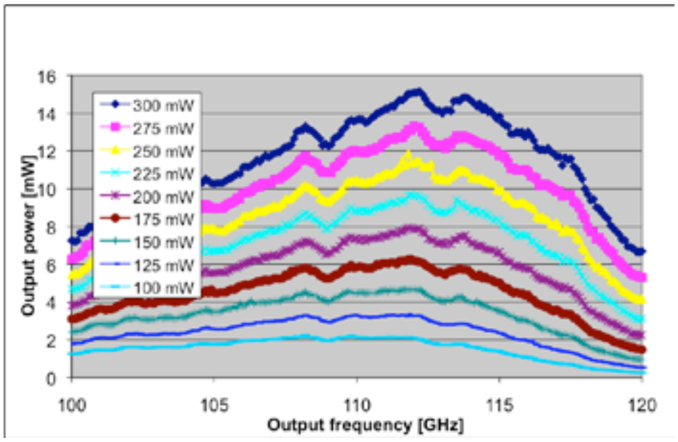

Fig. 5. Output power versus output frequency at constant input powers (100 – 300 mW).

VII. Conclusion

World-record bandwidth performance for HBV triplers has been demonstrated. With a careful circuit design, especially of the input network, it is possible to make a trade-off between conversion efficiency and bandwidth. The result is promising for a wide range of applications at terahertz frequencies demanding tunable sources and medium output power levels.

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