A High Power Frequency Tripler for 100 GHz

Tomas Bryllert, Josip Vukusic and Jan Stake

***Abstract*—We present a high-power frequency tripler for 100 GHz. The tripler - that is based on a single HBV diode - produces >200 mW of output power with a 3-dB bandwidth of 6%. This is the highest output power ever recorded for an HBV based multiplier irrespective of output frequency. The module features an ultra-compact waveguide block design and a microstrip matching circuit on high-thermal-conductivity AlN to improve the power handling capability.**

***Index Terms*—Heterostructure Barrier Varactor, HBV, multiplier, high power, aluminium nitride, THz source**

I. INTRODUCTION

MOST of the systems operating at THz frequencies today use single pixel receivers. There is however a lot of work invested to expand these systems to arrays of receivers, both to improve the scanning speed for radio telescopes and to do real-time imaging in other applications. As the number of pixels increase the demand for local oscillator power will increase – which is the issue we address in this work.

The Heterostructure Barrier Varactor (HBV) is a device well suited to produce high power levels at THz frequencies. The fact that several varactors can be stacked on top of each other during epitaxy allows for fabrication of diodes with high power handling capability while keeping the devices electrically small. In this work we present a circuit that can handle >1 W of input power with a single diode. Another feature that favors the use of HBVs in THz frequency multipliers is that the devices have a symmetric C-V characteristic which will produce only odd harmonics of the fundamental frequency; this simplifies the circuit design for higher order multipliers (x3, x5). Both triplers and quintuplers based on HBV diodes have been demonstrated at low THz frequencies by different groups [1-6]. In this work we present state-of-the-art results from a high output power frequency tripler at 111 GHz. Initially we describe the design and fabrication of the tripler which is followed by a report of the measurement results.

II. HIGH POWER HBV DIODES

We have fabricated HBV diodes out of InGaAs/InAlAs/AlAs on a InP S.I substrate. This material system offers high electron mobility (InGaAs) as well as a high conduction band offset in the varactor - resulting in low leakage current. The epitaxy consists of three stacked diode structures, and the diode is then fabricated with four series connected mesas (fig 1). This diode geometry gives a total of twelve varactor barriers, with a DC breakdown voltage of >40 V (fig 2).

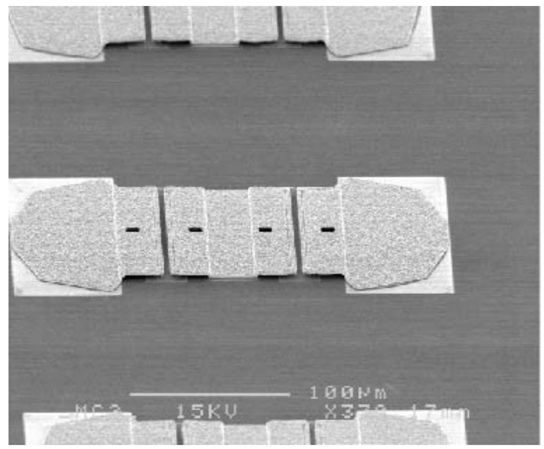

Fig. 1. SEM image of a high-power HBV diode on chip.

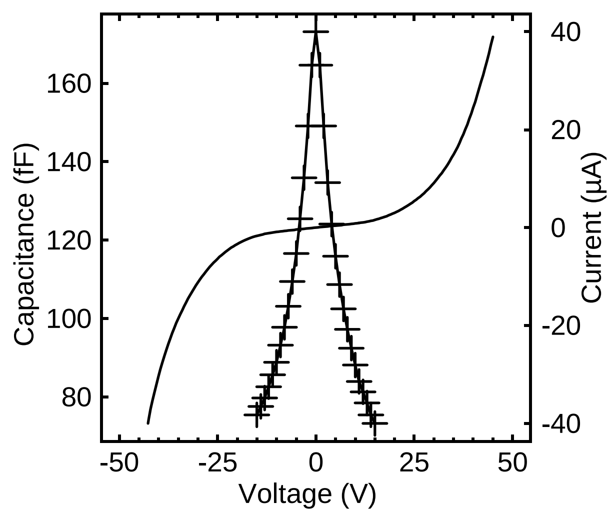

Fig. 2. DC characteristics of a high-power HBV diode with a mesa area of 1000 μm^2.

III. MULTIPLIER DESIGN

The HBV diode is flip-chip soldered onto a microstrip circuit that contains the impedance matching elements and waveguide probes. The microstrip circuit is then mounted in a waveguide block with waveguide input/output interfaces (WR22/WR10). One of the ambitions of the work was to make a design that was reliable and reproducible – therefore care was taken to minimize the number of manual steps in the fabrication and mounting. No DC electrical connection between the microstrip circuit and the waveguide block was therefore used, and a new layout of the block was introduced as described below.

A. Waveguide block

The waveguide block was machined in brass and electroplated with 2 µm of gold. The block is split in a plane perpendicular to the input- and output waveguides as seen in figure 3. This layout results in a very compact circular block only 6 mm thick and 30 mm in diameter.

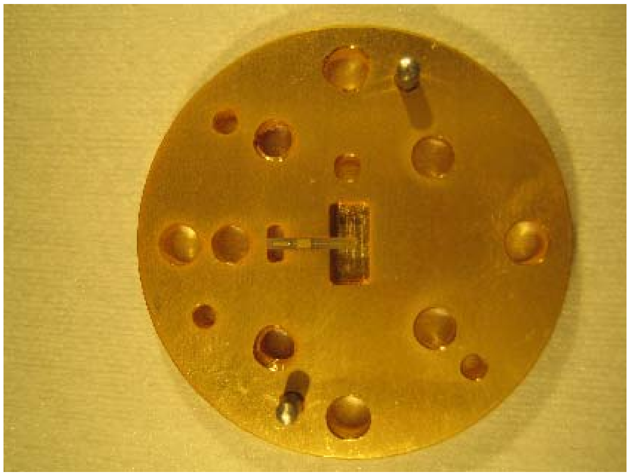

Fig. 3. One half of the waveguide block with a microstrip circuit mounted.

The two block halves are milled from one side only which gives simple and accurate machining. The microstrip matching circuit – including the HBV diode - is located in a channel connecting the input- and output waveguides. There are no mechanical tuners in this design.

B. Microstrip circuit

The microstrip circuit was fabricated on an AlN substrate to improve the power handling capability (AlN has a high thermal conductivity ~ 170 W/mK). No DC connection between the waveguide block and the circuit was used since simplicity was one of the design objectives. This also means that open waveguide probes were used both on the input and on the output side.

The optimum embedding impedances were extracted from harmonic balance simulations using the Chalmers HBV device model [7]. These impedances were then implemented using a quarter wave transformer and an inductive line for the fundamental frequency, and an open-stub stop-filter in combination with the output probe for the third harmonic (fig 4).

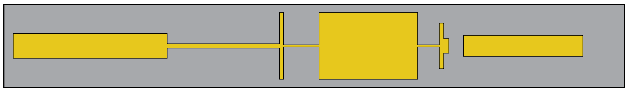

Fig. 4. The microstrip circuit showing the different matching elements and the input/output probes.

No power is generated at the second harmonic because of the symmetric capacitance-voltage characteristics of the HBV diode, which means that this harmonic does not have to be considered in the circuit design. The microstrip circuit was mounted in the waveguide block with glue.

IV. Results

The input signal to the multiplier was provided by a HP83650B frequency synthesizer followed by a Spacek power amplifier. To avoid having power reflected back from the multiplier to the power amplifier a waveguide isolator was inserted as shown in figure 5.

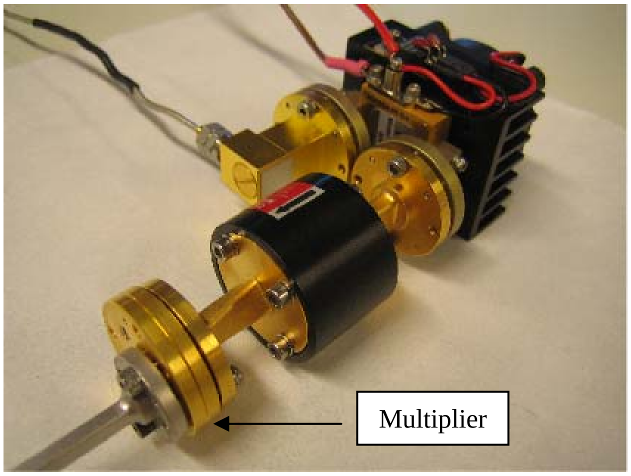

Fig. 5. Measurement setup showing power amplifier, isolator and multiplier.

The output power was measured using an Erickson PM2 power meter.

In figure 6 the output power is shown as a function of frequency at an input power of 1 W. A maximum conversion efficiency of 20% is measured at 111 GHz output frequency and the 3-dB bandwidth is 6%.

In figure 7 the output power is plotted as a function of input power showing a maximum output power of 240 mW.

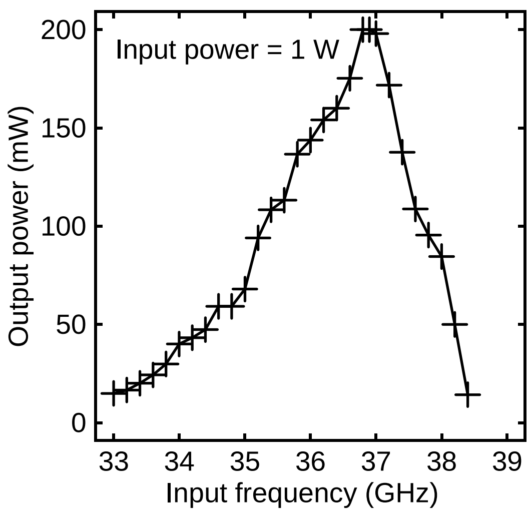

Fig. 6. Output power as a function of input frequency. The maximum conversion efficiency is 20% and the 3dB bandwidth is 6%

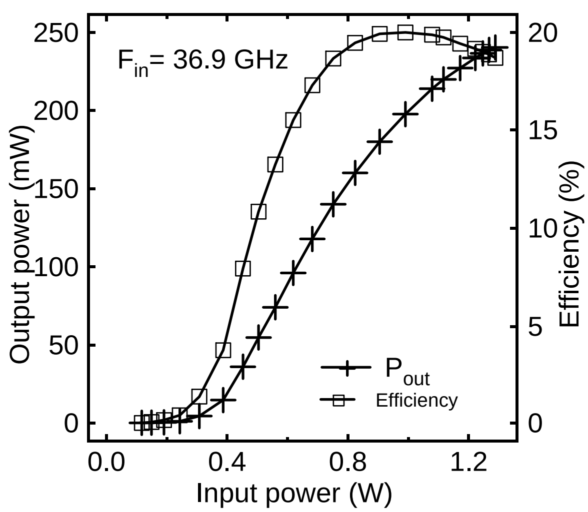

Fig. 7. Output power as a function input power. The maximum output power is 240 mW.

V. Conclusion

A high power frequency tripler to 111 GHz using a single HBV diode has been designed and fabricated. 240 mW of output power and a conversion efficiency of 20% have been measured. The fixed-tuned 3-dB bandwidth was 6%. A new design of the waveguide block has been presented that makes the machining of the block simple and reliable. The microstrip circuits are also designed for reliable mounting with no DC connection to the block.

Acknowledgment

The authors would like to thank Carl-Magnus Kihlman for fabricating the waveguide block and Mahdad Sadeghi for the growth of epi-material.

References

[1] J. Vukusic, T. Bryllert, T. A. Emadi, M. Sadeghi, and J. Stake, “A 0.2-W Heterostructure Barrier Varactor Frequency Tripler at 113 GHz” *IEEE Electron Device Lett.*, vol. 28, no. 5, May 2007.

[2] X. Melique, A. Maestrini, R.Farre, P. Mounaix, M. Favreau, O. Vanbesien, J.-M Goutoule, F. Mollot, G. Beaudin, T. Narhi, D. Lippens, “Fabrication and performance of InP-based heterostructure barrier varactors in a 250-GHz waveguide tripler” *Microwave Theory and Techniques, IEEE Transactions on*, vol. 48, no 6, June 2000 pp.1000 – 1006.

[3] T. David, S. Arscott, J.-M. Munier, T. Decoopman, G. Beaudin, and D. Lippens, “Monolithic integrated circuits incorporating InP-based heterostructure barrier varactors” *IEEE Microw. Wireless Compon. Lett.*, vol. 12, no. 8, pp. 281–283, Aug. 2002.

[4] Q. Xiao, J. L. Hesler, T. W. Crowe, R. M. Weikle II, F. Duan, and B. S. Deaver, “High-efficiency heterostructure-barrier-varactor frequency triplers using AlN substrates” *Proc. IEEE MTT-S Int. Microw. Symp. Dig.*, Jun. 12–17, 2005, pp. 443–446.

[5] Q. Xiao, Y. Duan, J. L. Hesler, T. W. Crowe, and R. M. Weikle II, “A 5-mW and 5% efficiency 210 GHz InP-based heterostructure barrier varactor quintupler” *IEEE Microwave and Wireless Comp. Lett.*, vol. 14, pp. 159-161, Apr. 2004.

[6] T. Bryllert, A. Olsen, J. Vukusic, T. A. Emadi, M. Ingvarson, J. Stake and D. Lippens, “11% efficiency 100 GHz InP-based heterostructure barrier varactor quintupler” *Electron. Lett.*, vol. 41, no. 3, pp. 131–132, Feb. 3, 2005.

[7] M. Ingvarson, J. Vukusic, A. Ø.Olsen, T. A. Emadi, and J. Stake, “An Electro-Thermal HBV Model” *Proc. IEEE MTT-S Int. Microw. Symp. Dig.*, Jun. 12–17, 2005, pp. 1151-1153.