A TERAHERTZ GRID FREQUENCY DOUBLER

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Abstract—**We present a 144-element terahertz quasi-optical grid frequency doubler. The grid is a planar structure with bow-tie antennas as a unit cell each loaded with a planar Schottky diode. The grid has an output power of 5.5 mW at 1 THz for 3.1-μs, 500-GHz input pulses with a peak power of 36 W. This is the largest recorded output power for a multiplier at terahertz frequencies.**

I. INTRODUCTION

There is increasing demand for submillimeter-wave sources for use in radio astronomy and remote sensing [1,2]. Conventional sources such as lasers and vacuum-tubes are large and heavy. They need high voltage power supplies and have limited tuning range. Therefore it is desirable to use solid-state diode multipliers to generate higher harmonics from low-frequency tunable signal sources such as Gunn-diode oscillators. Currently most of these diode multipliers are a single diode, or a cascade of two or more diodes mounted in waveguide with a whisker contact. Rydberg *et al.* have demonstrated a Schottky varactor-diode frequency tripler with an output power more than 120 μW at 803 GHz [3]. Erickson and Tuovinen have presented a waveguide tripler with an output power of 110 μW at 800 GHz [4]. Zimmermann *et al.* have demonstrated a cascade of two whisker-contacted Schottky-varactor frequency tripler with an output power of 60 μW at 1 THz [5].

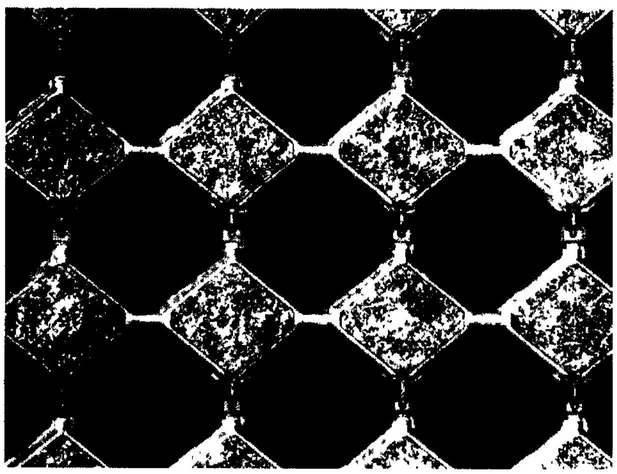

Fig. 1. A closeup picture of a portion of the 12 × 12 Schottky-diode frequency doubler. The unit cell size is 70 μm.

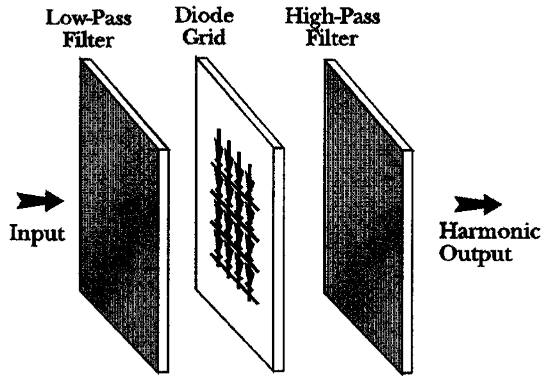

Fig. 2. A grid frequency multiplier [7]. The fundamental frequency enters the grid through a low-pass filter. The grid acts as a nonlinear surface and generates harmonics which pass through a high-pass filter.

At submillimeter-wave frequencies the losses associated with waveguide structures are high, and machining of single-mode waveguides is complicated. Quasi-optics allows the output powers of many solid-state devices to be combined in free space without transmission line losses. J-C. Chiao *et al.* have demonstrated a 6 × 6 doubler grid with a peak output power of 330 μW at 1 THz [6]. This grid had a null in the output beam because of the diode orientations used. In the grid presented in this paper, the diode orientation is corrected and the size increased to 12 × 12. A picture of the multiplier grid is shown in Fig. 1. A diode-grid frequency doubler is an array of closely spaced planar Schottky diodes. Fig. 2 shows this approach. The fundamental beam excites RF currents on the leads of the bow-tie. The diodes act as a nonlinear surface and generate harmonics. The low-pass filter in the input insures that

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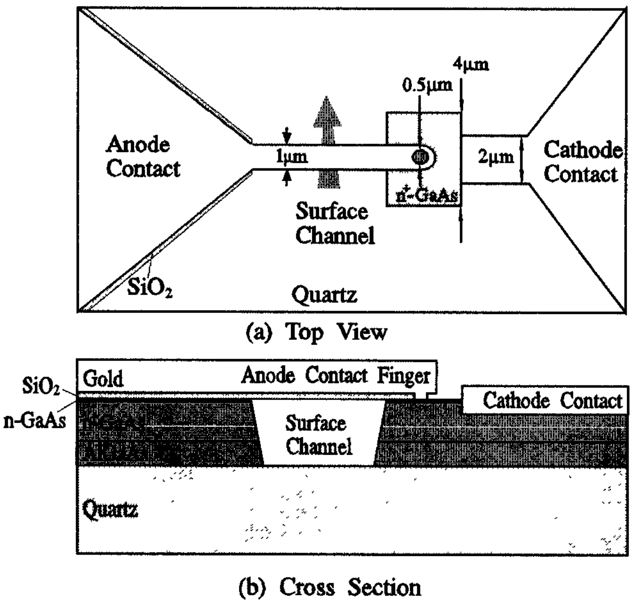

Fig. 3. Schottky-diode layout. (a) The top view. (b) The cross section. The n-GaAs layer is 0.1 μm thick and has a doping concentration of $4 \times 10^{17}\,\mathrm{cm}^{-3}$. The n^+-GaAs layer has a thickness of 3 μm and a doping of $5 \times 10^{18}\,\mathrm{cm}^{-3}$. The AlGaAs layer has a thickness of 1.5 μm.

only the fundamental frequency of the laser will hit the grid. The high-pass output filter allows the higher harmonics generated by the grid to pass through, but blocks the fundamental.

II. Construction

The grid multipliers were fabricated at the University of Virginia using monolithic technology [8]. To make diodes for terahertz frequencies, series resistance and shunt junction capacitance should be greatly reduced by reducing anode diameter and choosing optimum active layer doping and thickness. Fig. 3 shows the top view and the cross section of the Schottky diode. The anode has a diameter of 0.5 μm. A surface channel is etched under the anode contact finger to reduce the shunt capacitance. The diodes have an estimated junction capacitance of 0.6 fF at zero bias, and a dc-series resistance of 14 Ω.

The grid consists of an array of 12×12 bow-tie antennas on a 30 μm thick fused-quartz substrate. Fig. 4 shows the grid and the unit cell. Each unit cell is 70 μm on a side. The Schottky-diode junction is located at the center of the cell. The diode grid is first fabricated on a GaAs substrate. After the fabrication, the GaAs substrate is etched away and the diode structure is glued on a 30-μm thick quartz substrate.

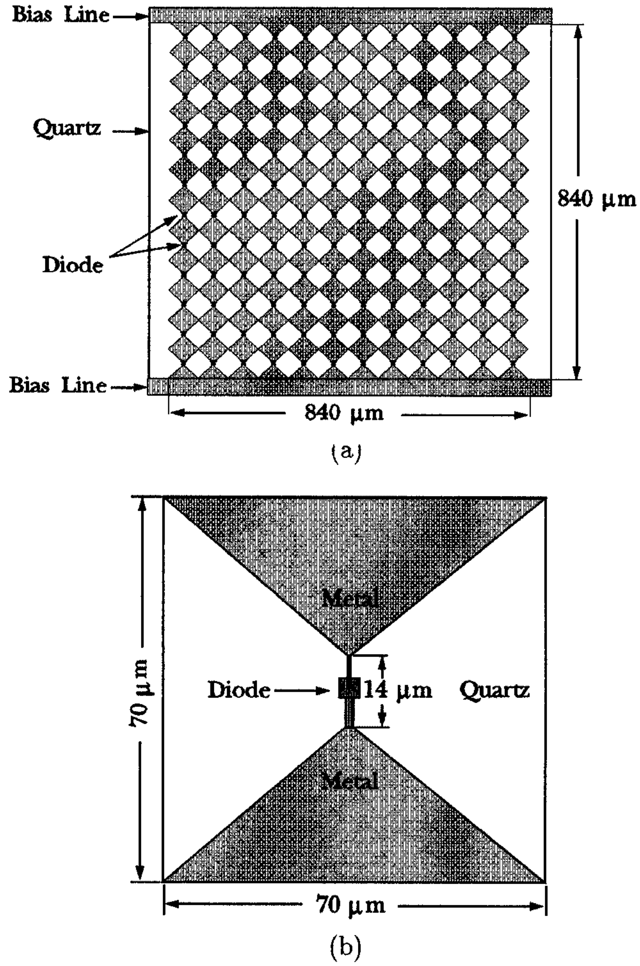

Fig. 4. The multiplier grid. (a) The entire 12×12 array. The diodes are in series from top to bottom. The grid can be biased through the bias lines at the top and bottom of the grid. The metal contacts in a row are all electrically connected. (b) The unit cell. The diode is located at the center of the cell.

III. Measurements

The measurement setup is shown in Fig. 5. The input source for these measurements is the free-electron laser (FEL) at the University of California, Santa Barbara [9]. The free-electron laser is capable of generating kilowatts of pulsed power tunable from 120 GHz to 4.8 THz. The pulse width in our measurements is 3.1 μs. The input power passes through a low-pass filter and is varied by rotating a polarizer. A beam splitter directs part of the input power into a pyroelectric reference detector. The rest of the input is focused onto the grid. A metallic-mesh Fabry-Perot interferometer is used to measure the frequency content of the output. The output beam is focused onto a liquid-helium-cooled InSb bolometer through a high-pass filter.

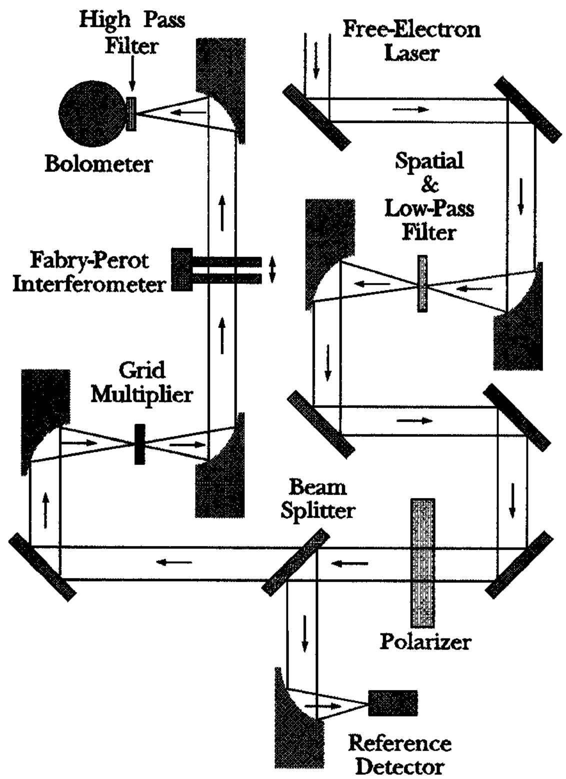

Fig. 5. Measurement setup. All the mirrors are f/1.2 parabolic, with focal length of 13 cm and diameter of 10 cm. Arrows indicate the direction of the beam.

The diode grids are suspended in air by gluing them over a hole in a microscope cover slip. The grid was placed in the setup shown in Fig. 5, and excited by a 500 GHz input beam. The output was detected by a InSb bolometer. In order to make sure that the output radiation is actually from the grid, we removed the grid. The output pulse disappeared. Also, rotating the grid by 90° has the same effect. This shows that the output signal is not a harmonic of the laser or generated by the GaAs epitaxial layer.

Fig. 6. shows the output as the Fabry-Perot interferometer is scanned. The period was 145 μm, indicating a second-harmonic frequency of 1.025 THz. No other harmonics were detected.

Fig. 7 shows the power dependence of the grid with normal incidence. A peak output power of 5.5 mW at 1 THz was measured with a peak input power of 36 W at 500 GHz. The pulse width was 3.1 μs. The grid was not biased or tuned. With low input power, the data follows a square-law relationship. There is a kink in the data for input powers near 1 W . It is possible that the kink is a self-biasing effect, where the RF power changes the diode impedance.

Fig. 8 shows the effect of rotating the grid about its axis. The output power stays within 30% of the maximum for angles up to 30°. This broad pattern indicates that the grid does not require precise alignment.

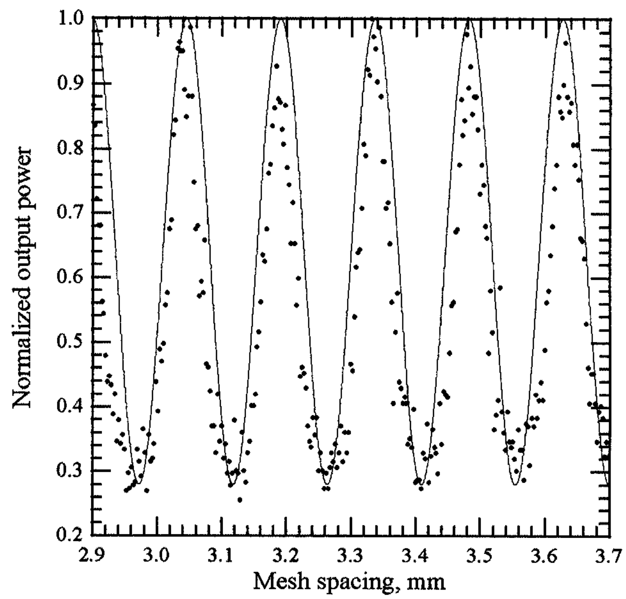

Fig. 6. Normalized output power as a function of the metal mesh spacing of the Fabry-Perot interferometer.

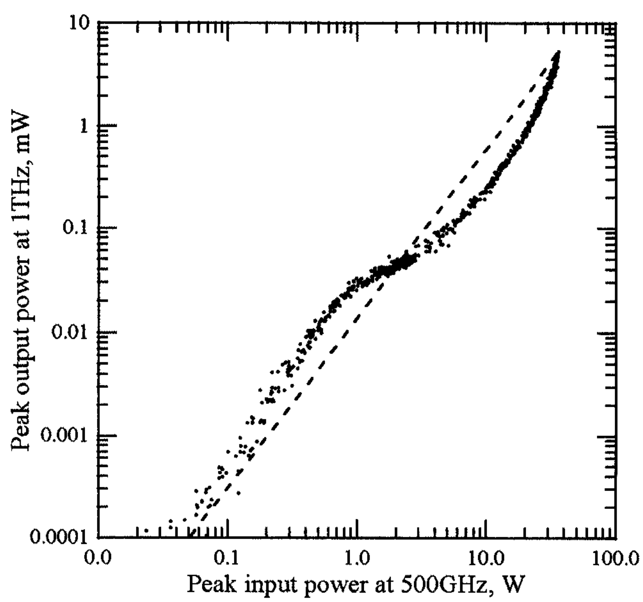

Fig. 7. Measured peak power dependance of the grid. The dashed line shows a square-law relationship.

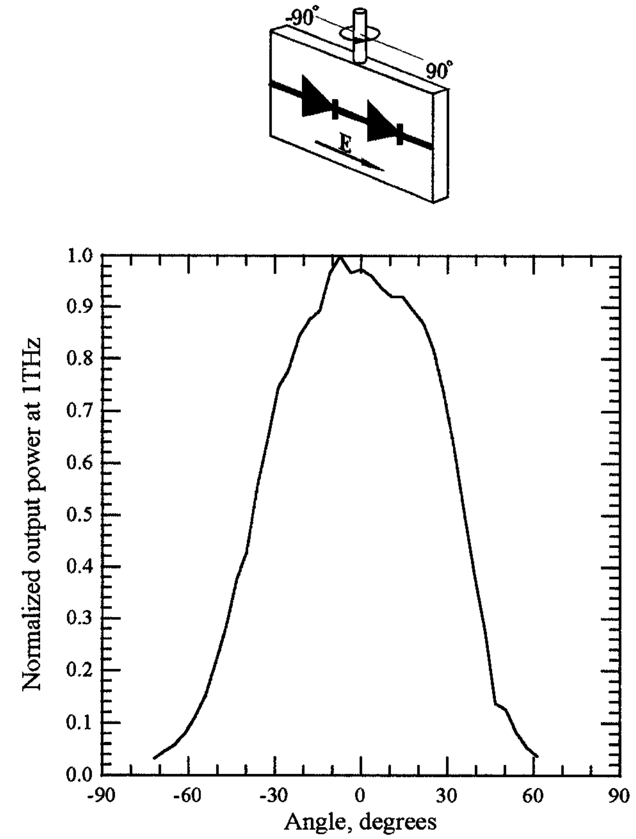

Fig. 8. Output pattern. The measurement was done by rotating the grid from $-90°$ to $90°$ with the electric field parallel to the diodes.

IV. Conclusion

In this paper we have presented a planar grid of 144 Schottky diodes suitable for use as a quasi-optical frequency doubler. A peak output power of 5.5 mW is measured at 1 THz for 3.1-μs 500-GHz input pulses with a peak power of 36 W.

V. Acknowledgements

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VI. References

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