150 GHz BAND IMPATT OSCILLATORS, FREQUENCY CONVERTERS AND DOUBLERS

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Abstract

Si p^+-n-n^+ IMPATT oscillators, GaAs frequency converters and doublers at 150 GHz band were developed. Oscillator output power was 85 mW at 161 GHz with 2.8 percent efficiency. DC incremental conversion loss was 5.5 dB with a Schottky-barrier mixer.

Introduction

Various types of semiconductor devices for millimeter-wave communication system below 90 GHz were developed and are actually under operation in the field test circuit in Japan. Recently, a great deal of effort and interest has been directed toward the development of solid state devices for frequencies above 100 GHz.

This paper presents recent experimental results of Si IMPATT oscillators, GaAs Schottky-barrier mixers and GaAs diffused junction varactors in the 150 GHz frequency range.

IMPATT oscillators

The optimum design of the diode parameters is very important for efficient operation of the short millimeter wavelength IMPATT oscillators [1,2].

Si single-drift-region diodes with p^+-n-n^+ structure were investigated. The space charge layer width was designed to be 0.2 μm for 150 GHz, which was estimated from the transit angle of about 0.7 π obtained in the 80 GHz band operation of Si SDR diodes[3]. This requires an n-region net doping level of about 3×10^{17} cm^{-3} with abrupt junction.

P doped n-epitaxial layers 0.35 ~ 0.70μm thick were grown by SiH_4 method on heavily As doped n^+-substrates. Preceding the fabrication, these wafers were checked by Sirtl etching and selected [4]. Shallow abrupt junctions were formed by thermal diffusion of boron at 900°C. The junction depth ranged from less than 0.1 to 0.25 μm, depending on the diffusion time. Doping profiles of the wafers used were measured by the C-V method and are given in Fig. 1. It is shown that the depletion layer of the sample B-2 reaches the n^+-substrate before breakdown and there is a sharp impurity transition at the n-n^+ interface.

The breakdown voltages of samples B-1, B-2, and C-2 were 8.6, 8.9 and 9.6V, respectively.

The diodes were thermally compression-bonded to gold plated copper heat sinks with junction side down and mounted with the quartz standoff configuration. Then, they were etched chemically until the junction diameter became about or less than 20 μm, which was derived from the analytical equation giving millimeter wave output power [3].

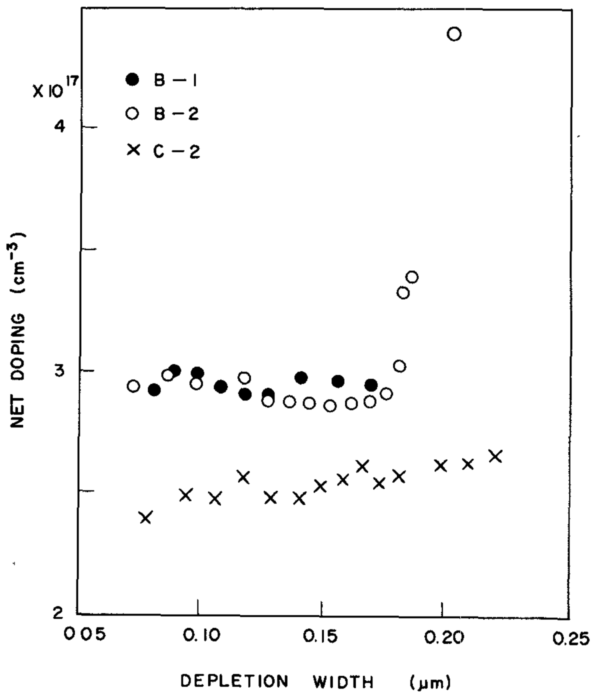

Fig. 1 Doping profiles of Si single-drift-region IMPATT diodes for 150 GHz band operation.

Oscillation performances were measured in a full-height hat structure cavity of R-1400 waveguide (1.65 mm by 0.825 mm). Tuning was accomplished by changing the dimensions of the hat and adjusting a sliding short and an E-H tuner.

Continuous wave output powers are plotted for the three types of diodes in Fig. 2. Best performance was obtained in sample B-1. Output power and frequency data with the highest performance are given in Fig. 3. Output power of 85 mW was achieved at 161 GHz with conversion efficiency of 2.8 percent.

Frequency converters and doublers

Packaging a semiconductor junction with negligible parasitic susceptance, as well as achieving small junctions, is of great importance in making short millimeter wavelength diodes.

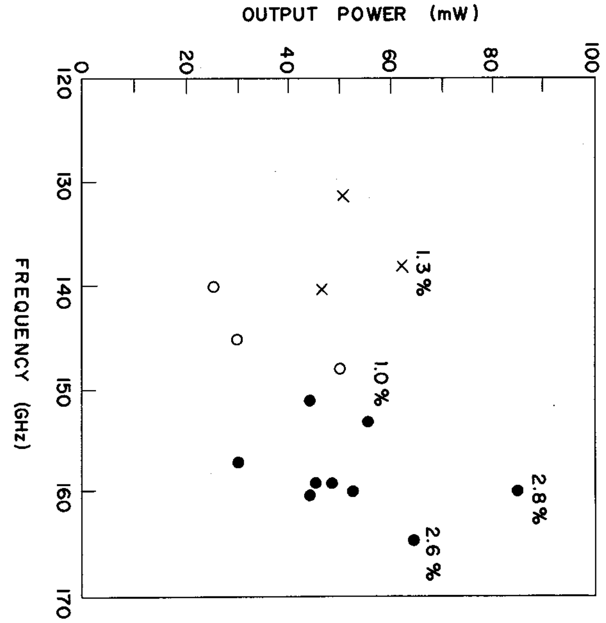

Fig. 2 Continuous wave output power versus frequency of IMPATT diodes. Inserted values with percent are the oscillation efficiencies. Symbols are the same as used in Fig. 1.

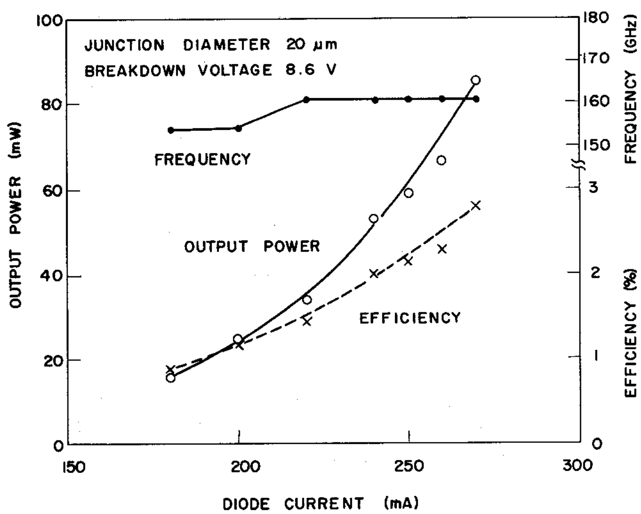

Fig. 3 Output power and frequency as a function of diode current for a diode with highest performance.

Cylindrical type packages involving R-740 (3.10 mm by 1.55 mm) and tapered R-1400 waveguides, which are crossed over at right angles and coupled each other through a coaxial filter, were fabricated (Fig. 4). A semiconductor pellet was mounted on the stud in a broad face of the reduced height R-1400 waveguide. DC bias was fed through an inner conductor of the coaxial filter, which also combined an IF circuit role. A Au-Zn whisker, 250 μm long and 15 μm in diameter, was soldered to the other end of the inner conductor and used to contact one of an array of the diodes on the surface of a 150 μm square GaAs pellet.

This package can be applied for harmonic mixers, frequency multipliers, parametric amplifiers and so on.

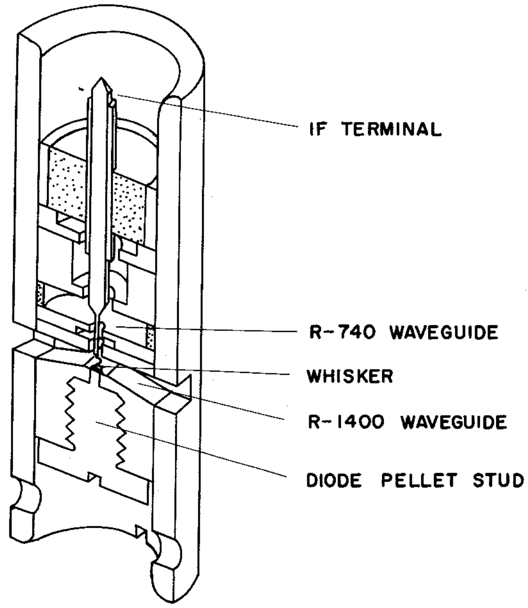

Fig. 4 Crossed-waveguide type package.

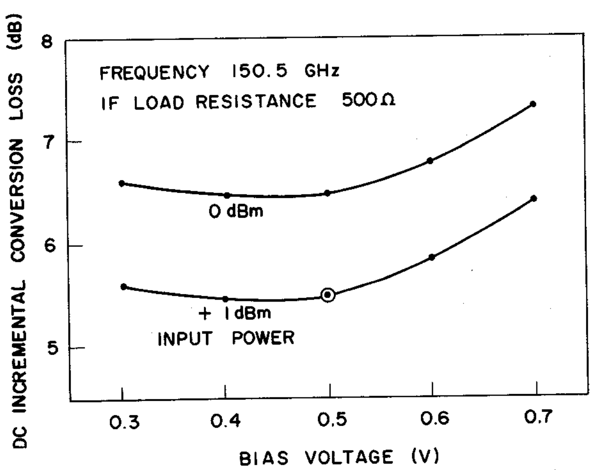

Fig. 5 DC incremental conversion loss as a function of bias voltage for a frequency converter at 150 GHz. ⊙ denotes the circuit tuning point.

For the frequency converters, planar Schottky-barrier diodes with Au•Ni-n GaAs junction were fabricated. In order to achieve a small junction capacitance, the junction diameter of 2 μm was made by photolithographic techniques[5]. Typical diodes with 1 x 10^{17} cm^{-3} doping level n-layer had an estimated junction capacitance of 0.002 pF and a measured dc resistance of about 20 Ω.

DC incremental conversion loss L_o values of 6.5 dB and 5.5 dB at 150.5 GHz were obtained for input power levels of 0 dBm and 1 dBm, respectively, as shown in Fig.5.

In the case of frequency doublers, GaAs diffused junction diodes with 5 μm junction diameter and 16 V breakdown voltage were used, whose dc spreading resistance was about 5 Ω [6].

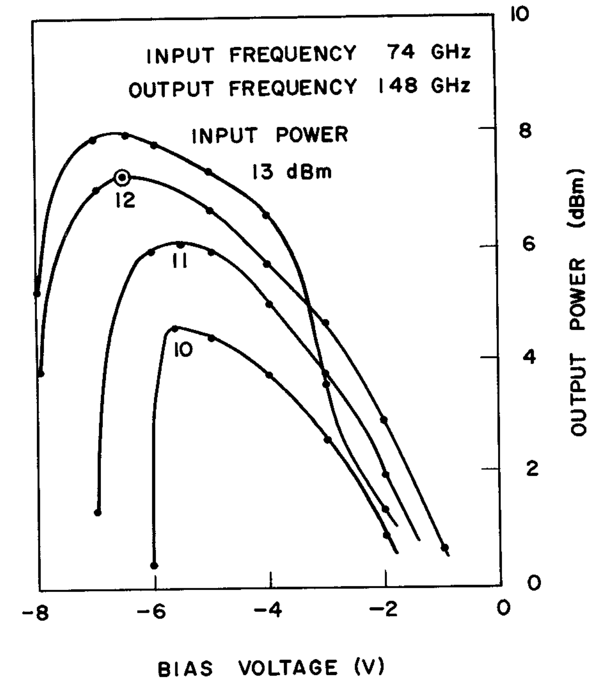

Fig. 6 Output power as a function of bias voltage for a frequency doubler pumped by a 74 GHz klystron.

Bias dependency of output power of a frequency doubler pumped by a 74 GHz klystron is shown in Fig. 6. In the figure, output powers of input power level = 13 dBm dropped abruptly above the - 3.5 V bias voltage. This is thought to be caused by the spurious generations. Minimum conversion loss of 4.8 dB with 12 dBm input power and maximum output power of 8 dBm with 13 dBm input power were obtained.

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References

(1) T. Misawa and L.P. Marinaccio, Proc. Symp. Submillimeter Waves, Polytechnic Institute of Brooklyn, 1970, pp.53-67.

(2) D.H. Lee, R.S. Ying and R.R. Hart, 4th Int. Conf. Ion Implantation in Semiconductors and Other Materials, Osaka, Japan, 1974, pp. 167-168.

(3) M. Ohmori and M. Ino, Trans. IECE Japan, vol. 56-C, pp. 285-292, May 1973.

(4) H. Niizuma and K. Suzuki, ECL Tech. Journal, vol. 23, pp. 191-202, February 1974.

(5) Y. Sato, M. Ida, M. Uchida and K. Simada, Trans. IECE Japan, vol. 55-C, pp. 1-8, January 1972.

(6) M. Fujimoto, Y. Sato, Y. Ishii and H. Yamazaki, Proc. 1st Conf. Solid State Devices, Tokyo, 1969, pp. 139-144.