X-BAND SILICON POWER TRANSISTOR*

Han-Tzong Yuan, James B. Kruger, You-Sun Wu
Texas Instruments Incorporated
Dallas, Texas 75222

ABSTRACT

A four cell silicon bipolar power transistor exhibiting 1.0 watts cw output power with 6 dB power gain and 30% collector efficiency at 8 GHz has been developed. The transistor has 1 μm metal contacts and 0.5 μm emitter width. Direct electron-beam slice writing was applied to define the fine geometries.

I. INTRODUCTION

The search of a solid state device which is suitable for X-band power generation and amplification has been in the central scene of microwave device research in many laboratories. As a result, the state of the art impatt diode, Gunn diode or varactor frequency multiplier have been reported capable to achieve the power level 1 to 5 watts.[1,2,3] However, the use of these devices in a practical circuit often requires compromise in the bandwidth, power gain, or conversion efficiency so that lately there has been considerable interest in the development of transistors (both silicon bipolar and GaAs field effect) for X-band power amplification.[4,5] The transistors are intrinsically easier to broadbond and have much less spurious frequency response. This paper will present preliminary efforts to achieve one watt output power at X-band frequency by means of silicon bipolar transistor technology.

II. DESIGN CONSIDERATIONS

The basic design principle of a microwave silicon transistor is guided by the figure of merit, normally called the maximum frequency of oscillation, f_{max}. It is defined as

$$f_{max} = \sqrt{\frac{f_t}{8\pi R_b{}'C_c}}$$

where:

f_t is the current gain-band width product
$R_b{}'C_c$ is the collector-base charging time

For a transistor to be useful at X-band frequencies, the f_t should be approximately 10 GHz and $R_b{}'C_c$ time constant should be better than 0.4 ps. Thus, the corresponding f_{max} would possibly exceed 30 GHz. Modern silicon processing technology, such as ultra-shallow arsenic emitter diffusion, has demonstrated the ability to achieve a transistor f_t in the neighborhood of 10 GHz. But in order to reduce the $R_b{}'C_c$ time constant, the transistor geometries must be refined. Most state of the art transistors with 2 μm geometry have demonstrated an f_{max} as high as 20 GHz. Therefore, if the nominal transistor geometry can be reduced further to $\lesssim$ 1 μm, the required f_{max} = 30 GHz for an X-band transistor if possible.

The transistor reported in this paper, shown in Figure 1, has 25 metal contact fingers. Each contact finger is 1 μm in width and 1 μm in separation. This fine resolution in transistor geometry is made possible only by applying the e-beam definition[6] and

* This work was sponsored in part by the Air Force Avionic Laboratory under Contract No. F33615-73-C-1237.

the ion-milling techniques. The detail transistor fabrication techniques will be reported in another paper.[7] Here only the transistor design parameters will be summarized in the following table.

X-Band Transistor Design Parameters

Base Area (A_B)	2.2	mil^2
Emitter Width	0.5	μm
Emitter Periphery (L_E)	22.0	mil
Packing Density (L_E/A_B)	11.0	mil^{-1}

III. DEVICE CHARACTERIZATION

Small signal characterization of the transistor has shown that it indeed has $f_t \sim 10$ GHz and f_{max} exceeding 25 GHz. The common base power amplifier performance of this transistor is shown in Figure 2. It can be seen that this transistor has useful power gain up to 12 GHz. Particularly as it is measured against the power added efficiency $\eta_{(pa)}$ which is defined as

$$\eta_{pa} = \eta_c \left(1 - \frac{1}{G}\right)$$

where:

η_c is the simple collector efficiency
G is the power gain of the amplifier,

this transistor shows far superior properties than other solid state devices operating in this frequency range.

In order to achieve higher power output, it is necessary to combine the power of several of the transistors discussed above. The success of any effort to combine the power from several transistors will depend a great deal on the packing and assembly technique employed. Figure 3 shows an example of the packaging technique used to combine the power from four transistors. The 140 x 140 mil BeO package has both the input and output matching network integrated into the package configuration. The performance of this four-transistor, combined package is shown in Figure 4. At 8 GHz, the measured output power is 1 watt with 6 dB power gain and better than 30% collector efficiency.

IV. CONCLUSION

The silicon bipolar transistor has been demonstrated to have useful power amplification capability up to 12 GHz. With the advances of modern processing technologies and the sophistications of packing and assemblying techniques, the silicon bipolar transistor is expected to join the other solid state devices in becoming one of the important ingredients in X-band circuit applications.

REFERENCES

1. K. Kamei and L. F. Eastman, "A High Efficiency CW Transferred-Electron Oscillator With Optimized Doping Profile," 7.1, IEDM Digest 1974.

2. H. Q. Tserng, W. R. Wisseman, and T. E. Hasty, "Characterization of GaAs Schottky Impatt Diodes," 24.2, IEDM Digest 1973.

3. C. W. Sirles and R. Allison, "3.5 watts High Efficiency Frequency Quadruple for X-band Application," to be presented in G-MTT Symposium, Palo Alto, California, 1975.

4. M. Fukuta, H. Ishikawa, K. Suyama, and M. Meada, "GaAs 8 GHz-Band High Power FET," 13.1, IEDM Digest 1974.

5. J. M. Gladstone, P. T. Chen, P. Wang, S. Kakihana, "Computer-Aided Design and Fabrication of An X-band Oscillator Transistor," 19.3, IEDM Digest 1973.

6. J. M. Pankratz and H. T. Yuan, "A High Gain Low-Noise Transistor Fabricated With Electron Beam Lithography," 3.1, IEDM Digest 1973.

7. J. B. Kruger, Y. S. Wu, H. T. Yuan, "Electron Beam Delineated X-band Silicon Transistor," to be presented in 13th Symposium on Electrons, Ion and Photon Beam Technology, Colorado Springs, Colorado, 1975.

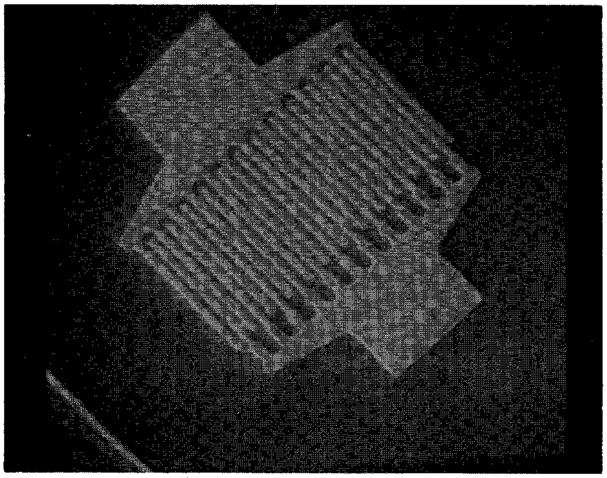

Figure 1 A SEM micrograph of the single cell x-band silicon power transistor (base area = 51 x 28 μm)

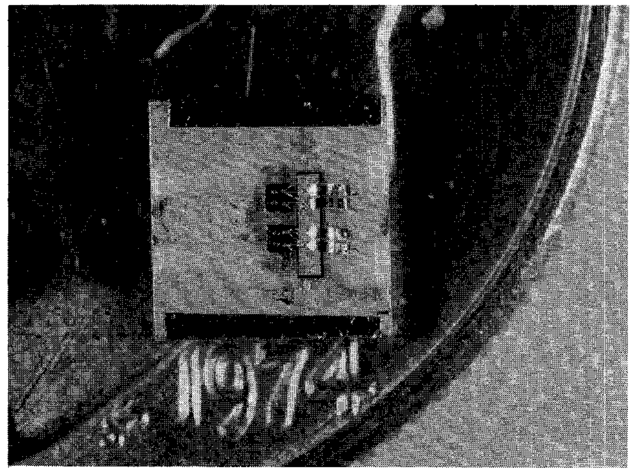

Figure 3 An example of the packing technique used in combining the power from 4-cell x-band transistor

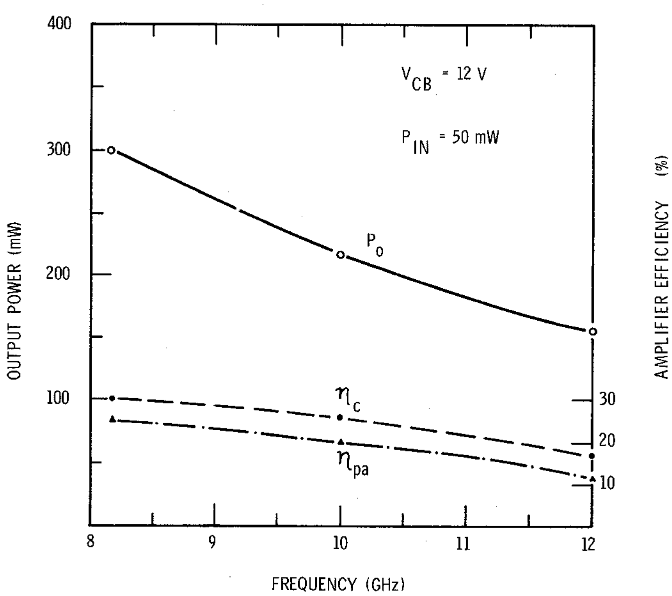

FIGURE 2 The Common Base RF Amplifier Performance of 1 cell X-band Transistor

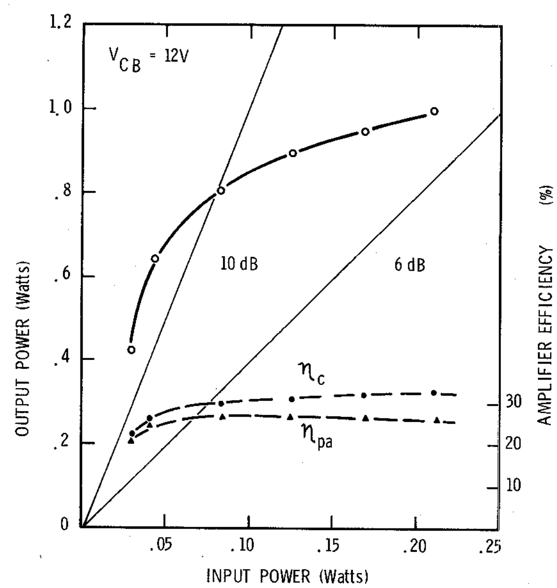

FIGURE 4 The RF Performance of 4-cell X-band Transistor at 8 GHz