MILLIMETER-WAVE SILICON IMPATT SOURCES AND COMBINERS FOR THE 110-260 GHz RANGE

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ABSTRACT

This paper reports the recent progress in CW and pulsed silicon IMPATT sources in the 110-260 GHz frequency range. A bridged double-quartz-standoff package has been developed and successfully used for the entire frequency range. Power combiners at center frequencies of 140 and 217 GHz have also been developed with peak output power of 9.2 and 1 W respectively.

INTRODUCTION

Recently, significant progress in output power has been achieved with silicon IMPATT oscillators in both CW and pulsed modes of operation at frequencies above 100 GHz.[1-6] Most results were achieved with double-drift diodes in direct contact or single-quartz-standoff packages. The double-drift diode requires a multiple-layer structure, which is more difficult to control in high frequency diode fabrication. The direct contact or single-quartz-standoff package uses a gold ball for a contacting pad that can be easily knocked off, causing irrepairable damage to the diode. This paper describes single-drift diodes that deliver comparable or higher output power levels than those previously reported. Pulsed output power levels of 3, 1.3 and 0.7 W and CW output power levels of 100, 60 and 25 mW have been consistently achieved at 140, 170 and 217 GHz, respectively. A bridged double-quartz-standoff package was developed and used successfully for the entire frequency range of 110-260 GHz. This package is much more reliable and rugged than the direct contact package or the single-quartz-standoff package. Although the double-quartz-standoff package has higher package parasitics than the single-quartz-standoff package, these effects can be compensated by better diode designs. In fact, the package parasitics can be used to transform the low diode impedance to high circuit impedance. To further increase the output power, a four-diode combiner was developed at 140 GHz with peak output power of 9.2 W. Peak output power of 1.05 W has also been achieved at 216 GHz from two 600-mW diodes.

DIODE DEVELOPMENT

Theoretically, the double-drift diode can provide higher power and efficiency, as well as device impedance for easier circuit matching, than the single-drift diode. However, the double-drift diode requires a more complicated doping profile than the single-drift diode. Multiple-layer structures have to be fabricated using multiple epitaxy or ion-implantation techniques, with precision control on thickness and doping density. Both techniques result in a graded profile around the p-n junction, which degrades the diode performance. For this reason, the single-drift structure (p^+-n-n^+) is attractive for its ease of fabrication.

At frequencies beyond 100 GHz, diode fabrication requires a considerable amount of care because of the extremely small dimensions involved. For example, the typical epi thickness is on the order of only a few tenths of a micron. Due to these small dimensions, the performance of the IMPATT diode depends critically on how well the diode parameters are controlled. The problem is further complicated by the fact that an accurate description of the high frequency IMPATT is virtually impossible without fully understanding the large-signal interaction between the diode and circuit. For our design, therefore, an analytical approach backed by empirical data was employed. The theoretical values for the diode parameters such as doping densities and epi thickness were first obtained by a small-signal computer calculation. IMPATT diode wafers were then fabricated using these diode design parameters, with some variations in the doping profiles intentionally made for optimization purposes. After diode fabrication, the diode profile was characterized by C-V measurement and secondary ion mass spectroscopy (SIMS) analysis. Finally, RF testing of diodes will yield information as to how the various parameters can be improved or optimized for maximum output power at the desired frequency.

The single-drift IMPATT profile was first formed by epitaxially growing an n layer on an n^+ arsenic-doped substrate, followed by a shallow p^+ boron diffusion forming a p-n junction. A typical doping profile of a 200-250 GHz diode is shown in Figure 1, obtained from SIMS analysis.

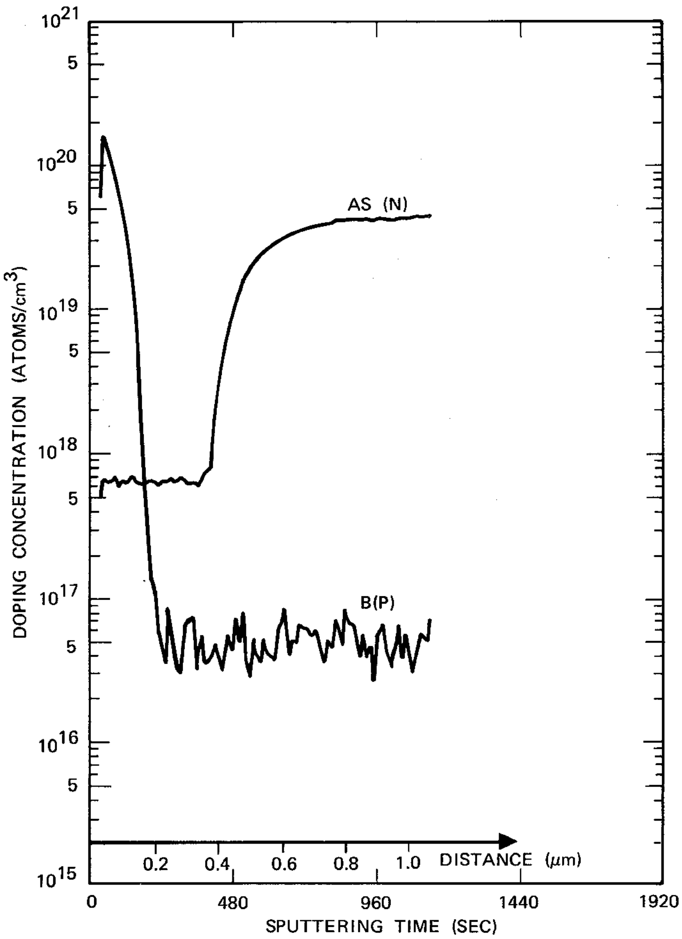

FIGURE 1: DOPING PROFILE OF A 200-250 GHz DIODE OBTAINED FROM SIMS ANALYSIS.

A bridged double-quartz-standoff package was developed and has been successfully used for frequencies up to 255 GHz. As shown in Figure 2, this package is much more reliable and rugged than the previously used direct contact package or single-quartz-standoff package.

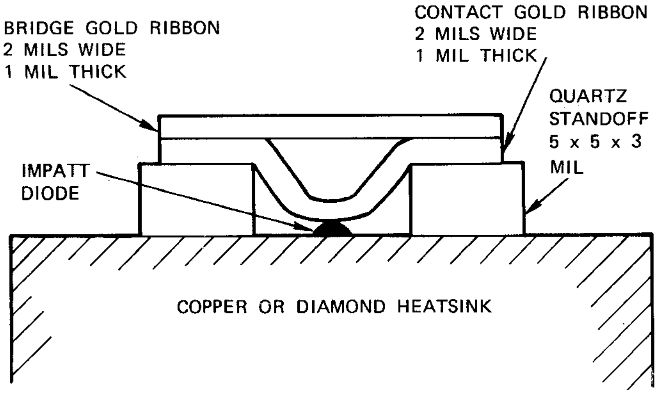

FIGURE 2: BRIDGED DOUBLE-QUARTZ-STANDOFF PACKAGE.

DIODE EVALUATION

The diodes were tested in a reduced height waveguide circuit as illustrated in Figure 3. In this circuit, a tapered transition was designed for impedance matching and an adjustable short was employed for power and frequency optimization.

For pulsed operation, peak output power levels of 3, 1.3 and 0.7 W have been consistently achieved at 140, 170 and 217 GHz respectively. The highest peak output power observed was 5.6 W at a center frequency of 140 GHz, 6.5 W at 130 GHz, 1 W at 217 GHz, and 620 mW at 240 GHz. The diodes were operated with 100 ns pulsewidth at 25 kHz repetition rate. For CW operation, typical output power of 100, 60 and 25 mW has been achieved at 140, 170 and 217 GHz respectively. For selected diodes, output power levels of 110 mW at 140 GHz, 150 mW at 152 GHz, 75 mW at 170 GHz, 50 mW at 217 GHz, 50 mW at 245 GHz, and 12 mW at 255 GHz have been achieved. The diode performance is summarized in Figure 4.

COMBINER DEVELOPMENT

To further increase the output power to meet many system requirements, power combiners are required. A two-diode and a four-diode combiner have been constructed for 140-GHz pulsed operation. Peak output power of 9.2 W and 5.2 W has been achieved from the four-diode and two-diode

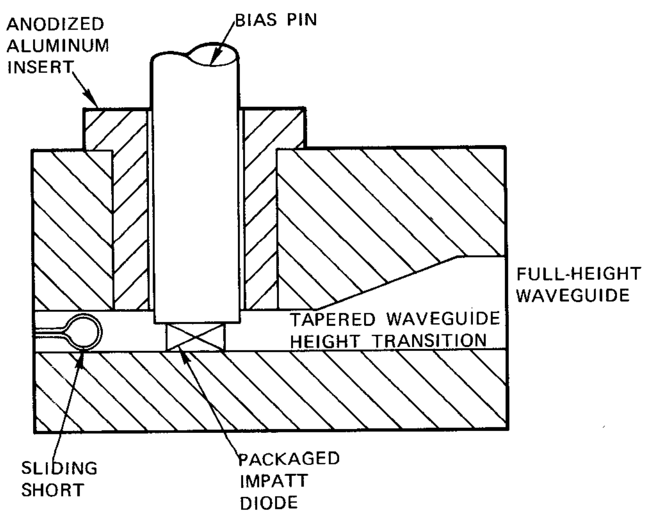

FIGURE 3: SINGLE DIODE TEST CIRCUIT CONFIGURATION.

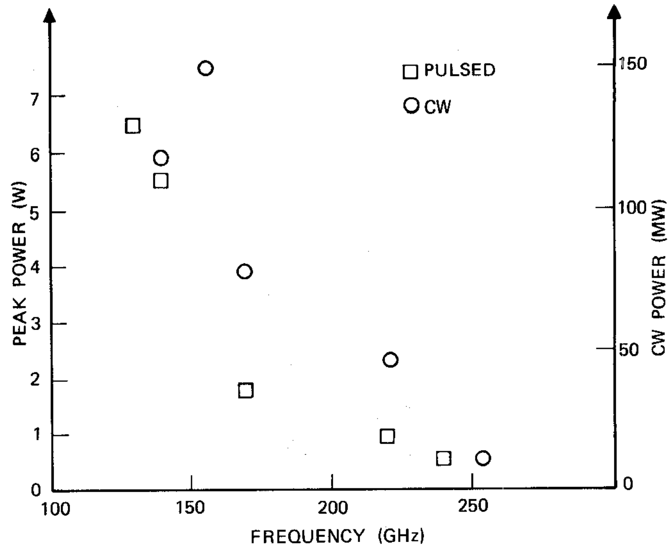

FIGURE 4: SUMMARY OF DIODE PERFORMANCE.

combiner respectively. The typical single-diode power capability is 3-4 W. The combiner circuit is similar to that proposed by Kurokawa.[7] A photograph of the four-diode combiner is shown in Figure 5.

A 217-GHz two-diode combiner has also been developed. Peak output power of 1.05 W at 216 GHz has been achieved from two 600-mW diodes.

CONCLUSIONS

Single-drift diodes in a bridged double-quartz-standoff package have been developed for the 110-260 GHz frequency range in CW and pulsed modes of operation. Power combiners were also demonstrated at 140 and 217 GHz that delivered state-of-the-art power outputs.

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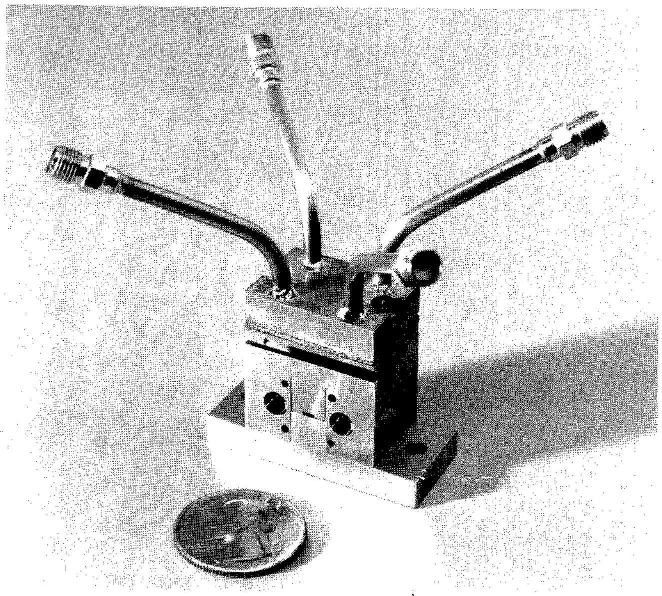
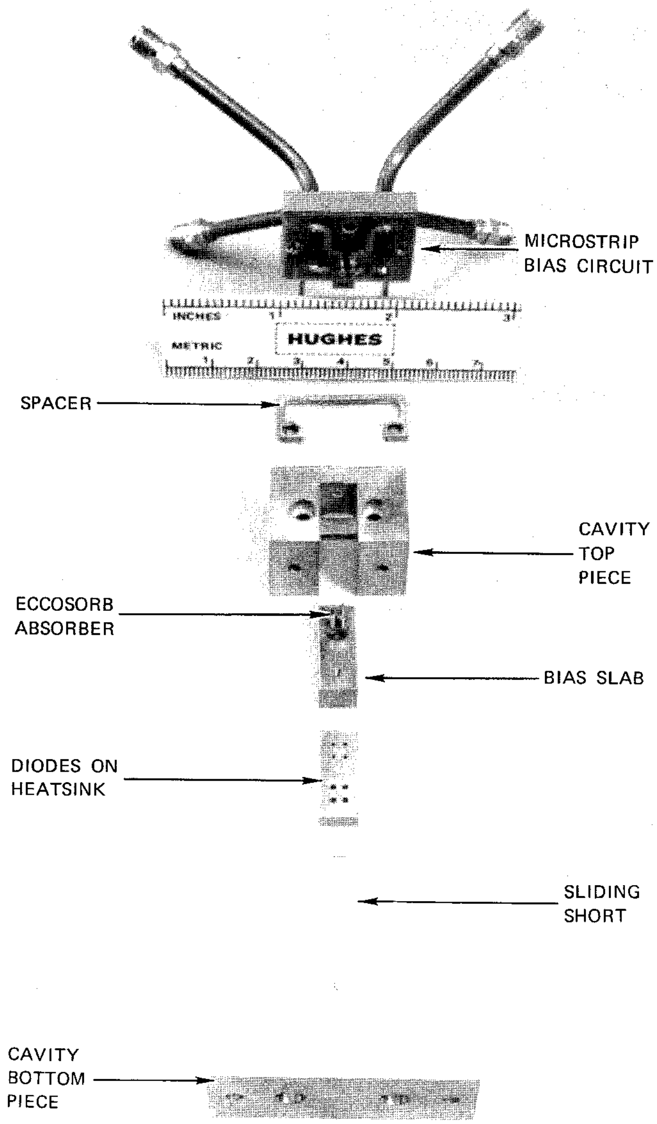


(a)



(b)

FIGURE 5: FOUR-DIODE COMBINER AT 140 GHz. (a) ASSEMBLED WAVEGUIDE CIRCUIT (b) DISASSEMBLED WAVEGUIDE CIRCUIT.

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