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MILLIMETER WAVE SILICON DEVICE AND INTEGRATED CIRCUIT TECHNOLOGY

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ABSTRACT

Silicon millimeter wave integrated circuit (SIMMWIC) technology has been developed utilizing novel fabrication techniques. These techniques have been applied to IMPATT and PIN diode fabrication schemes, the results of which are presented.

INTRODUCTION

SIMMWICs offer three key advantages: low cost, high yield, and full millimeter wave band capability [1]. Silicon IMPATT diodes can be tailored to operate anywhere in the millimeter wave band [2],and SIMMWIC technology is a high yielding controllable technology utilizing selective ion implantation, pulsed laser annealing, secondary ion mass spectrometry(SIMS) profile diagnostics, and novel wafer thinning [2,3]. Using selective ion implantation and laser annealing over a part of the wafer assures that the high resistivity of the other parts is retained. This is essential for the integration of millimeter wave devices with low loss microstrip circuits on silicon.

In this paper, we demonstrate the fabrication of several types of PIN and IMPATT diodes. A power output of 96 mW at 43 GHz was obtained from a double drift IMPATT diode, the p^+ contact and p type drift region of which were ion implanted and pulsed laser annealed.

IMPATT DIODES

To prove the validity of this technology for fabricating IMPATT diodes, double drift IMPATT diodes with one contact and one drift region ion implanted and pulsed laser annealed were tested and a power output of 96 mW at 43 GHz was achieved.

These diodes were fabricated (Figure 1) by epitaxially growing an arsenic doped drift region followed by a lightly doped

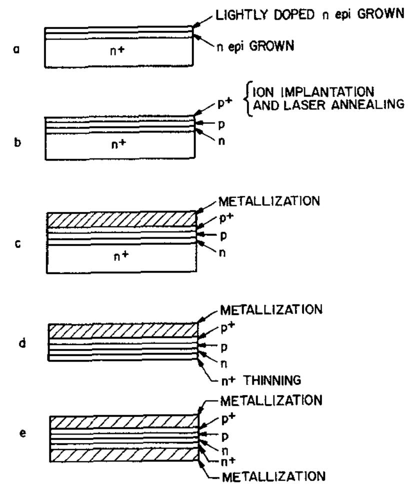

FIG. 1. FABRICATION OF DOUBLE DRIFT IMPATT DIODES UTILIZING SIMMWIC TECHNOLOGY.

arsenic layer ($1 \times 10^{15} cm^{-3}$) on heavily arsenic doped substrates (.001 ohm-cm). The lightly doped arsenic layer was then ion implanted with boron according to Table 1, followed by pulse laser annealing. The SIMS profile of the resulting structure is shown in Figure 2. Diodes defined from these wafers were mounted in an alumina ring type enclosure and tested in a reduced height waveguide cavity.

Table 1

Double Drift Structure With One Contact And One Drift Region Implanted

	Ion	Equivalent Energy (KeV)	Equivalent Dose (Atoms/cm^2)
1	B	50	1.54×10^{15}
2	B	240	3.16×10^{11}
3	B	350	4.86×10^{11}
4	B	480	6.67×10^{11}

Steps to obtain rf results from all ion implanted and laser annealed double drift IMPATT diode fabricated from 5000 ohm-cm silicon substrate are presently

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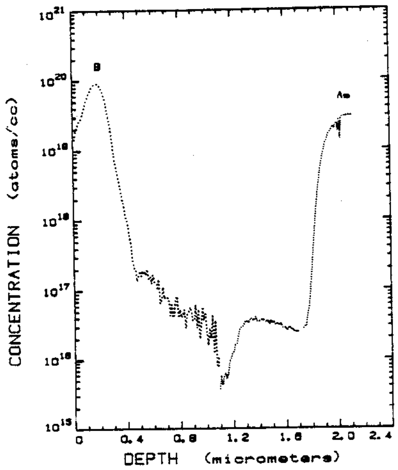

FIG. 2. SIMS OF THE DOUBLE DRIFT STRUCTURE WITH ONE CONTACT AND ONE DRIFT REGION IMPLANTED AND LASER ANNEALED.

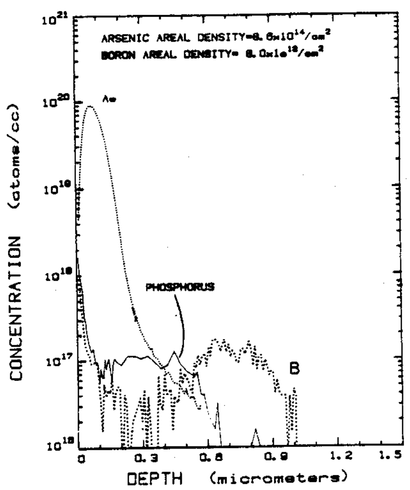

FIG. 3. SIMS OF SIDE I OF THE DOUBLE DRIFT, ALL IMPLANTED STRUCTURE.

underway. The SIMS of this structure (side I only) is shown in Figure 3, the ion implantation steps are summarized in Table II and the resulting I-V characteristic of this diode is shown in Figure 4.

PIN DIODE

Mesa PIN diodes were fabricated utilizing ion implantation and laser annealing (Figure 5). The breakdown voltage exceeds 400 V and the C-V measure indicate that full depletion of the i-layer occurs at a bias voltage (V_B) of -1 Volt. The C-V characteristics of a typical diode is shown in Table III and plotted in Figure 6 ("V" is the applied bias voltage).

Table II

Double Drift All Implanted Structure

	Side	Ion	Equiv. Energy (KeV)	Equivalent dose (Atoms/cm^2)
1	I	As	90	3.31×10^{14}
2	I	As	150	4.93×10^{14}
3	I	P	170	9.67×10^{11}
4	I	P	270	1.49×10^{12}
5	I	P	400	2.55×10^{12}
6	I	B	220	2.96×10^{12}
7	I	B	320	2.45×10^{12}
8	II	B	400	1.00×10^{15}
9	II	B	190	2.83×10^{15}
10	II	B	60	1.71×10^{15}

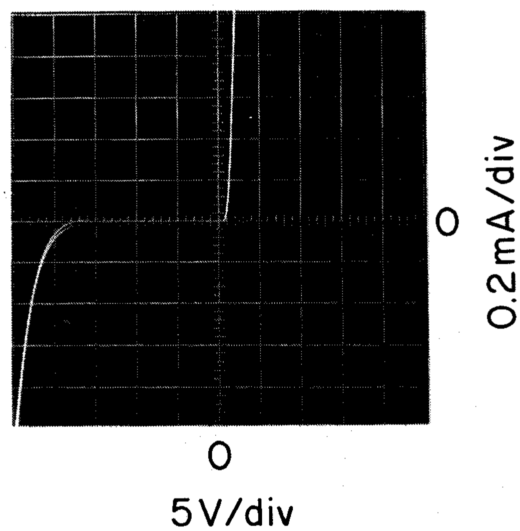

FIG. 4. I-V CHARACTERISTIC OF THE DOUBLE DRIFT, ALL IMPLANTED STRUCTURE.

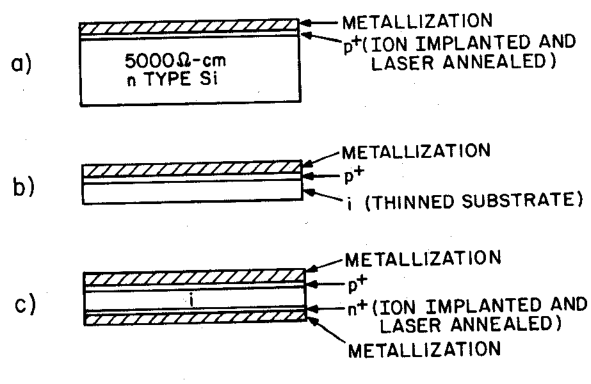

FIG. 5. FABRICATION OF PIN DIODES UTILIZING SIMMWIC TECHNOLOGY.

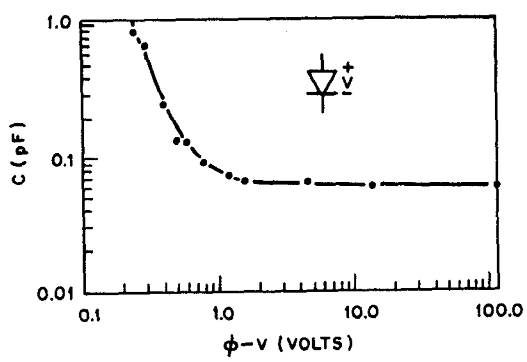

FIG. 6. C-V CHARACTERISTIC OF A PIN DIODE UTILIZING SIMMWIC TECHNOLOGY (ϕ = 0.6V).

Table III

Mesa PIN C-V at 1MHz

V (V)	C(pf)	V(V)	C(pf)
.35	.889	-.59	.075
.30	.669	-1.05	.069
.20	.257	-4.0	.068
.10	.138	-14.0	.062
-.20	.095	-149.0	.060

Lateral PIN diodes were also fabricated utilizing aligned masks to first implant the p^+ contact and then the n^+ contact into 5000 ohm-cm n type silicon. The wafers were then annealed, and the metal contacts were defined. The first run was annealed by conventional high temperature techniques with the resulting diode breakdown voltage (I_R = 10 μA) of 700 V. The second run is presently being pulsed laser annealed. Figure 7 depicts a typical lateral PIN in a series configuration with a transmission line, ideally a silicon microstripline.

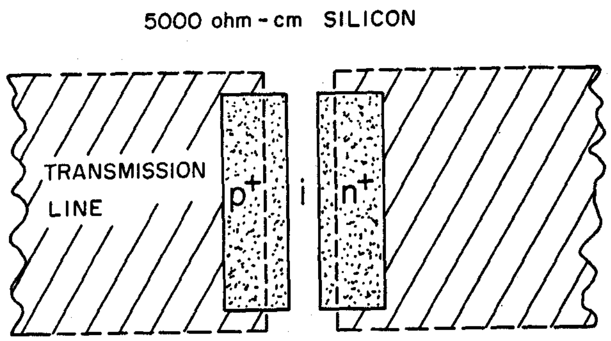

FIG. 7. LATERAL PIN DIODE IN A SERIES CONFIGURATION.

CONCLUSION

Utilizing SIMMWIC technology, silicon IMPATT and PIN diodes have been fabricated. 96 mW at 43 GHz have been achieved from a double drift IMPATT diode with one drift region and one contact region ion implanted and pulsed laser annealed. Double drift all implanted diodes have been made from high resistivity substrates using ion implantation, laser annealing and novel wafer thinning. Lateral and mesa type PIN diodes have also been made using this technology. We have demonstrated that SIMMWIC technology is ideal for complete millimeter wave subsystem integration.

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