77 GHz Monolithic MMIC Schottky- and PIN-Diode Switches Based on GaAs MESFET and Silicon SIMMWIC Technology

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ABSTRACT

We report on the design, fabrication and evaluation of 77 GHz monolithically integrated MMIC switches. Single-pole double-throw (SPDT) and single-pole three-throw (SP3T) switches were realized with Schottky diodes in a 0.25 μm GaAs MESFET technology. To our knowledge, this is the first fabrication of Schottky diodes as switching elements at W-band. In a silicon SIMMWIC technology SPDT switches were developed with PIN diodes. Insertion losses of 1.5-2.5 dB and isolations better than 20 dB were obtained at 77 GHz for the different switch types. A comparison between the GaAs MESFET and the SIMMWIC technology concerning switch RF-performance, power capability and switching speed is given in this paper.

INTRODUCTION

In recent years there has been a steady advance in implementing millimeter wave systems in monolithically integrated circuits. These circuits will be the key for low cost, small size and high volume production, whereby the choice of the substrate material (GaAs or silicon) is of essential importance for the planar integration of mm-wave circuits. A developed 0.25 μm GaAs MESFET technology, which allows the integration of Schottky diodes and MESFETs on the same chip, has been described in /1, 2/. On the other hand high resistivity silicon is also a suited substrate material and the basis for the silicon millimeter-wave IC (SIMMWIC) technique /3/.

This paper describes the design, fabrication and evaluation of 77 GHz monolithically integrated MMIC switches. Depending on the application switches may be involved to alternately route the RF-signal either to the antenna/mixer in the transmit/receive mode with SPDT switches or to several antenna feeds with SPnT switches. Using the GaAs MESFET technology we have realized SPDT and SP3T switches with Schottky diodes as active devices. In the silicon based SIMMWIC technology SPDT switches were developed with PIN diodes. The RF performance, power handling capability and switching speed is presented and a comparison between the GaAs MESFET and the silicon SIMMWIC technology is given.

FABRICATION PROCESS

The 0.25 μm GaAs MESFET technology for the realization of the Schottky diodes has been described in a previous paper /4/. Figure 1 shows the schematic cross-section of a planar Schottky diode. The technology includes a n+ buried layer ,which is formed by selective implantation,to reduce the diode series resistance. The fingers of the Schottky diodes are defined by electron beam lithography. The technology includes MIM capacitors and via-holes for low inductance ground connection.

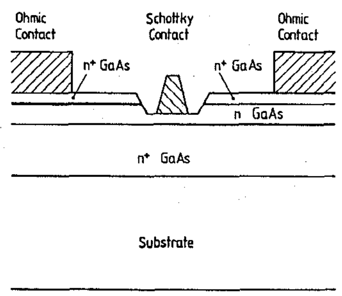

Fig. 1: Schematic cross-section of a planar GaAs Schottky diode

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In the SIMMWIC fabrication process for the realization of the Si PIN diodes, described in /3/, /5/, the high resistivity, undoped silicon substrate itself is used for the intrinsic (I) zone. The I-region is defined by the distance of the implantation layers. The concept of the planar PIN diode is shown in figure 2. The fabrication process of lateral PIN diodes is very simple, as no epitaxy process is needed.

Both the GaAs and Silicon switches were realized on 150 μm thick substrate.

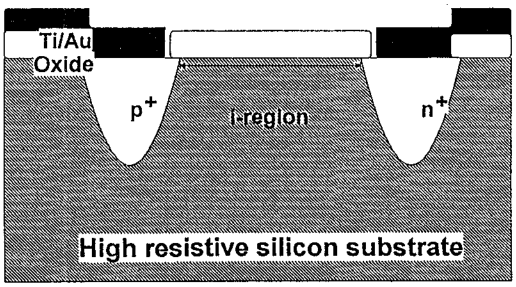

Fig. 2: Concept of the planar Si PIN diode

SWITCH DESIGN

For the GaAs Schottky diode switch a 6-finger diode with a fingerlength of 5 μm is used. In the ON-state the diode is biased in forward direction, representing a small ON-resistance $R_{on} = 3.5\ \Omega$. In the OFF-state (reverse biased) the diode is modelled by the OFF-capacitance $C_{OFF} = 50$ fF. The SPDT switch shown in figure 3 consists of two symmetrical cells for the ON and OFF arm. Each arm contains two shunt diodes, connecting the microstrip line to ground through via-holes. MIM capacitors are used to DC-isolate the input and output of each switch arm. In the ON arm the shunt diodes are biased in the OFF-state, forming a lumped element transmission line with the diode shunt capacitance C_{OFF} and the inductive series line. In the OFF-state the low impedance R_{ON} of the ON biased diodes is transformed to an open at the input of the tee-junction to isolate the OFF arm. The chip size is 2.6 x 1.3 mm^2. In a high power version of the SPDT the single shunt diode is replaced by a double diode (two diodes in series) between microstrip line and ground. This increases the reverse breakdown voltage and the power handling capability.

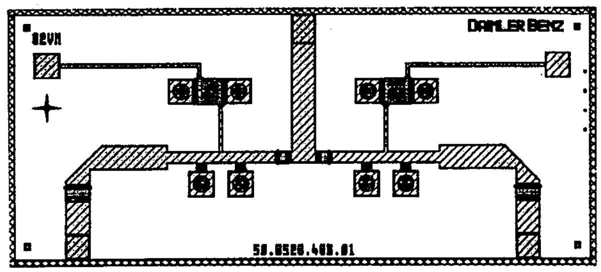

Fig. 3: Layout of the SPDT switch with GaAs Schottky diodes

In the SP3T switch with Schottky diodes of figure 4 the tee-junction of the SPDT is replaced by a cross-junction and a third output switch arm added. The outer arms are enlarged by a transmission line, λ/2 long, in order to orientate the diodes in all three arms in the same direction. The chip size of the SP3T switch is 1.2 x 2.6 mm^2.

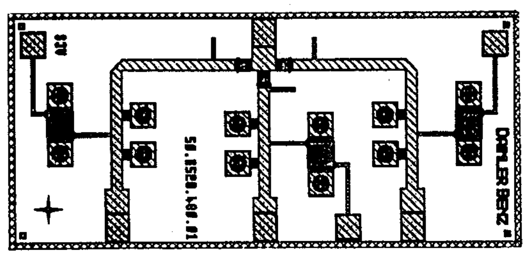

Fig. 4: Layout of the SP3T switch with GaAs Schottky diodes

For the switch design in SIMMWIC technology PIN diodes with 5 μm I-region width are used and modelled by the ON-resistance $R_{ON} = 4\ \Omega$ and the OFF-capacitance $C_{OFF} = 10$ fF. A photo of the SPDT switch is shown in figure 5. A radial stub is used as RF-short at the grounding side of the shunt diode. The DC-short is achieved by a via-hole. In one switch arm the anodes and in the other arm the cathodes of the two shunt diodes are connected to ground. With this antiparallel combination of the diodes in the different arms only one bias supply voltage ±Ud is necessary for biasing both arms simultaneously. Furthermore no MIM capacitors in the switch arms are needed. The bias is injected at the common input port isolated for the RF by a radial stub.The final chip size is 3.3 x 1.7 mm^2.

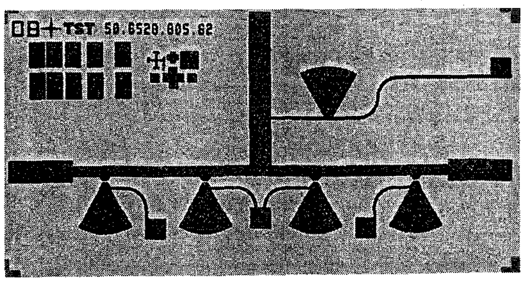

Fig. 5: Photo of the SPDT switch with silicon PIN diodes

SWITCH PERFORMANCE

Millimetre-wave measurements of the SPDT and SP3T switches were made in the E-band from 60 GHz to 90 GHz with a specially developed 4-port waveguide test fixture. A photo of the test fixture is shown in figure 6. Broadband transition from waveguide to microstrip is achieved by E-probes on 150 µm thick ceramic substrate. With a straight 50 Ω microstrip transmission line in the test fixture an insertion loss of 1.0 -1.2 dB was obtained at an input return loss better than 20 dB over a frequency range from 62 GHz to 85 GHz. For the measurements of the SPDT and SP3T the test fixture was calibrated with 50 Ω microstrip transmission lines from the input port to the corresponding output port, so that no test fixture loss has to be substracted from the switch measurement data.

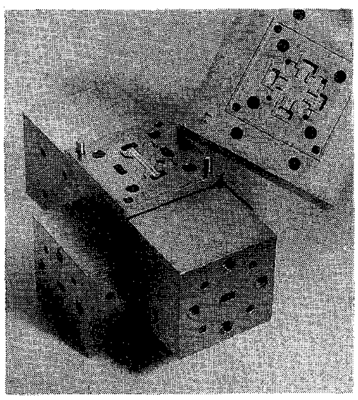

Fig. 6: Photo of the waveguide test fixture

Figure 7 depicts the ON/OFF performance of the GaAs Schottky diode SPDT switch from figure 3. In the transmission mode an insertion loss of 1.5 -2.0 dB was measured from 69-85 GHz with input/output return losses better than 10 dB. At 77 GHz the insertion loss is 1.8 dB. The isolation in the OFF-state is better than 20 dB. For the high power SPDT similar RF-performance was obtained (insertion loss of 1.5 - 2.5 dB, isolation better than 20 dB). The SP3T switch with Schottky diodes (figure 8) has an insertion loss of 2-2.5 dB and an isolation better than 20 dB in all the three arms at 77 GHz. The SPDT PIN switch in the silicon SIMMWIC technique (figure 5) shows an insertion loss in the ON-state of 2.0-2.5 dB and an isolation in the OFF-state better than 25 dB from 63 GHz to 83 GHz (figure 9). The input and output return losses of the ON arm are better than 15 dB and 10 dB respectively.

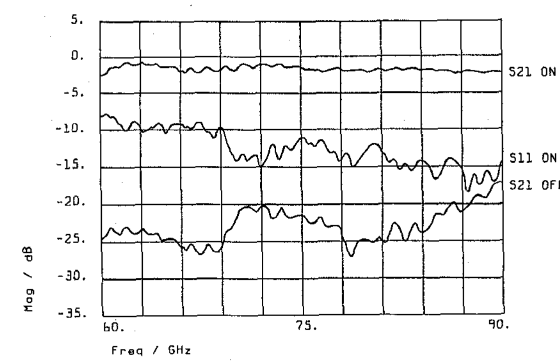

Fig. 7: Measured switch performance of the GaAs Schottky diode SPDT

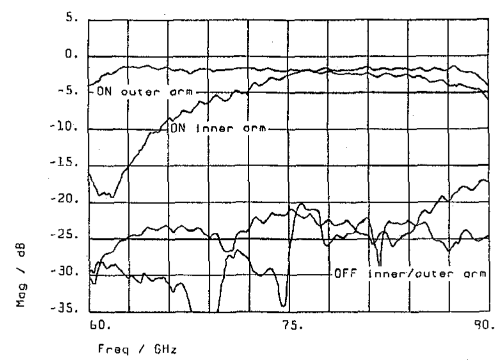

Fig. 8: Measured switch performance of the GaAs Schottky diode SP3T

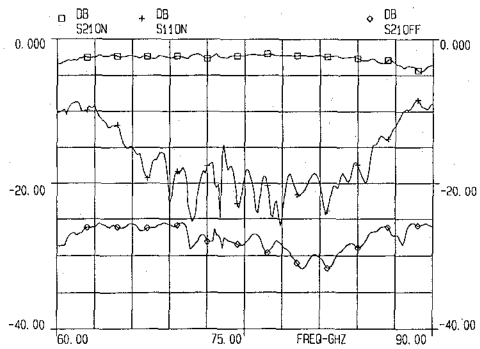

Fig. 9: Measured switch performance of the silicon PIN diode SPDT

Power measurements were made with an IMPATT oscillator at 78 GHz delivering a maximum output power of 23 dBm. The ON insertion loss versus input power is plotted in figure 10. The 1 dB compression point for the GaAs SPDT switch with single Schottky diode is obtained for an input power of 20 dBm, whereas the 1 dB compression point for the high power version was increased to power levels greater than 24 dBm. The PIN diode with its high breakdown voltage and a measured 0.2 dB compression point at 23 dBm is capable of handling greater power levels.

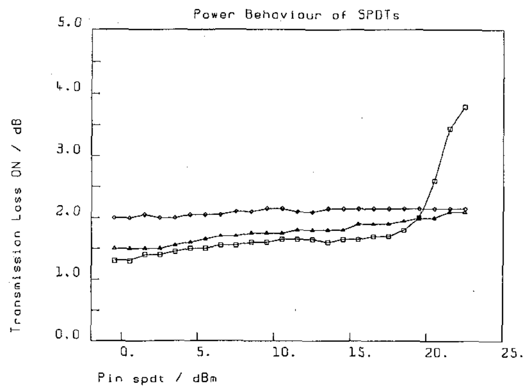

Fig. 10: Power behaviour of the SPDT switches
□-□-□ GaAs Schottky diode
△-△-△ GaAs Schottky diode, high power
◇-◇-◇ Silicon PIN diode

The Schottky diodes have a very fast switching speed with a measured transistion time of less than 2 ns. With the PIN diode a switching speed OFF-ON of 2 µs and from ON-OFF of 6 µs was achieved.

CONCLUSION

Single-pole double-throw SPDT and single-pole three-throw SP3T switches at 77 GHz have been realized in both a GaAs MESFET technology with Schottky diodes and in a silicon SIMMWIC technology with PIN diodes as switching elements. In both techniques the switches have shown an insertion loss of 1.5 - 2.5 dB in the ON-state and an isolation better than 20 dB in the OFF-state. The GaAs MESFET technology with Schottky diodes has the advantage of fast switching speed and of integration of several functions (doubler, switch, mixer) on one chip. The silicon SIMMWIC technique with a very simple fabrication process (no epitaxy, no MIMs) for the PIN switch diodes has a high power handling. Depending on the application and the requirements for the mm-wave front-end the appropriate technique (GaAs or silicon) has to be chosen.

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