W-Band SPST Transistor Switches

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***Abstract*—A single-pole, single-throw (SPST) transistor switch has been developed. Three types of switches, that is, GaAs MESFET, AlGaAs/GaAs HEMT, and pseudomorphic HEMT (PM-HEMT), have been fabricated, and the performances at W-band are compared. To reduce on-state resistance and off-state capacitance, a gate length was varied as a parameter. Moreover, an inductance for resonance was installed in parallel to the off-state capacitance between source and drain to obtain a high isolation. A relatively low insertion loss of 1.6 dB and a high isolation over 20 dB at W-band have been obtained from the 0.8-μm gate length PM-HEMT.**

I. Introduction

A SWITCHING DEVICE is a key component together with high-power and low-noise amplifiers in the radar systems. A p-i-n diode is widely used as a switching device because of its low insertion loss, high isolation, and high power handling capability. An extremely low insertion loss and high isolation of less than 1 dB and higher than 25 dB at W-band, respectively, have been achieved by the GaAs p-i-n diode [1]. A transistor switch using field-effect transistor (FET) or heterojunction bipolar transistor (HBT) is preferable, however, when taking the fabrication of monolithic microwave integrated circuits (MMIC's) into account. As for transistor switches, the performance at W-band has not been reported except for [2], where an insertion loss of 2 dB is achieved from the pseudomorphic HEMT (PM-HEMT).

In this letter, fabrication and performances of the W-band single-pole, single-throw (SPST) transistor switches are described. Since the reductions of on-state resistance ($R_{\rm on}$) and off-state capacitance ($C_{\rm off}$) are the key for the switching operation, three types of switches, that is, GaAs MESFET, AlGaAs/GaAs HEMT, and PM-HEMT are fabricated with varying the gate length and the performances of those are compared. The best performance of insertion loss and isolation of 1.6 and 22 dB at W-band, respectively, has been obtained from the 0.8-μm gate length PM-HEMT.

II. Design of SPST Switch

The keys for the successful operation of the switching characteristics are the reduction of $R_{\rm on}$ and $C_{\rm off}$. $R_{\rm on}$ is the sum of a resistance between source and gate, a channel resistance beneath the gate and a resistance between gate and drain. Among them, a channel resistance takes the most part. The channel resistance is decreased by shortening the recess length and making the sheet electron density higher. Since HEMT has a higher sheet electron concentration as compared with GaAs MESFET, it is expected to show a lower $R_{\rm on}$. On the other hand, $C_{\rm off}$ increases with shortening the recess length and making the electron density higher. From this point of view, GaAs MESFET is expected to give a lower $C_{\rm off}$.

From these considerations, both GaAs MESFET and HEMT's are fabricated with varying the gate length as a parameter. Moreover, an inductive strip line is installed between source and drain to get the parallel resonance for obtaining higher isolation. The width and length of the inductive strip line are designed by the microwave circuit simulator "LIBRA" using the device parameters. The device parameters were derived from the equivalent circuit model referred to in [3]. The determined strip line width and length of the inductance were 8 and 160 μm, respectively. To obtain a higher accuracy in the circuit design, a T-junction and rectangular bend were simulated using electromagnetic simulators.

III. Fabrication Process

Three types of wafers, GaAs MESFET, AlGaAs/GaAs HEMT, and PM-HEMT were prepared. All the wafers were processed in the same manner. The gate with lengths of 0.4, 0.8, and 1.2 μm were defined by electron-beam lithography for each wafer. The spacing between source and drain was kept constant to be 3 μm for all the gate lengths. The gate width is 100 μm with four fingers. The transmission line was gold plated with a thickness of 4 μm. The top view of the fabricated switch and the corresponding equivalent circuit are shown in Fig. 1(a) and (b), respectively. The control voltage is applied via the open gate resistor of 2.5 kΩ.

IV. RF Performances

Radio-frequency (RF) measurements were performed by using the on-wafer probing system at the frequencies between 75 and 110 GHz. The control voltage for changing switching state is $-6/0$ V for GaAs MESFET and $-2.5/0$ V for AlGaAs/GaAs HEMT and PM-HEMT. Table I lists the insertion loss and isolation of the fabricated switches at 94 GHz. In the table, the result of 0.4-μm gate PM-HEMT is not shown because of the processing failure. A lowest insertion loss of 1.6 dB with an isolation of 22.5 dB is obtained from the 0.8-μm gate length PM-HEMT. It is found that the insertion loss increases with increasing the gate length for all the wafers, while an isolation decreases with increasing the gate length for GaAs MESFET and increases for AlGaAs/GaAs HEMT and PM-HEMT. The dependence of isolation on the gate length is attributed to the differences of the resonant frequencies. Fig. 2

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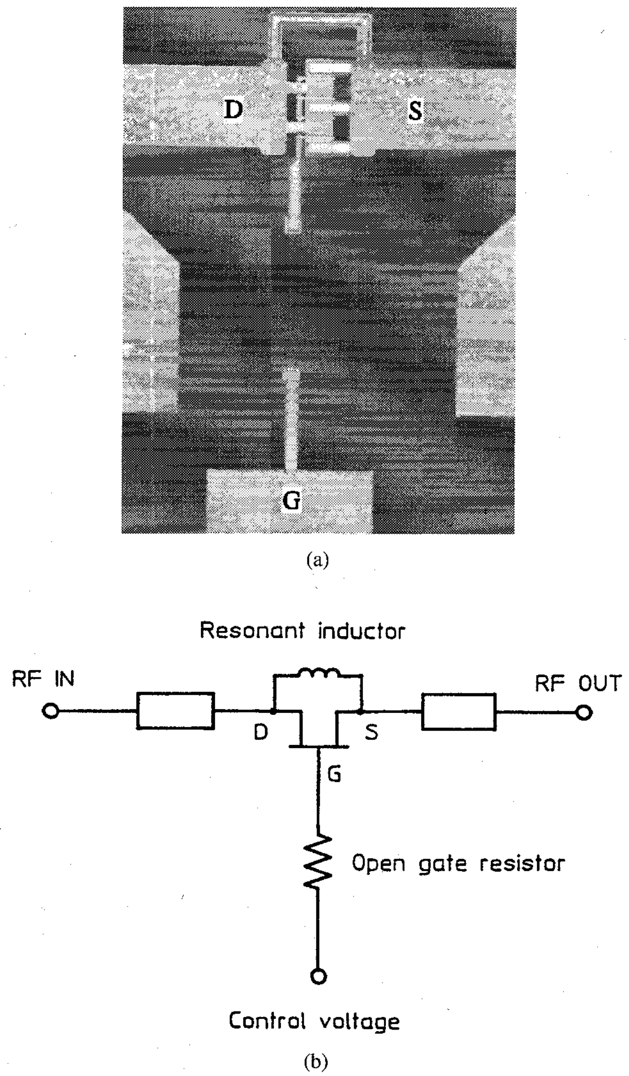

Fig. 1. (a) Top view of the fabricated SPST switch and (b) equivalent circuit.

TABLE I
INSERTION LOSS AND ISOLATION AT 94 GHz OF THE FABRICATED SPST SWITCHES

Gate length (μm)	Insertion loss (dB)			Isolation (dB)		
	MESFET	AlGaAs/GaAs HEMT	PM-HEMT	MESFET	AlGaAs/GaAs HEMT	PM-HEMT
0.4	1.98	1.76	——	21.3	13.5	——
0.8	2.02	2.19	1.6	14	19.5	22.5
1.2	2.4	2.4	2.0	14	22	23

shows the frequency response of 0.8 μm-gate length GaAs MESFET and PM-HEMT switches. As can be seen in the figure, an isolation over 20 dB is obtained for both switches at each resonant frequencies.

The comparison of R_{on}, C_{off}, breakdown voltage between source and drain (V_{br}) and device quality factor Q defined by $1/(\omega C_{\text{off}} R_{\text{on}})$ at 94 GHz for three types of switches are shown in Table II. R_{on} and C_{off} were determined with the fitting to

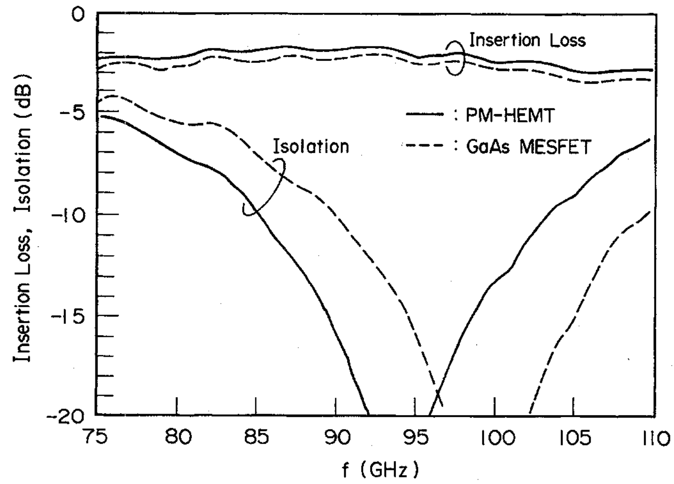

Fig. 2. Frequency response of 0.8-μm gate length GaAs MESFET and PM-HEMT switches.

TABLE II
COMPARISON OF THE DEVICE PARAMETERS. V_{br} IS MEASURED AT DRAIN CURRENT (I_{ds}) OF 0.1 mA/mm

	MESFET	AlGaAs/GaAs HEMT	PM-HEMT
Ron (Ω)	31.6	24.4	20.0
Coff (pF)	0.019	0.023	0.026
Vbr (V)	10.8	5.6	2.7
Q	2.82	3.02	3.26

the measured S-parameters. PM-HEMT gives the lowest R_{on} while it shows the highest C_{off}. Although PM-HEMT shows the highest Q-value, it is inferior in the V_{br} to other devices.

V. CONCLUSION

Three types of SPST transistor switches are fabricated, and their performances at W-band are compared. It is found that the PM-HEMT switch gives the best performances, although it is inferior in the breakdown voltage and hence power handling capability. The insertion loss of 1.6 dB with an isolation of 22.5 dB has been obtained at W-band. The obtained performances seem to open the key for the fabrication of amplifier/switch combined MMIC's for various radar systems.

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