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Substrate material effect on the RF MEMS Capacitive type shunt switch

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***Abstract* — The Radio Frequency Micro-Electro-Mechanical Systems (RF-MEMS) becomes, nowadays, a promising component widely used in microwave applications where its effectiveness can be improved by a proper choice of the substrate materials. In this work, simulations of RF-MEMS capacitive design behavior is presented and performed for different semi conductor material of substrates. Scattering parameters and current density are obtained, for a frequency range of 1-40 GHz, by the radio frequency simulator Ansoft, High Frequency Structure Simulator (HFSS), based on the finite element method. As a result, a comparative study between silicon, gallinium arsenide and silicon carbon substrates is established. The obtained results confirm that the silicon carbon exhibit better performances as compared to the other materials in terms of return loss, insertion loss and current density distribution in the ON/OFF states of the RF MEMS.**

***Keywords*— RF MEMS capacitive, Silicon, Silicon carbide and Gallium arsenide.**

I. INTRODUCTION

Many industrial and telecommunication applications demand high frequency (HF) systems and their electronic applications are in constant development especially in the frequency band between 300MHz and 300GHz [1]. This necessity of the HF system requires a permanent development of their radio frequency (RF) components with respect to their size and their effectiveness.

In recent years, MEMS switches are used in a variety of RF applications phase shifters, resonators, filters, and amplifiers [2]. In [3], it has been shown that RF MEMS switches have lower insertion loss and better linearity versus the PIN diodes and FETs. In addition, the good insulation over a wide frequency band, make the RF MEMS privileged for low loss applications such as attenuators, filters, phase shifters and RF switch. In the literature, these micro-actuators can implement various operating principles such as electrostatic [4], piezoelectric [5] electromagnetic [6], electrothermal [7] thermopneumatic [8], electrochemical [9], memory form [10]. As a conclusion, the RF MEMS switches present an alternative candidate to replace the conventional GaAs FET and p-i-n diode switches in RF and microwave communications systems. Indeed, the low insertion loss, the good isolation, the linear characteristic and the low power consumption permit a better feature management [11] [12]. Different substrates are used for fabrication the MEMS for example Silicon [13], GaAs [14] and Silicon carbide [15]. Comparative properties between Si, GaAs, 4H-SiC and GaN semi conductor devices are used in wireless power amplifier [16]. The power densities using Si, SiC and GaAs for RF MESFET are presented in [17]. In [18] a comparative simulation between Ge and sGe versus Si and sSi for the on-current improvements in support of nano-MOSFETs.

The presented paper falls in to three parts: in section II, it is treated the physical construction and the different characteristics for different materials; in section III, the modeling approach of the RF-MEMS is presented taking into account the substrate impedance; in section IV, the simulation results for the MEMS parameters, such as the return loss, the insertion loss and the current density at the ON-OFF states of the MEMS switch, are shown for different substrates and are discussed.

II. DESIGN RF MEMS CAPACITIVE

The proposed RF MEMS capacitive (metal, isolator, metal) is an active microwave component which is normally in the ON state. A shunt-capacitive MEMS switch consists of a thin metal membrane bridge suspended over the center conductor of a coplanar waveguide (CPW).

Figure 1 shows that the RF MEMS capacitive contains six parts:

- High substrate equal to 675µm with Si otherwise 4H-SiC or GaAs.
- SiO_2 layer equal to 1µm.
- Depth circuit metal equal to 1µm by copper.
- Dielectric equal to 0.5µm by Silicon Nitrade.
- SU-8 200.5 thickness equal to 3µm.
- Aluminum membrane 1µm.

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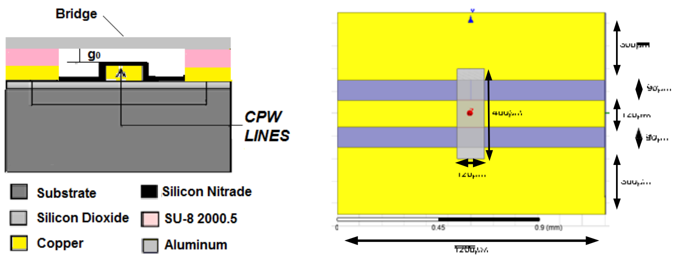


(a) (b)

Fig. 1. (a) Cross-sectional view, (b) Top view: Design RF MEMS

In table 1, the electrical characteristic (relative permittivity, relative permeability, dielectric loss and resistivity) for three different substrate materials for RF MEMS capacitive are presented.

TABLE I: Substrate material characteristics [16]

Substrate Type	Si	GaAs	SiC
Dielectric Constant	11.9	9.66	12.94
Relative permeability	1	1	1
Dielectric Loss	0.0025	0.003	0.006
Resistivity (KΩ-cm)	8.10^{10}	$1.\ 10^{3}$	1.10^{8}

III. Modeling RF MEMS Capacitive

Figure 2 present the RF MEMS capacitive model [19]. In this study, the used RF MEMS capacitive present a bandwidth between 1 GHz and 40 GHz. The proposed circuit model is arranged by tow CPW lines in parallel with a bridge.

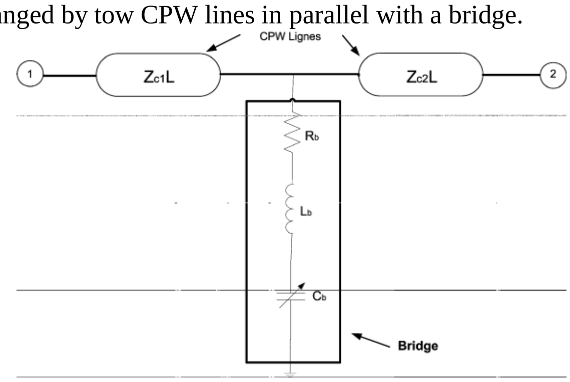


Fig. 2. Electrical Model of RF MEMS

The nature of the substrate has a major effect on the CPW line model. The characteristic impedance "Z_C", and the effective permittivity "ε_{eff}", are calculated by The ADS software using the LineCalc method of the CPW. Table 2 shows the obtained results for the different used semi-conductor substrate.

TABLE 2: Electrical characteristic for different substrates

Substrate Type	Si	GaAs	SiC
Zc (Ω)	53.038	58.33	51.026
ε_{eff}	6.37	5.26	6.847

The bridge is set with Resistor (R_b), inductor (L_b) and capacitor (C_b). These parameters are independent of the substrate. The proposed RF MEMS has a variable capacitive component, with $Z_b = R_b + jX_b$ and $X_b = L_b\omega + 1/C_b\omega$. The capacitor parameter range is given by equation (1) [19].

$$C_b = \begin{cases} C_{down} = \dfrac{\varepsilon_0 \varepsilon_r A}{th} \\ C_{up} = \dfrac{\varepsilon_0 A}{g_0 + \dfrac{th}{\varepsilon_r}} \end{cases} \quad (1)$$

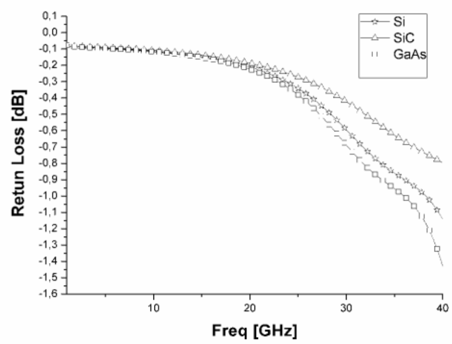
IV. Simulation Result

All simulations in this paper are performed on DELL Precision T3610 Intel(R), Xeon, CPU E5-1620v2, @3.70 GHz and 16GB of RAM.

In this study, a comparative simulation result for RF MEMS is obtained using the HFSS parametric optimizer at OFF and ON states. Return Loss, Insertion Loss and current density are compared in the two states. At the Bridge position g= 0µm, the RF MEMS is at OFF state and for g= 3µm, the RF MEMS is at ON state.

A. Comparative study for Return Loss

The obtained Return Loss results of the capacitive switch from the finite element EM simulator is presented in figure 3. In fig.3 (a), the component in down-state is shown. The return losses of the different substrates for frequencies lower than 20 GHz exhibit similar behavior with a constant level of 0.1dB. For upper frequencies than 20 GHz, the return loss parameter for SiC is comprise among 0.1 and 0.8dB, against for the Si this parameter is include between 0.1 and 1.1 dB, for the GaAs the parameter rang is 0.1 and 1.6dB. Fig.3 (b) the component is in up-state, the SiC present the advantage of the return loss compared to the Si and GaAs material.



(a)

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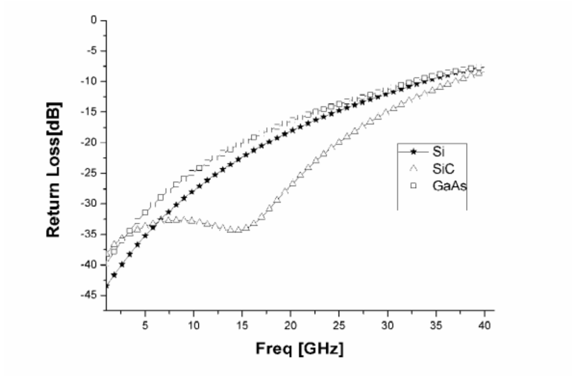
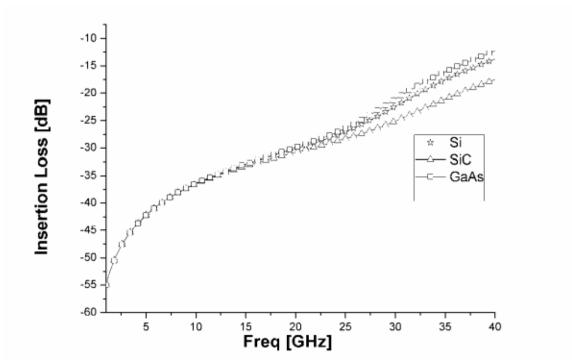


(b)

Fig. 3. Return Loss for different substrates (a) in the OFF state, (b) in the ON state.

B. Comparative study for Insertion Loss

The insertion Loss results of the different substrates are shown for OFF state and ON state in the figure 4.(a) and 4.(b) respectively. The insertion losses lower than 20 GHz are similar for the three substrates. For upper frequencies, the insertion loss parameter in down state and up state for SiC is better than Si and GaAs semi-conductor material.



(a)

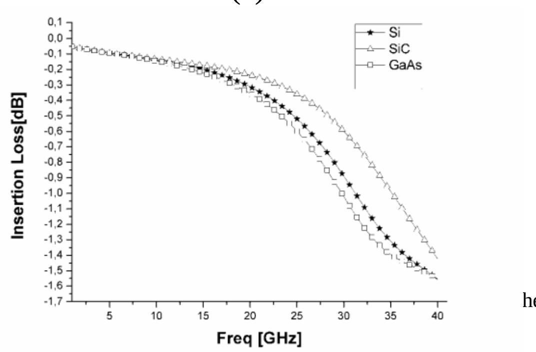


Fig. 4. In he

C. Comparative study for density current

Surface current distribution of RF-MEMS component is plotted in figure 6 and figure7 for different substrates (Si, GaAs and SiC) versus various frequencies (4, 10, 18 and 30GHz). The current density is contrasted between the red color for the high level and the blue color for the low. Figure 6 shows the current density in OFF state. The current density in the off state is more important of the SiC than Si and GaAs. The leakage current is higher for the GaAs than Si and SiC. Therefore the SiC presents the best insulation parameter for different simulation condition.

Figure 7 shows the current density in ON state (g=3µm). The current density is proportional of the frequency. The current density is better for the SiC than Si and GaAs for various frequencies.

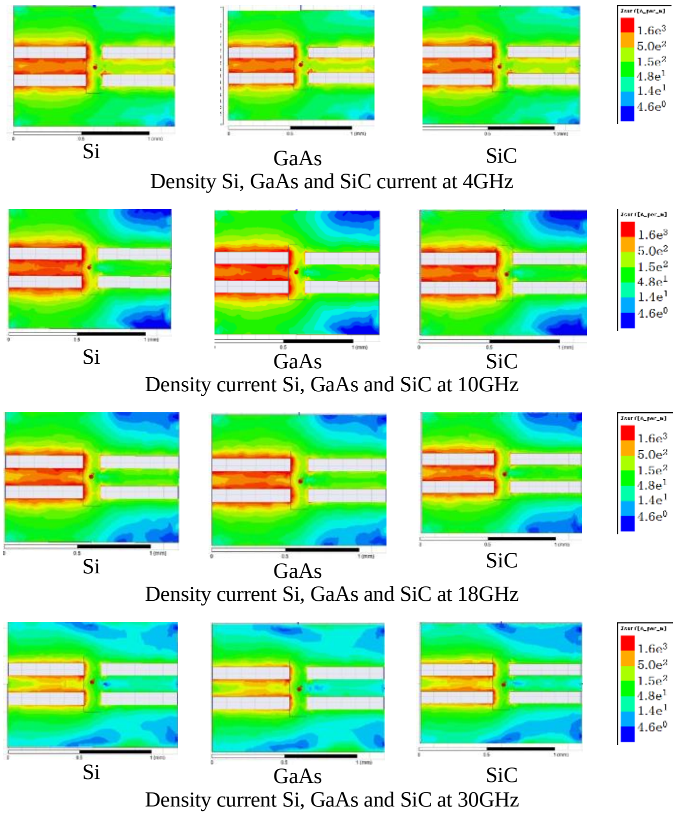
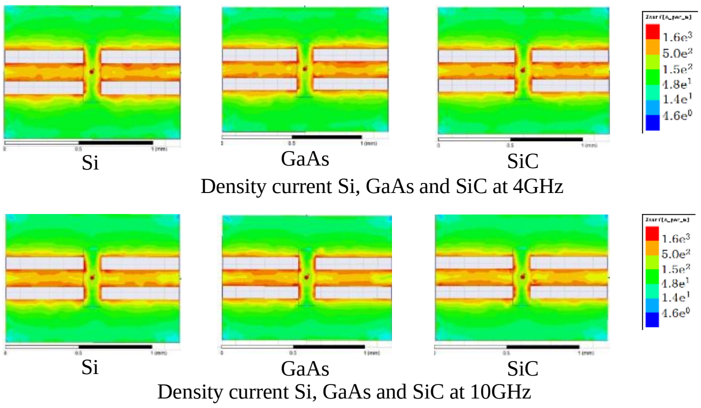


Fig. 6. Current density in the OFF state for different substrates and different frequency



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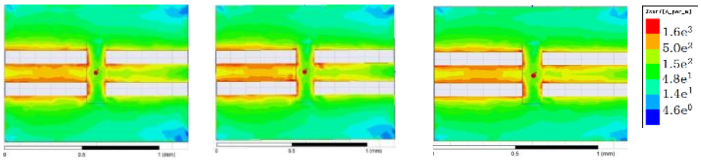
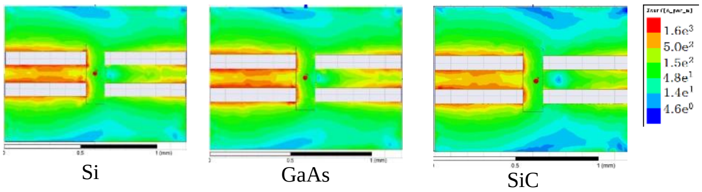


Si GaAs SiC

Density current Si, GaAs and SiC at 18GHz



Si GaAs SiC

Density current Si, GaAs and SiC at 30GHz

Fig. 7.Current density in the ON state for different substrates and different frequency

V. CONCLUSIONS

In this paper we have demonstrated that the semi-conductor material for the RF MEMS component is important in the behavior of its effectiveness. The current density is directly proportional to the frequencies.

Comparison simulation results show that the SiC substrate is more important than Si and GaAs. Furthermore, the Silicon Carbide has a good return loss, insertion loss and current density in the RF MEMS design application.

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