Design and Implementation of Stoppers to Capacitive RF MEMS Switch For Low Frequency Applications

Bandlamoodi Sravani

Abstract*: *This work presents the fixed-fixed type capacitive RF MEMS switch. The device additionally includes nonuniform meanders which can reduce the actuation voltage of the device. The switch accomplishes 0.5-1.5µN of applied force for actuation voltages of 6.9-7.9 V. The simulated and calculated spring steady is 1.49N/m to evaluate the actuation voltage the concept of stoppers is introduced in this work. Incorporating stoppers and meanders to the proposed device is to improve the RF performance. The proposed switch produces perfect electromagnetic behavior low insertion and high isolation with the addition of stoppers at the thickness of 1.2µm for 3µm air gap and aluminum nitride as dielectric layer followed by silicon nitride, silicon dioxide and Kapton polyimide in the device. The switch performance undergoes two conditions here with the addition and without inclusion of the stoppers. The RF Performance of the device with the stoppers, are lower insertion, better return losses and higher isolation are -0.07dB, -82 dB, -69dB at the 8- 8.1GHz frequency having Al3N4 as dielectric film followed by Si3N4 as-0.06dB, -77dB and -71dB then SiO2 as-0.06dB,-87dB, -71dB finally, Kapton polyimide as -0.06dB, -77dB,-76dB at 8- 8.5Ghz frequency. The S-parameter analysis like isolation, return loss and insertion loss are carried using FDTD tool CST which gives good performance.

Keywords* : *shunt switch, pill-in voltage, spring constant

I. INTRODUCTION

RF MEMS switches are a substitute option in contrast to semiconductor switches employed in the wireless and satellite communication applications (Rebeiz G M et al. 2001, Peroulis et al. 2003).Most relevant studies have proved that MEMS switches have numerous characteristics like lower insertion loss, near to lesser power consumption, higher isolation. Especially switches are owing to the excellent electromechanical and electromagnetic performance (Sharma et al. 2007). From the literature it is observed that low-actuation voltage (Pacheco et al. 2000) is significant for MEMS switches to attain a major lifetime. On the other hand, very low-voltage MEMS device can experience the effects of stiction (Van Spengen et al. 2002) because of low-mechanical restoring force. The dielectric layer is a crucial element of a capacitive switch that helps in accomplishing high capacitance ratio during switch on and off positions. Higher the capacitance ratio enhances the figure-of-merit (FOM). Along these lines, to overcome the effect of dielectric charging due to high actuation voltage and other mechanical and environmental issues and to upgrade the lifetime of a device, low actuation voltage is an absolute necessity. In view of the reported works, we note that the reliability (Huang et al. 2012) of MEMS switches relies on various factors, dielectric charging (Yuan et al. 2004) (because of the existence of dielectric layer), buckling effect (Park S 2007) , temperature sensitivity (Goldsmith et al. 2005)and Stiction phenomenon (Mercado et al. 2003) (because of stress) is one of them, that confine their commercial deployment. The above-mentioned characteristics influencing the device performance can be eliminated by the integrating stoppers into the switch. According the literature study device consists of nonuniform meanders along with perforations (Anil kumar et al. 2015) reduce the operating voltage. To acknowledge the robust RF MEMS switches, geometry is significant (Rebeiz G M 2004). The switch must perform many switching cycles in a controlled manner before it fails because of different electromechanical reasons. Related to environmental conditions, capillary action due to high humidity can cause stiction in MEMS switches. Material consideration can optimize the better performance of the switch. For attaining higher switching speeds, lower losses proper selection of materials is also important for the proposed switch (Ashish kumar et al. 2007).In the present work, we report the new capacitive-type RF MEMS switch with nonuniform meanders and Stoppers. The comparative analysis of the proposed device with and without addition of the stoppers is observed. Thus, four dielectrics are considered for the oxide layer such as Aluminum nitride, silicon nitride, Kapton Polyamide and silicon dioxide materials is considered. Therefore, the reliability of the device increases with minimum stiction losses. We first model the conductivity of the gold layer in the up-and downstate position having stoppers at that point study the effect of this tuneable conductivity is on the scattering parameters of the switch. The Electromechanical and electromagnetic performance of the switch is executed using FEM tool and the CST EM solver. The proposed capacitive switch has improved RF performance when the stoppers are integrated to the device. The implementation of the proposed switch with and without incorporation of stoppers, the execution can be observed with the preceding sections. Section -II illustrates the design of the proposed device with nonuniform meandered switch.

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Section-III outlines the electromechanical and electromagnetic features of the proposed switch. Section IV is ultimately summarized in the conclusion.

II. DESIGN OF THE RF MEMS SWITCH METHODOLOGY

The top perspective of the proposed device is displayed in Fig.1. is normally in the ON state. The beam is hanging above the coplanar waveguide (CPW). The switch structure comprises of two grounds and the signal line lies on the single plane. The nature of the substrate has a significant effect on the CPW. The dielectric layer presented over the dielectric influence the switching behaviour and reliability. The bridge layer holds on the ground to avoid the interference. The bridge layer consists of a gold material with nonuniform type meanders on both sides of the device. Variation in the dielectric layer thickness may vary the resonant frequency of the device in the OFF state. the dielectric layer and its thickness are significant for the switch design. The initial stress effect is introduced by concerning actuating voltage, it needs spring restoring force to retain beam back to its rest. Establishing stoppers does not disturb the of the device behaviour and execution, it improves the performance. The developed initial stress improves the stiffness. The cross-section perspective of the stopper along with meanders are observed in Fig. 2.and 3.

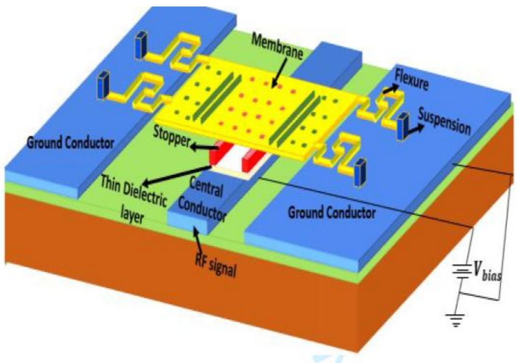

Fig. 1.The top perspective of the proposed nonuniform meander switch

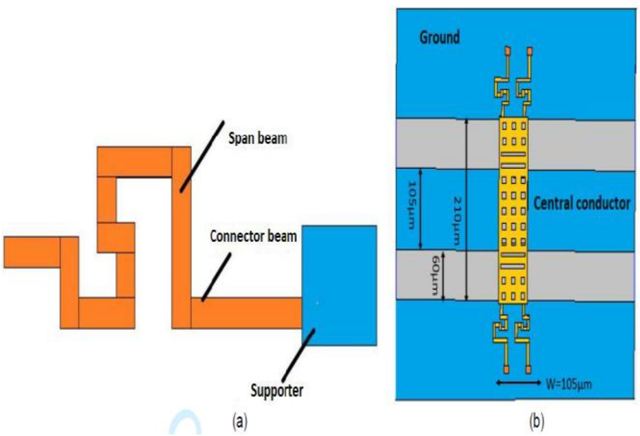

Fig. 2&3. The close view of the non-uniform zig-zag meanders of the proposed switch

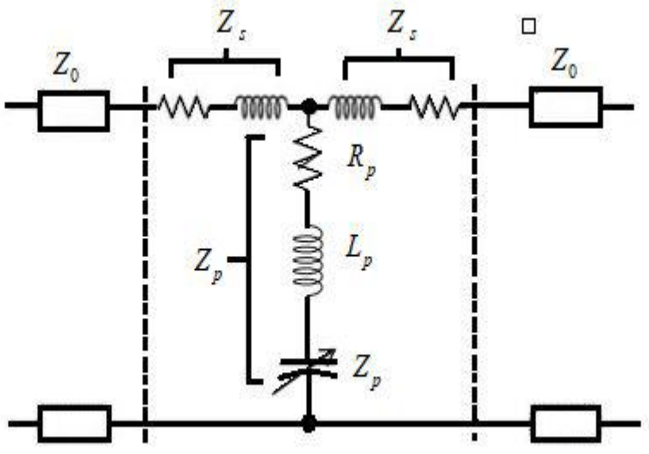

Fig. 4. Equivalent circuit model of proposed RF MEMS switch

The equivalent circuit model for the gold-based RF MEMS switch is made and the outcomes are contrasted with the 3-D electromagnetic solver is observed in fig-4. From Fig.2.addition of stoppers does not disturb the actuation voltage of the device. Without changing the actuation voltage, it increases the spring restoring force. The beam displaces up to the 2/3 portion, stiction effect is reduced. The reliability in terms of lifecycle is increased. The devices resonate at 8GHz frequency, by the addition stoppers it does not deviate from the existing frequency range. It improve the performance in terms of decibels In the OFF state the resonant frequency is completely determined by the and L with an increase in the air gap height up state d C capacitance decreases there by decreasing the reflected power from the switch. (Hanan el al. 2007, Patel et al. 2011). A thin dielectric layer (td =0.3μm) over the signal line is considered to accomplish a high capacitance proportion of the switch. A high-K dielectric Al3N4 is picked as a material for the dielectric layer compared to other three dielectric films asSi3N4, Sio2 and Kapton polyimide, for two principle reasons. Initially, High-K dielectrics are used to reduce impurity scattering, Second, its higher dielectric constant (Ɛr = 7.6), lead to a superior switch execution at high frequency.

TABLE I: The Geometry Specifications Of The Proposed Device

Parameter	Dimension	Material
Beam length	320μm	Gold
Supporter length	10 μm	Aluminum
Beam thickness	1.3 μm	Gold
Width of the signal line	60 μm	Aluminum
Thickness of the CPW	2 μm	Aluminum
Dielectric layer height	0.3 μm	Al3N4,Si3N4, Sio2, Kaptonpolyimide
Hole size	8*8 μm	

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RF gap	2.-3µm	
Height of the stoppers	1-1.5 µm	Polyimide
Dielectric constant of substrate	11.9	Silicon
Dielectric constant of stopper	3.48	Polyimide

III. RESULTS AND SIMULATIONS

A. Electromagnetic performance

Isolation loss:

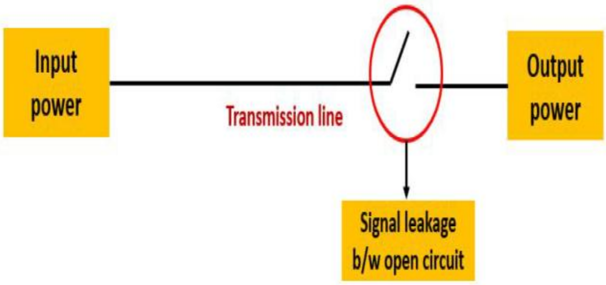


Fig. 5. The proposed device as two port network

From the figure isolation loss was stated as the amount of power leakage occur in the system when the device is in off state. It was calculated using the below equation

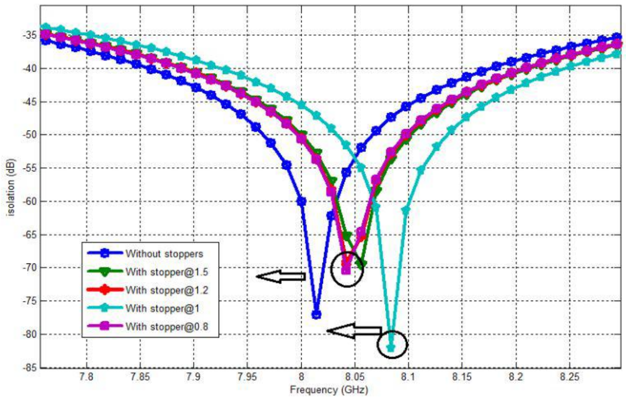


Fig. 6. Isolation performance of the proposed device with AL3N4 as dielectric film with and without stoppers in OFF state.

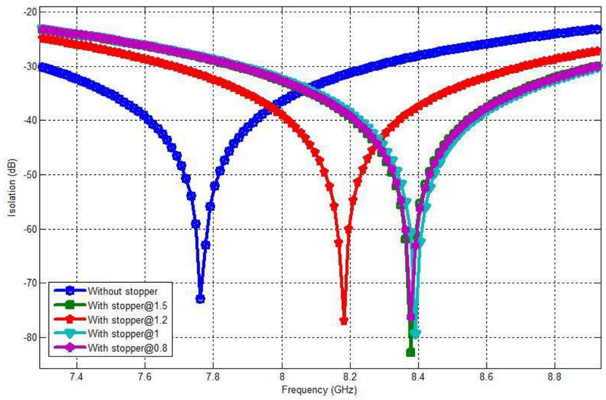


Fig. 7. Isolation performance of the proposed device with Si3N4 as dielectric film with and without stoppers in OFF state.

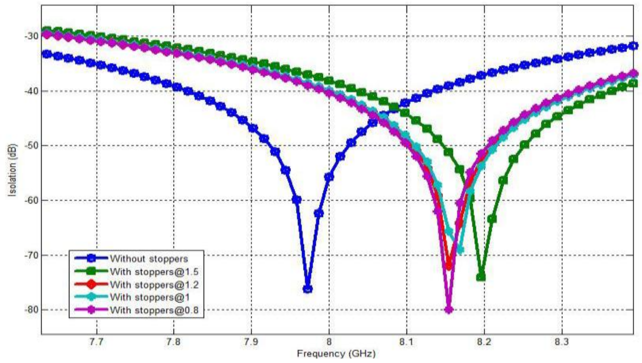


Fig. 8. Isolation performance of the proposed device with Sio2 as dielectric film with and without stoppers in OFF state.

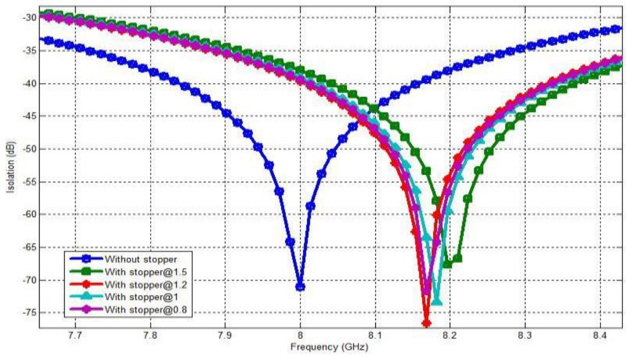


Fig. 9. Isolation performance of the proposed device

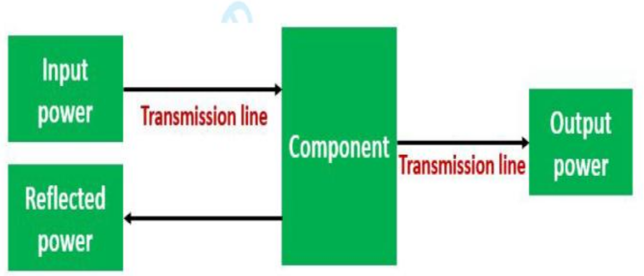
The electromagnetic performance of the device is observed in Table-IV. From the above figures 6-9 it was observed that the device having aluminum nitride as the dielectric layer with 0.3µm thickness showing high performance value -82dB, -77 with and without implementation of stoppers with the acceptable frequency range 8.05GHz followed by silicon nitride, silicon dioxide and Kapton polyimide. While we considering isolation loss parameter, down state capacitance value was considered which can also having the effect of fringing field capacitance along with inductance and resistance value. Aluminum nitride having high dielectric constant value, high electrical resistivity and high thermal conductivity which leads to the decrease of hold down voltage value, avoids the dielectric charging and improves the stability of the device. Aluminum nitride can withstand high amount of temperature value which improves the lifetime of the switch.

TABLE II

The mechanical properties of dielectric films

Material information for the proposed design	Aluminum nitride	Silicon nitride	Silicon dioxide	Kapton polyimide
Dielectric constant	9.14	7	3.7	3.46
Electrical resistivity	1.4*10^14	2*10^14	1*10^13	1*10^12

Return loss:



From the Fig.10 return loss states that the amount of power reflected where there is an insertion of any component in between the transmission line. It was calculated using the below equation.

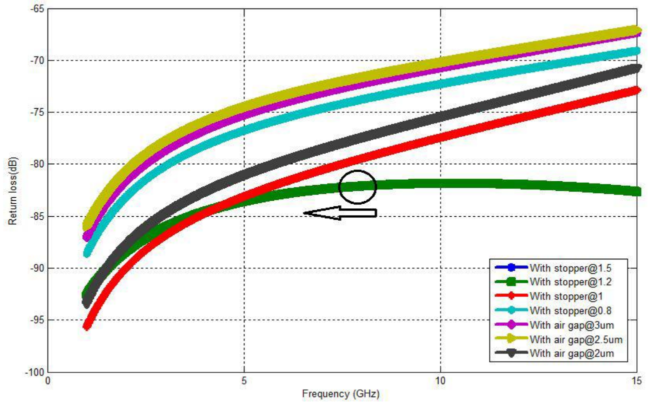


Fig. 11. The return loss of the proposed device with and without stoppers considering Al3N4 as dielectric film in ON state

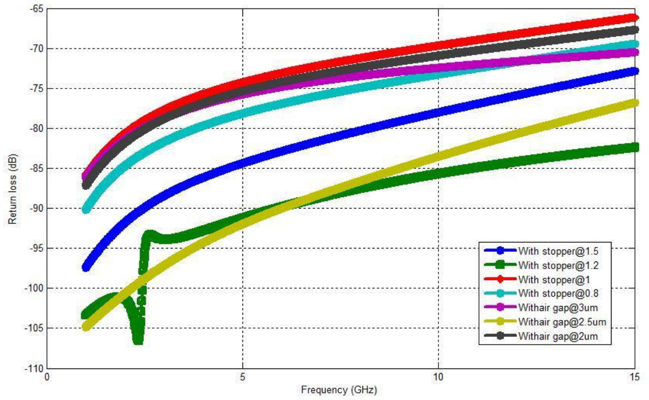


Fig. 12. The return loss of the proposed device with and without stoppers considering Si3N4 as dielectric film in ON

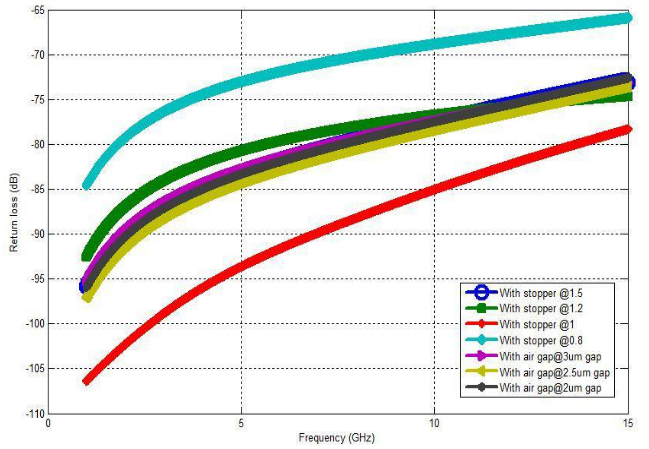


Fig. 13. The return loss of the proposed device with and without stoppers considering Sio2 as dielectric film in ON state

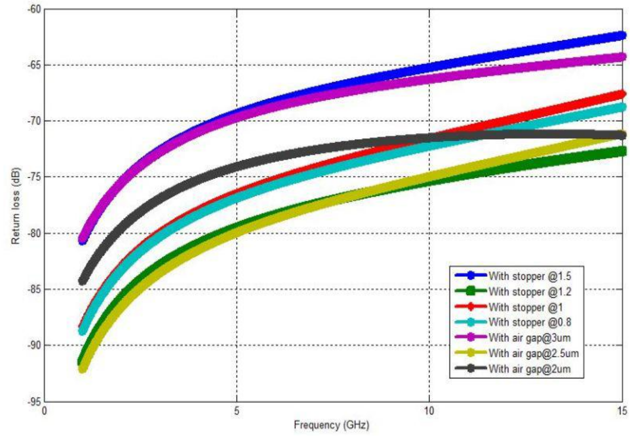


Fig. 14. The return loss of the proposed device with and without stoppers considering Al3N4 as dielectric film in ON state

From the above figures it was observed that the device having aluminum nitride as the dielectric layer with 0.3µm thickness showing better return loss value -82dB,-71dB with and without implementation of stoppers and having Al3N4 as dielectric layer with the acceptable frequency range 8GHz followed by silicon nitride, silicon dioxide and Kapton polyimide. While we considering return loss, up state capacitance value was considered which does not have the effect of fringing field capacitance along with inductance and resistance value. Aluminum nitride having high dielectric constant value which helps to produce better return loss value to the device.

Insertion loss:

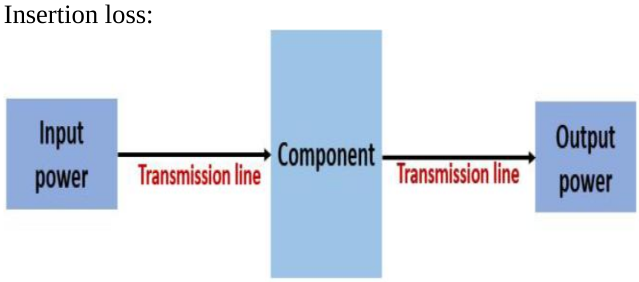


Fig. 15. The description of the insertion loss as a two port network

From the figure insertion loss was stated as the amount of power leakage occur in the system when any component is placed in between the transmission line. It was calculated using the below equation.

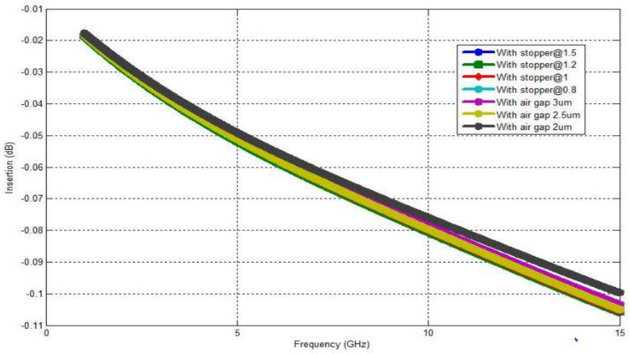


Fig. 16. The insertion loss of the proposed device along with and without stoppers considering Aluminum nitride as dielectric film

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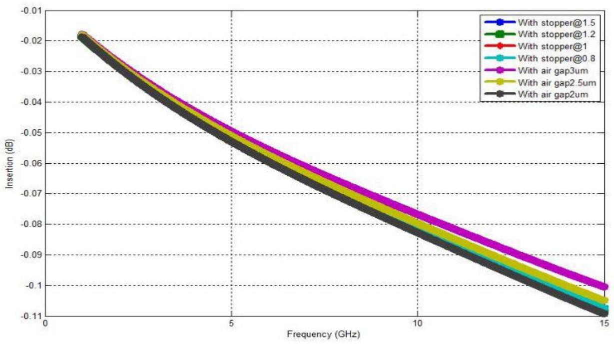

Fig. 17. The insertion loss of the proposed device along with and without stoppers considering Silicon nitride as dielectric

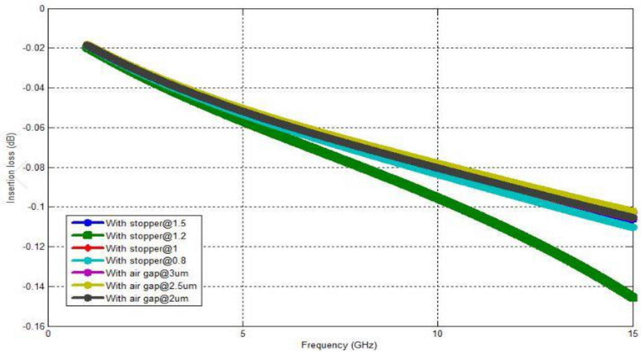

Fig. 18. The insertion loss of the proposed device along with and without stoppers considering Silicon dioxide as dielectric film

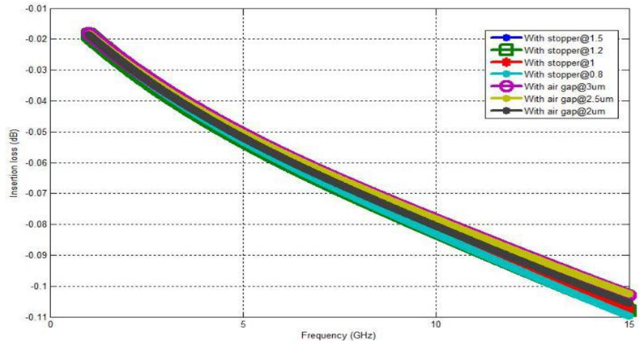

Fig. 19. The insertion loss of the proposed device along with and without stoppers considering Kapton polymide

IV. CONCLUSION

Our outcomes demonstrate that Al3N4 can be a good candidate as a dielectric film for the RF MEMS switches in applications where low actuation voltage and fast switching speed are required. The conductivity of the thin film is precisely displayed in the all-over UP state and Down state of the switch by considering the impact ofAl3N4. The relative analysis is carried out for the nonuniform meander switch with and without stoppers in between the electrodes is shown in the contemporary work. The height of the stoppers is a major concern, it should be the half of the distance between the bridge and the signal line. The electromechanical and electromagnetic study of the MEMS switch is performed to justify the behaviour of the switch. The contrast of the switch with regards to stoppers is clearly explained with necessary graphs and tables. The stiffness state is observed when the initial stress effect is introduced with lower actuation voltage. Developing stoppers into the switch does not affect the actuation voltage of the switch. The investigation on s-parameters of the nonuniform meander switch is carried out corresponding to isolation, return and insertion loss. The actuation in the resonating frequency does not change, but it differs with performance. The device with stoppers having thickness of 1.2µm for an air gap of 3µm and considering Al3N4 as dielectric layer exhibit good performance compared to the rest of the three dielectric layers.

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