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MEMS switch with an intermediate electrode for high-speed communication networks

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Abstract. MEMS switches are considered as a promising element base of microwave electronics, but their performance has not reached the required level yet. The ratio of capacitances in the closed and open states does not exceed 10 and has to be increased. A possible method is to apply an intermediate electrode over the dielectric coating of a transmission line. In this work, a MEMS switch with an intermediate electrode is proposed for use in 5G communication networks.

Keywords: MEMS switch, intermediate electrode, capacitance ratio, isolation, insertion loss, finite element method

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МЭМС-переключатель с дополнительным электродом для систем высокоскоростной связи

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Аннотация. МЭМС-переключатели рассматриваются в качестве основы перспективной элементной базы СВЧ-электроники, но к настоящему времени их характеристики не достигли нужного уровня. Отношение емкостей в разомкнутом и замкнутом состояниях не превышает 10 и требует увеличения. Один из способов заключается в нанесении дополнительного электрода на диэлектрическое покрытие линии передач. В настоящей работе представлен МЭМС-переключатель с дополнительным электродом, предназначенный для работы в сетях связи 5G.

Ключевые слова: МЭМС-переключатель, дополнительный электрод, отношение емкостей, изоляция, вносимые потери, метод конечных элементов

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Introduction

Development of 5G high-speed communication networks with frequency ranges of 3.4–3.8 and 4.4–4.99 GHz requires advanced electronic components for switching microwave signals. Widely used semiconductor switches are fast and reliable due to the absence of movable mechanical structures, but suffer from high signal loss and power consumption. Alternative switches are fabricated using microelectromechanical systems (MEMS) technology. These are miniature electromechanical relays that operate on an electrostatic principle. MEMS switches provide low insertion loss and high isolation combined with low power consumption and short switching time.

The important parameter of a MEMS switch with a capacitive contact is the ratio of capacitances in the closed and open states. This value usually does not exceed 10 [1–3] and does not provide the required switching effect. The capacitance ratio can be improved by applying an intermediate electrode on top of the dielectric. In this case, the capacitance ratio can be varied widely by changing the size of the intermediate electrode and the dielectric layer material. This work is devoted to the investigation of the working characteristics of a switch with an intermediate electrode designed for the frequency range of 3.4–4.99 GHz.

Materials and Methods

The MEMS switch is schematically shown in Fig. 1, *a*. A movable electrode is an aluminum cantilever with a length of 50 μm attached to a grounded conductor of a coplanar waveguide. A signal conductor with width w_l = 150 μm passes under the cantilever at a distance of 1 μm. A 50 nm thick dielectric layer and 100 nm thick intermediate electrode of ruthenium are formed on the signal conductor. When the cantilever is located horizontally (Fig. 1, *b*), the switch is open. The capacitance C_{up} between the signal and the grounded conductor is small, so the signal goes through the transmission line with minimal loss. When a voltage is applied to the driving electrode, the switch is closed. The cantilever bends under the electrostatic force and touches the intermediate electrode. The capacitance between the signal and the grounded conductor increased significantly due to the high capacitance C_{down} between the signal conductor and the intermediate electrode. This capacitance shunts the signal conductor and blocks the signal path. A necessary condition is low contact resistance between the cantilever and the electrode.

The capacitance ratio can be estimated using an expression [4]:

$$\frac{C_{down}}{C_{up}} = \varepsilon \frac{l_e w_l}{S} \frac{g - t_d - t_e}{t_d}, \tag{1}$$

where ε is the dielectric constant of the material between the intermediate electrode and the signal conductor, l_e is the length of the intermediate electrode, S = 179 μm^2 is the overlap area between the cantilever and the electrode, g = 1 μm is the air gap between the cantilever and the signal conductor, t_d = 50 nm and t_e = 100 nm are the thicknesses of the dielectric and the electrode, respectively. For ε ~ 10 and l_e ~ 100 μm the capacitance ratio is 10^4. This estimate is three orders of magnitude higher than the C_{down}/C_{up} of conventional switches.

The passage of a signal in two states of the switch can be estimated by a single parameter S_{21}:

$$S_{21} = 20 \cdot \log_{10}\left(\left|\frac{2Z}{Z_0 + 2Z}\right|\right), \tag{2}$$

$$Z = R + j\left(\omega L - \frac{1}{\omega C}\right), \tag{3}$$

where Z_0 = 50 Ohm is the characteristic impedance, Z is the series impedance, ω is the frequency of the switched signal, R, L, C are the resistance, inductance and capacitance of the switch. In the open state, S_{21} has a minimal value with a capacitance C_{up}, and a maximum value in the closed state with a capacitance C_{down}. However, formulas (1)–(3) use ideal capacitance between cantilever and the signal line. The real switch uses a capacitance between the grounded and the signal conductors, which includes a parasitic component. Parasitic capacitance increases total C, and therefore we have a larger signal loss and lower capacitance ratio. It is impossible to account for all parasitic relationships analytically. Precise calculation is performed by the finite element method. It simulates an actual chip design and takes into account parasitic capacitances.

The model includes a sapphire substrate with an area of 1.7×1.6 mm^2 and a thickness of 460 μm, on which a coplanar waveguide is formed (Fig. 1, *c*). The conductors consist of ruthenium and an aluminum layers with a thickness of 0.1 and 3 μm, respectively. The cantilever is placed in the central area of the chip, while the driving electrode is connected to a contact pad on the periphery. To reduce the calculation time, the bending of the cantilever under electrostatic force is not considered. The change of the switch state is simulated by varying the height of contact bumps of the cantilever.

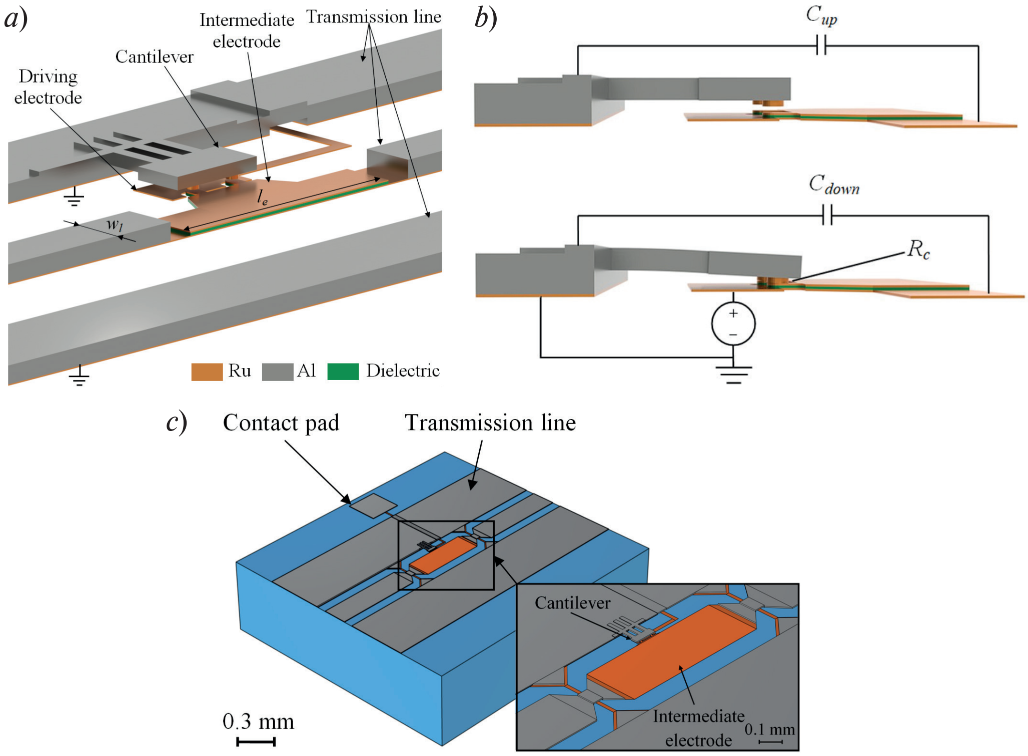

Fig. 1. MEMS switch with an intermediate electrode: general view (*a*); open and closed states (*b*); a model of the chip (*c*)

Results and Discussion

Switch performance is optimized by varying the length of the intermediate electrode and the material of the dielectric layer. The initial parameters are l_e = 400 μm and ε = 3.9 (for SiO_2). The radio frequency characteristics of a switch with these parameters are shown in Fig. 2, *a*. Acceptable insertion loss below 0.15 dB and isolation more than 20 dB are provided in the range of 1.3–4.8 GHz, which does not include an upper part of the target range. To shift the operating range upward, one has to increase the resonant frequency f_0, at which the isolation takes the maximum value. An increase of f_0 is achieved by reducing l_e, which reduces the capacitance C_{down}. The performance of the switch with an electrode length of 100 and 200 μm is shown in Fig. 2, *a*. The optimal value is l_e = 200 μm, which provides the working range of 2.1–5.7 GHz. The calculated C_{down} and C_{up} are 20.40 pF and 0.14 pF. The capacitance ratio of 146 is more than an order of magnitude higher than the typical value for switches without an intermediate electrode.

A further growth of the capacitance ratio is possible by use of dielectrics with higher ε. AlN, Si_3N_4, Al_2O_3, Ta_2O_5, HfO_2, TiO_2 and $SrTiO_3$ are considered as an alternative to SiO_2. The highest ratio of 6502 is provided by $SrTiO_3$ (ε = 120) [5]. Increasing ε has negligible effect on insertion loss, but significantly changes isolation, as shown in Fig. 2, *b*. The maximum isolation increases with ε, but the operating range shifts below the target frequencies. For the range of 3.4–4.99 GHz, SiO_2 remains the best material.

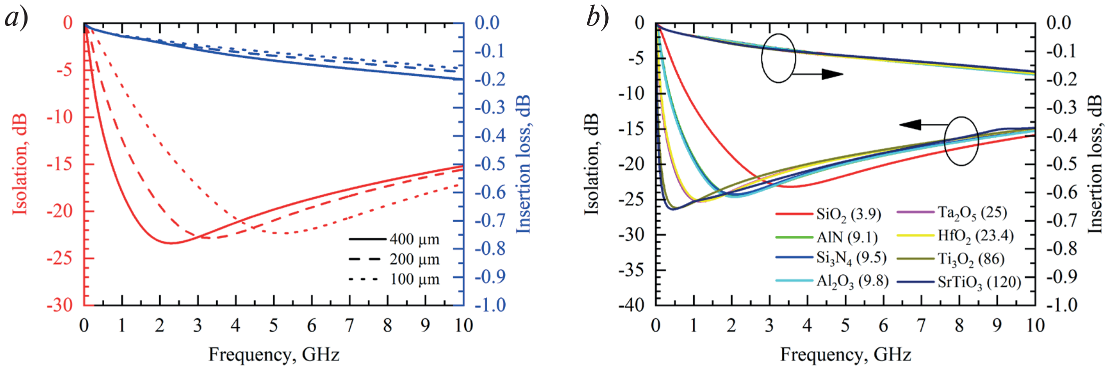

Fig. 2. The dependence of isolation and insertion loss on the signal frequency: for different lengths of the intermediate electrode (*a*); for different dielectrics at l_e = 200 μm (*b*). The values of ε are shown in brackets

Conclusion

The paper describes a MEMS switch with an intermediate electrode designed for 5G communication networks. The finite element method was used to calculate the capacitive characteristics, as well as isolation and insertion loss in the frequency range up to 10 GHz. A switch with an intermediate electrode length of 200 μm and a dielectric layer of SiO_2 provides a capacitance ratio of 146, which is more than an order of magnitude higher than that for switches without an intermediate electrode. Acceptable insertion loss of less than 0.15 dB and isolation higher than 20 dB are achieved in the range of 2.1–5.7 GHz, fully covering the operating frequencies of 5G communication networks.

REFERENCES

1. **Yang H.-H., Zareie H., Rebeiz G.M.,** A high power stress-gradient resilient RF MEMS capacitive switch, J. Microelectromech. 24 (2015) 599–607.

2. **Grichener A., Rebeiz G. M.,** High-reliability RF-MEMS switched capacitors with digital and analog tuning characteristics, IEEE transactions on microwave theory and techniques. 58 (10) (2010) 2692–2701.

3. **Zareie H., Rebeiz G. M.,** High-power RF MEMS switched capacitors using a thick metal process, IEEE transactions on microwave theory and techniques. 61 (1) (2012) 455–463.

4. **Morozov M.O., Uvarov I.V.,** Performance Calculation for a MEMS switch with a Floating Electrode, Russ. Microelectron. 52 (6) (2023) 493–503.

5. **Park J.Y., Kim G.H., Chung K.W., Bu J.U.,** Electroplated RF MEMS capacitive switches, Proceedings IEEE Thirteenth Annual International Conference on Micro Electro Mechanical Systems (Cat. No. 00CH36308). (2000) 639–644.

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