RF MEMS MODULATOR SIMULATION

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I. INTRODUCTION

At present the RF MEMS switch is a common microsystem used in various high frequency devices. The design of such systems must provide for millions of load/unload cycles [1-3]. The stress-strain analysis is a convenient technique used for plasticity and fatigue prediction. These effects may occur during electrostatic actuation and will negatively influence the actuator lifetime. To calculate the parameters of such electromechanical systems both analytical [4, 5] and numerical methods are used, in particular, the finite element method (FEM) [6, 7], the latter is preferable in this case though resource-intensive. Moreover, FEM permits simulating actuation process resulting in full stress-strain state to predict its lifetime. Power consumption is a significant problem for the MEMS switch design, it depends on the actuation voltage, which should be minimal [7, 8]. Hence, it results in the study of very thin and flexible membranes (100-700 nm) [9]. Another problem in the switch design is heating, which in its turn requires the use of new materials in MEMS such as tungsten [10-12]. It increases device lifetime and reliability.

II. MODULATOR DESIGN AND MODELING STEPS

As a sample for simulation, a well-known switch design with a membrane on torsion beams was chosen [13-16] (Fig 1, Fig 2, table 1).

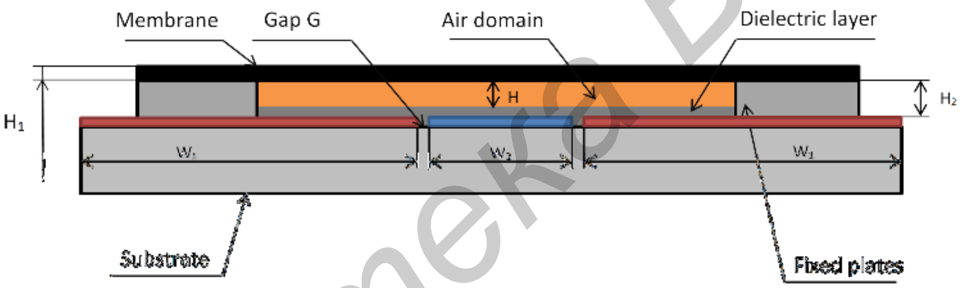


Figure 1 – Switch draft, side view. W1 – side (pull-down) electrode width, W2 - signal electrode (microstrip line) width, H – gap height, H1 – membrane thickness. H2 – fixed plates height, Gap – gap size between electrodes

Table 1 – Geometrical parameters of switch

Membrane and torsions thickness H1, nm	100, 400, 700	Membrane length L1, μm	600
Side (pull-down) electrode width W1, μm	290	Membrane width M1, um	100
Signal electrode (microstrip line) width W2, μm	120	Torsion bridge length M2, μm	300
Gap height H, μm	4	Dielectric layer thickness, μm	1000
Fixed plates height H2, μm	5	Gap between electrodes G, μm	80

RESULTS AND DISCUSSION

Modulator mode

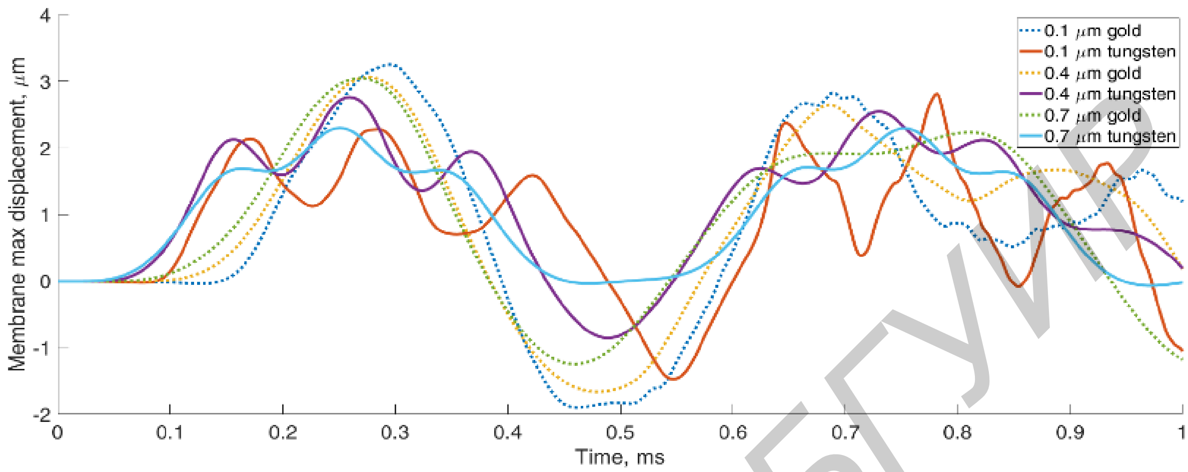
The main idea of RF modulator is to perform smooth RF signal AM modulation with the help of changing capacity due to membrane displacement. Bouncing effect could be used to increase modulation frequency.

The electrodes were fed with a sine wave signal with three characteristic frequencies - 1 kHz 0.1 kHz [3] and 5 Hz for modelling quasi-static working regime. The maximum displacement of the membrane was evaluated by the displacement of its geometric centre.

With the switching frequency of 1 kHz, a 100 nm thin membrane (both gold and tungsten) exhibits a bouncing effect (Figure 2a). Actuation force in this case also exhibits non-monotonous character (Fig. 3b), which is due to the nature of the membrane displacement.

With 100 Hz actuating frequency, golden membrane shows strongly periodical bouncing effect as well (Fig. 2, b) which may be the key feature of proposed RF modulator (fig. 4). Device would be able to switch its capacity for approximately 10% with frequency up to 4 kHz (actuation frequency in that case is only 1 kHz). Thus, using a simple pull-in beam, it is possible to perform modulation effect at the frequency 4 times higher than actuation.

Fig. 3 shows longitudinal median profiles of a membrane displacement at a different time. The figure shows that at the initial time point (up to 0.067 ms inclusively) only those parts of the membrane bend which are close to the actuating electrodes. Then the centre begins to move, as a result a "wave" passes through the membrane with a variable speed (Fig. 3 a,b). The wave almost disappears with the increase of the membrane thickness to 700 nm (Fig. 3, c).



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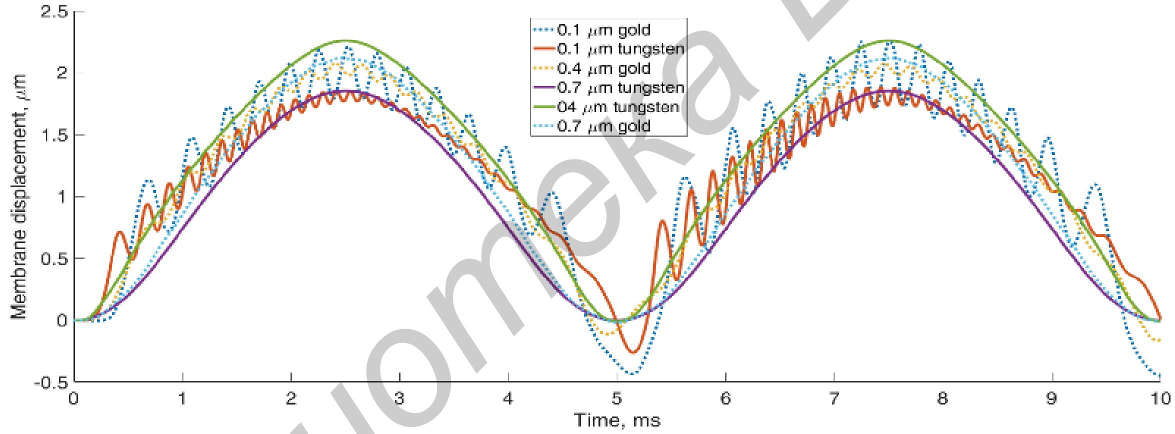

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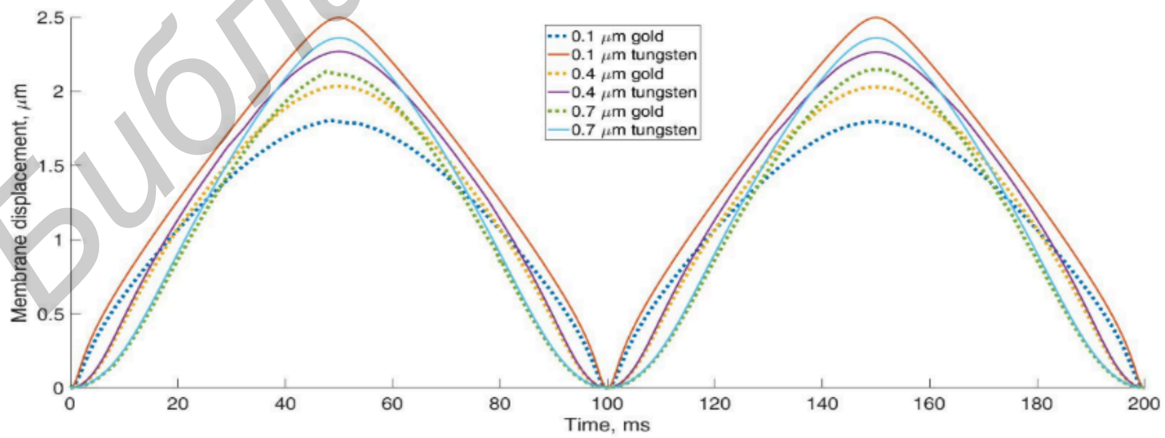

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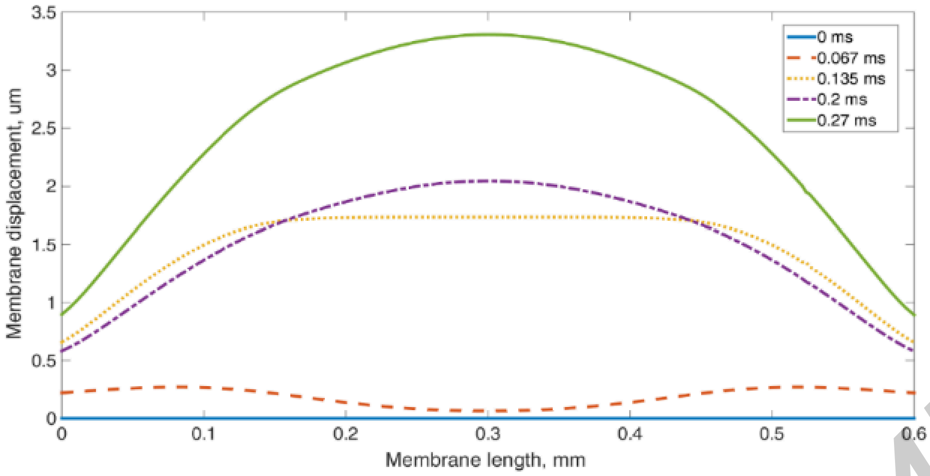
Figure 2 – Dynamic membrane performance. a) displacement of the center of membrane versus time and actuation voltage, 1 kHz b) 100 Hz c) 5 Hz



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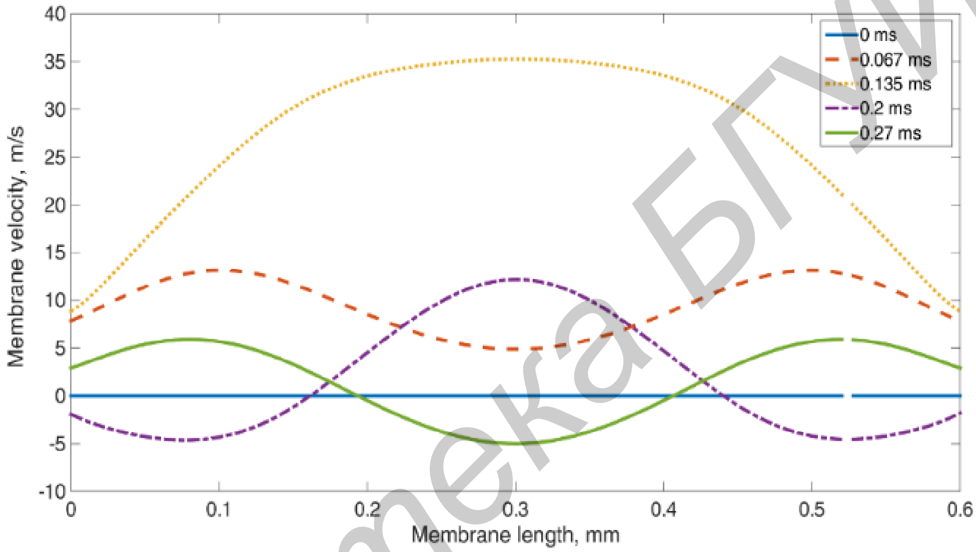

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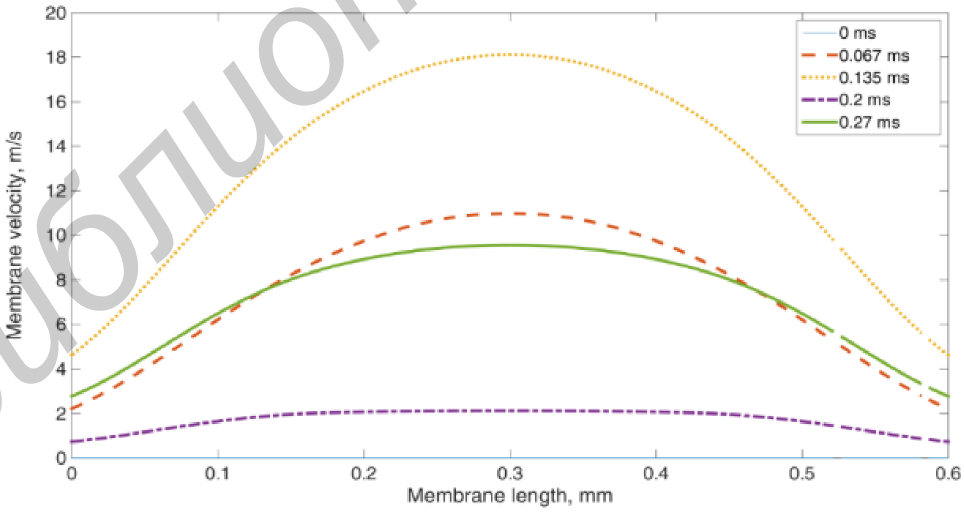

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Figure 3 – Longitudinal median profiles of 100 nm membrane in various time moments (frequency 1 kHz)
a) displacement profiles b) velocity profiles c) velocity profile at 100 Hz frequency, 700 nm tungsten membrane

Switch mode

In addition, proposed RF modulator scheme may be used in RF switch regime. To simulate this mode, the steep actuation voltage with three switching frequencies up to 1 kHz was applied to electrodes, causing various bounces during actuation (Fig. 4)

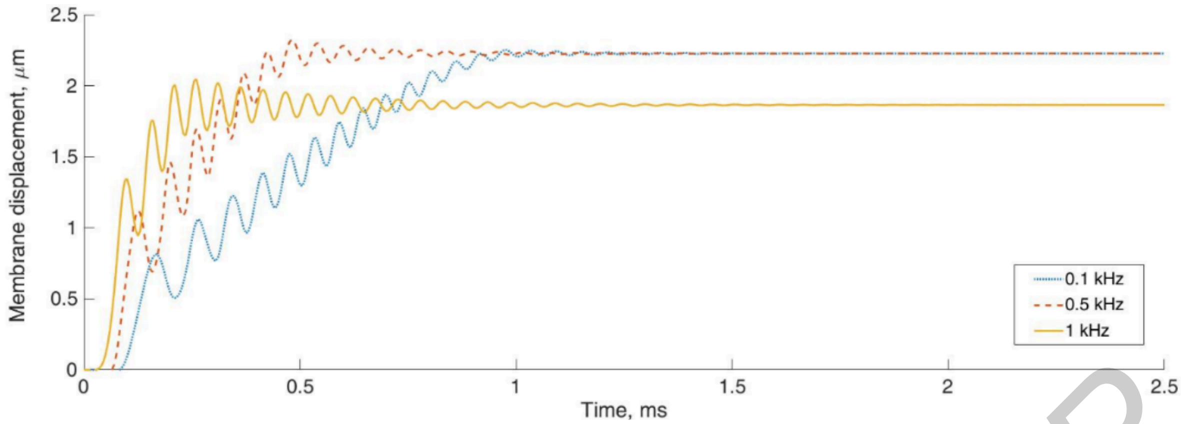

Figure 4 – Bounces during single steep actuation. Membrane thickness: 400 nm, material: gold

Due to the strong air damping effect number of bounces changes depending on frequency. In such switch scheme this effect is potentially harmful and requires various reducing schemes. Switching time is approximately 0.25 – 1 ms (depending on frequency).

III. CONCLUSION

The paper describes application of RF MEMS switch scheme in modulator and switch modes.

Performance of MEMS switch in 2 modes with thin membrane was studied in detail. It was revealed that an ultra-thin membrane (with 100 nm thickness) working at a low actuation voltage has a relatively low lifetime and high residual stress after the first work cycle. Such membranes also have a strong bouncing phenomena. This effect demonstrates a strict time-dependence and shows a significant decrease with actuating frequency reduction and membrane thickness growth. Otherwise, this effect is very useful in modulation scheme, where it is possible to multiply modulation frequency by at least 4 times using the same geometry.

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