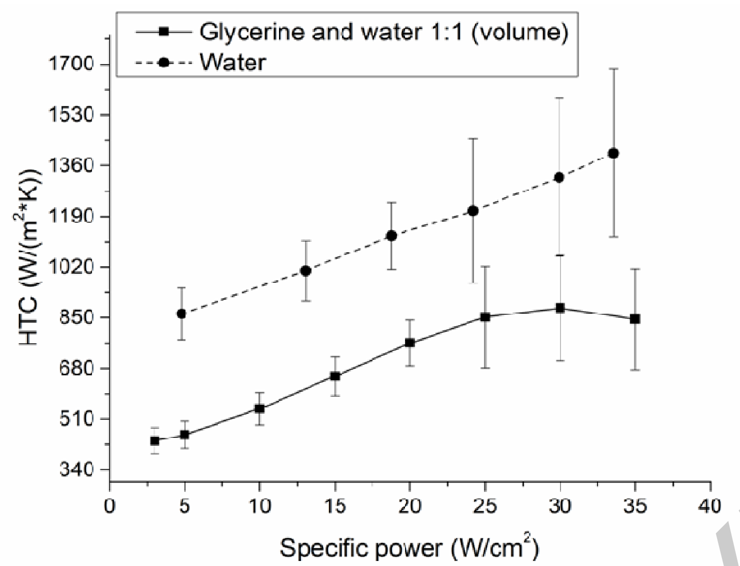

Figure 4 – The dependence of the heat transfer coefficient (HTC) from specific power during anodization of aluminum in electrolytes with different viscosity

IV. CONCLUSIONS

We have established that the increase in temperature of the growing anodic alumina during the anodizing process can reach several hundred degrees. The electrolyte composition is an important parameter that affects the heat transfer from the growing oxide. The experimental-based calculations showed that average values of heat transfer coefficient for low viscous (aqueous) electrolyte is in the range of 800-1400 W/(m^2·K) and of 400-850 W/(m^2·K) for high viscous electrolyte. HTC determines the temperature in the zone of growth of anodic oxides. Consideration of heat generation will allow to provide the stability of the anodizing and make possible to conduct controlled anodizing under extremely high temperatures.

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ACCUMULATION OF POROUS SILICON COMBUSTION ENERGY FOR MECHANICAL PULSE ENHANCEMENT IN MEMS

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I. INTRODUCTION

Microthrusters have received significant attention during the last few years, though early development in the microelectromechanical systems (MEMS) field began approximately 15 years ago. The principle applications of microthrusters are for primary propulsion and attitude control of microspacecraft and micro-, nano-, picosatellites. These small-scale satellites require efficient propulsion systems that can approach and maneuver around objects in a space orbit. Technological efforts are

converging from two directions: the miniaturization of conventional thrusters and the development of new solid energetic materials and device concepts [l]. One of the solutions for the aforementioned problem is to use energetic nanocrystalline porous silicon as an energy source.
Nanoporous silicon is an inert material, usually formed by the anodization of a silicon wafer in the electrochemical etch process [2]. Nanoporous silicon becomes an energetic material when its nanopores are infused with an oxidizer [3]. Porous silicon impregnated with solid state oxidizers has demonstrated the combustion and explosion processes [4, 5].

In this paper we present the measurements of thrust generation using nanoporous energetic silicon fixing on carrying platforms with intermediate elements from elastic material.

II. EXPERIMENTAL AND CALCULATION DETAILS

Silicon wafers of p-type (B-doped) with resistivity of 10 Ω·cm were used to fabricate porous silicon samples using the anodization technique in the HF/ethanol electrolyte (2 parts of 48% HF to 1 part of ethanol) at the current density of 50 mA/cm^2. Ethanol helps to wet the hydrophobic surface of Si and to remove H_2 bubbles. The porous region was etched from the front surface defined by a mechanical O-ring mask with an internal drameter of 12 mm. The etching times were varied to get porous layer thicknesses from 40 µm to 70 µm. The samples were rinsed in ethanol and the residual ethanol in the pores was slowly evaporated at normal laboratory conditions. The porous silicon samples were then impregnated by ethanol saturated solution of $NaClO_4$. The oxidizer are applied (the pores are filled) by dropping oxidizer solution with a pipette directly on the porous silicon. In all cases we fill the pores with two drops of the solution. Then samples dried in the oven at 40 °C.

We designed a simple propulsion system by attaching the silicon chip to the carrying platform through the elastic spacer made from rubber (Figure 1).

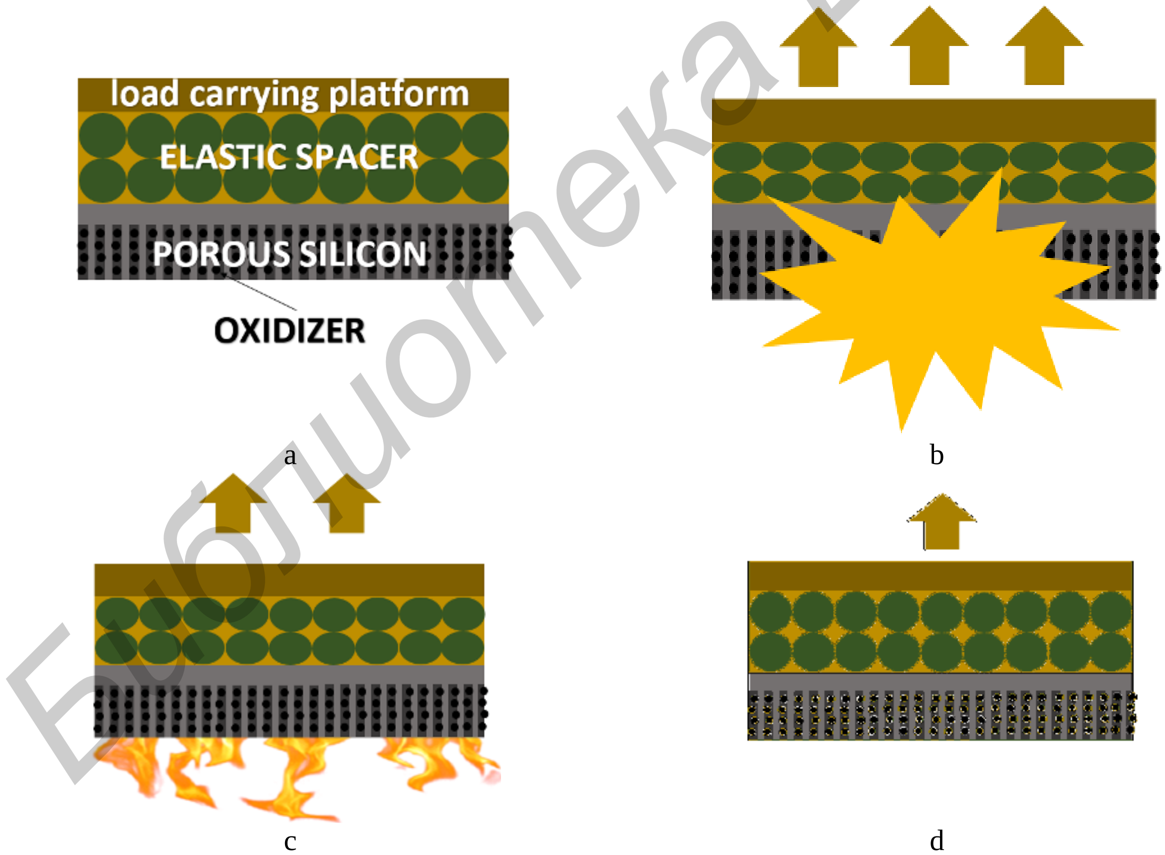

Figure 1 – MEMS: (a) initial structure; (b) initiation of the combustion process and the beginning of motion; (c) the motion in the process of burning out the porous silicon; (d) the motion due to inertia

Ignition of combustion and explosion processes in the porous layers were initiated by putting the samples to a hotplate heated up to 500 °C. After the explosion took place, the thrust lifted up the whole system from the ground. A video camera records (30 frames per second) the motion of the propulsion system, and a scale in the background was used to calculate the velocity and height that the device achieved.

The impulse was estimated as $P = m(\Delta l/\Delta t)$, where m is the mass of the carrying platform, Δl is the distance that the carrying platform passed within the time (Δt) of recording the picture by the camera.

III. RESULTS AND DISCUSSIONS

The elastic spacer performs the role of accumulator for porous silicon combustion energy. The potential energy of compressed elastic spacer later transforms in kinetic energy of moving microsystem as it schematically is shown in Figure 1 (b, c, d).

The using of elastic spacer allowed us to increase the mechanical pulses of designed microsystem up 30-50% in comparison with one without it (Figure 2).

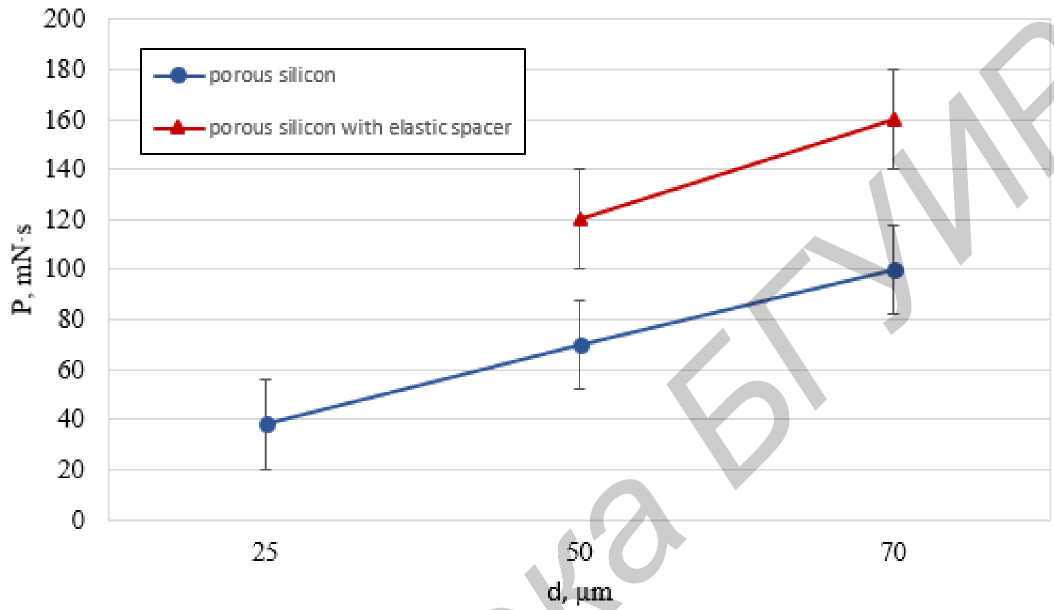

Figure 2 – Dependences of the pulse intensity on the transverse pore size of nanoporous silicon pores using $NaClO_4$ (20%) as an oxidant

The developed approach allowed us to obtain the mechanical pulses up to 180 mN·s for porous silicon thickness 70 µm.

It should be noted that the investigated systems without the elastic spacer after testing have showed the destroying of silicon chip. Meantime the investigated systems with elastic spacer keep the silicon chip integrity after testing. It can be explained by the, low differential pressure in the shock wave front for the last case.

The developed microsystem can be integrated with silicon integrated circuit using for controlling and driving.

IV. CONCLUSIONS

We have shown that our system based on porous silicon provides mechanical impulse which increases by accumulation of porous silicon combustion energy. The estimated impulse value was 80-180 mN·s, which is very promising for as the energetic material in MEMS.

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