Article Identifier
DOI: 10.22032/dbt.58885
URN: urn:nbn:de:gbv:ilm1-2023isc-103:7

60th ILMENAU SCIENTIFIC COLLOQUIUM
Technische Universität Ilmenau, 5 – 8 September 2023
URN: urn:nbn:de:gbv:ilm1-2023isc:1

UNDERLYING PHYSICS OF THERMAL ACTUATION IN COMPOSITE MEMS

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ABSTRACT

Integrated micro- and nano-electromechanical (N/MEMS) sensor and actuator technology has become increasingly important to any applications with parallel processes, which clearly provide advantages in fields such as e.g. high-speed imaging and precision metrology of large substrates. Although micro-fabrication processes for integrated technology are well-established, there remain several fundamental research questions regarding optimized design parameters for an improved performance of sensors and actuators. In this work we investigate the underlying physics of a thermal actuator of a composite MEMS structure for a selected range of design parameters such as e.g. layer thicknesses, number of layers, as well as material properties. We derive and present a one-dimensional heat conduction model of an M-layered composite slab and investigate the heat transfer across three layers using Green's function. The work, although entirely theoretical here, finds direct meaning and implementation in our ongoing collaborative work on MEMS arrays for Atomic Force Microscopy (AFM).

Index Terms – electro-thermal actuator, integrated actuator, bi-morph actuator

1. INTEGRATED ACTUATOR TECHNOLOGY

We consider the thermal actuation process of a MEMS device [1] with integrated sensor and actuator (Fig. 1, left panel). The actuation concept is based on the bimorph effect. With each layer having a different thermal expansion coefficient when exposed to heat, bending and therefore motion of the multi-layered structure can be induced. An Aluminum layer is used as the heating element that is set onto Silicon based layers [1].

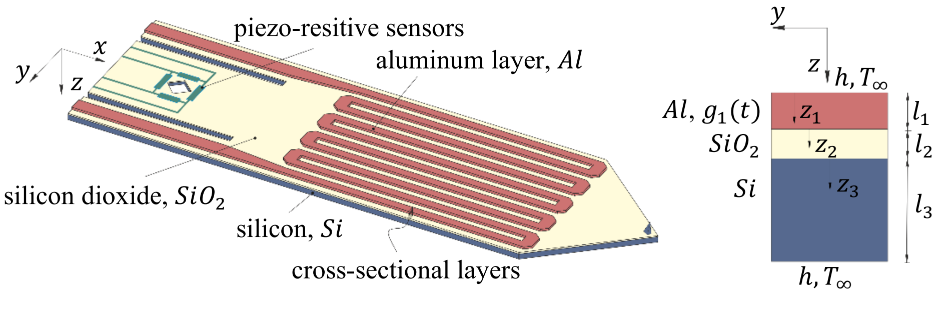

Figure 1: [left] CAD model of composite MEMS structure; [right] representative layer model across the thickness of the structure.

To provide additional electrical and thermal insulation of the Aluminum heater, a thin layer Silicon Dioxide (SiO_2) is designed between the Silicon base and the Aluminum layer. As the current passes through the Aluminum, electrical energy is converted into thermal energy by resistive Joule heating. When the temperature increases with the resistive heating, the Aluminum layer expands at a much higher rate than the underlying layers resulting in a bending of the MEMS structure [1].

2. HEAT CONDUCTION MODEL

The description of the diffusion of heat in the composite media is separated into continuum coordinate systems of discrete layers. Therefore, the generalised problem of an M-layered composite slab subject to volumetric heating is represented by the heat equation (Fourier's Law)

$$\frac{1}{\alpha_i}\frac{\partial T_i}{\partial t} = \frac{\partial^2 T_i}{\partial z_i^2} + \frac{1}{k_i} g_i(z_i, t) \qquad \text{with } 0 < z_i < l_i,\;\; t > 0 \text{ and } i = 1,2,\ldots,M, \qquad (1)$$

where T_i, α_i, k_i are the temperature, thermal diffusivity, and material's conductivity of any layer i. z_i, t, l_i and $g_i(z_i, t)$ in (1) are the free variables (see Fig. 1 [right panel]), time, thickness, and transient heating function (input), of layer i, respectively.

Green's function is used to determine the transient solution in the composite slab [2,3]. The initial temperature and the temperature associated with convection at the boundaries are equal and constant. Analyses and investigations focus on the linear problem and rely on the principle of super positioning of solutions.

3. RESULTS

The Al layer is heated at a frequency of 10 kHz and a volumetric power rate of 0.2 mW/µm^3 (Fig. 2a). The temperatures of the outer surfaces are presented in Fig. 2b for the first 10 pulses.

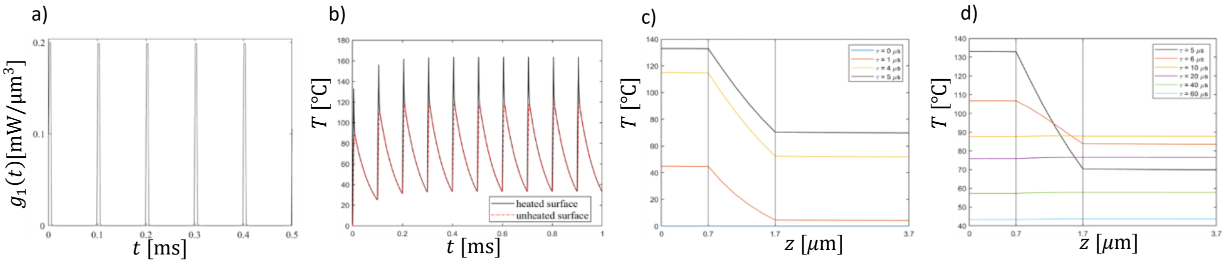

Figure 2: Selected Results: a) Input pulse function (Al layer); b) temperature responses at top and bottom surfaces; c,d) spatial temperature profiles of first heating pulse c), and first cooling cycle d)

Figure 2 c,d) present the spatio-temporal effects within slab during the first heating pulse (c) and cooling phase thereafter (d). All layers are initially at uniform ambient temperature and the heated top layer rapidly increases in temperature according to the pulsing function. Since the thermal resistance in the Al and Si layers are very low, these profiles remain relatively uniform during the heating phase. However, the higher thermal resistance of the SiO_2 layer results in an approximately 60˚C temperature difference between these two layers.

4. CONCLUSIONS

The presented work provides new insights about design optimization and operation parameters. Furthermore, materials for layers as well as the number of layers can be strategically designed for targeted applications such future imaging and lithographical technologies.

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