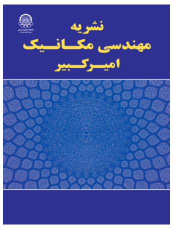

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Increasing the Sensitivity of SiO_2/Al Micro Cantilever Infrared Detector Based on Micro Electromechanical Systems Technology by Optimizing of Dimensions

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ABSTRACT: In this paper, the sensitivity of the micro-cantilever infrared detector has been increased by optimizing its geometric dimension. The detector's main body consists of an absorbing area, bi-material, and isolation legs, which are made up of silicon dioxide. Bi-material regions (absorbing area and bi-material legs) include a thin film layer of aluminum, which is placed on the main body layer. In this detector, the amount of bending at the end of the tip detector depends on the thickness of insulating and metal layers and the width of isolating and bi-material legs. Furthermore, it has been proved that the detector's displacement and sensitivity are optimized when the thickness of the metal layer is selected the half of the thickness of the absorbing layer. The results of the calculations show that by applying boundary conditions for 100 pW/µm2 constant thermal flux on the absorber, amount of displacement, thermomechanical, power, displacement, and body temperature sensitivities are increased by 26%, 27%, 28%, 2.3%, and 26%, respectively. In addition, the calculation results show that the sensitivities and response time are improved to 4.24, 54, 12.4, 12.8, 54, 4.2, 54.48, 54, and 1.5 times, respectively, in the vacuum environment if the leg's width, the isolating and metal layers' thicknesses are selected as 1µm, 0.1µm, and 0.05µm, respectively.

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1. INTRODUCTION

In previous works, we reported the fabrication of an uncooled SiO_2/Al microcantilever Infrared (IR) detector based on Micro Electromechanical Systems (MEMS) technology [1-5]. In Ref. [6], the design and simulation of this detector were presented and explained that the sensitivity and responsivity are better than other detectors especially when it is fabricated by different materials such as SiN_3/Au. Since the sensitivity and responsivity are dependent on its dimensions, so they can be improved by optimizing layers' thickness and legs' width. In the current work, our previous work is improved by optimizing its dimensions.

2. PRINCIPLE OF OPERATION

The detector's main body consists of three parts including 1) IR absorbing area, 2) bi-material legs, and 3) thermal isolation legs. The temperature of the IR absorbing area increases by absorbing IR power. Then, Heat transfers from the absorbing area to the legs. So, the detector bends due to the Coefficient of Thermal Expansion (CTE) [6].

3. THERMODYNAMIC ANALYSIS

The thermal conductance (G) must be evaluated to calculate temperature changes and the bending of the detector. Total thermal conductance can be expressed as Eq. (1):

$$G = G_{leg} + G_{rad} + G_{amb} \quad (\mathrm{WK}^{-1}) \tag{1}$$

In which, G_{leg}, G_{rad}, and G_{amb} are the thermal leg's conductance, thermal radiative conductance, and the thermal conductance between detector and environment, respectively. G_{leg} can be calculated as [7]:

$$G_{leg} = 2\times\left(\frac{l_b}{k_{SiO_2}A_{SiO_2} + k_{Al}A_{Al}} + \frac{l_i}{k_{SiO_2}A_{SiO_2}}\right)^{-1} \quad (\mathrm{WK}^{-1}) \tag{2}$$

Where k_{SiO2} and k_{Al} are thermal conductivity of SiO_2 and Al, respectively, A and l are the cross-section area and the legs' length, respectively. G_{rad} is calculated as:

$$G_{rad} = 4.\sigma.A_{pixel}\left(\varepsilon_{Al} + \varepsilon_{SiO_2}\right)T^3 \quad \left(\mathrm{WK}^{-1}\right) \tag{3}$$

Where, σ, T and ε are Stefan–Boltzmann constant, temperature, and emissivity, respectively.

The detector's deformation results from temperature changes (ΔT). The detector temperature is analyzed when the detector is in thermal equilibrium with the surrounding area. Therefore, ΔT can be calculated the incident power on the pixel [8]:

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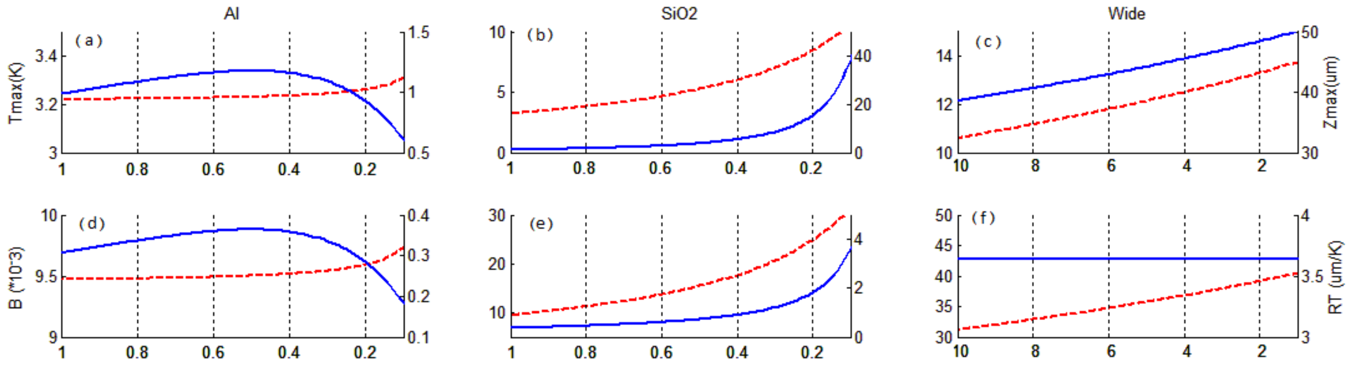

Fig. 1. Figure shows the results of Calculations with respect to changes of t_{Al}, t_{SiO2} and W, which are shown in the left to right of horizontal axis, respectively. The rad dash lines show the temperature changes and heat transfer coefficient from top to bottom, respectively, in the left vertical axis on diagrams. The blue solid lines show the displacement changes and Thermomechanical sensitivity from top to bottom, respectively, in the right vertical axis on diagrams.

Where P_0 can be calculated from Eq. (5):

$$\Delta T_c = \frac{P_{\cdot}}{G} \quad (°\mathrm{C}) \tag{4}$$

$$P_0 = A\,W_s \quad (\mathrm{W}) \tag{5}$$

In which, W_s is absorbed IR density. When temperature changes, the microcantilever bends due to different CTE. Δz can be calculated from Eq. (6):

$$\Delta z = 3.(\alpha_1 - \alpha_2).\frac{r(1+r)}{t_2 K}.l_b^2.\Delta T$$
$$K = 4r + 6r^2 + 4r^3 + \frac{E_1}{E_2}r^4 + \frac{E_2}{E_1} \quad , \quad r = \frac{t_1}{t_2} \tag{6}$$

where (t_1 and t_2), (α_1 and α_2), and (E_1 and E_2) are the thickness, CTE, and Young's modulus of Al and SiO_2 layers, respectively.

4. OPTIMIZATION METHOD

Displacement will increase with respect to the decrement of legs' width and layers' thickness. With control of fabrication process parameters, one may be able to decrease the thickness of layers and width of legs. Since E_1 is approximately equal to E_2 for Al and SiO_2 layers, then Eq. (6) can be simplified to Eq. (7).

$$K = 1 + 4r + 6r^2 + 4r^3 + r^4 = (1+r)^4$$
$$\Delta z = 3.(\alpha_1 - \alpha_2).\frac{r(1+r)}{t_2 K}.l_b^2.\Delta T \tag{7}$$

Eq. (7) will change into Eq. (8) by substituting K into the equation:

$$\Delta z = 3.(\alpha_1 - \alpha_2).\frac{r}{t_2(1+r)^3}.l_b^2.\Delta T \tag{8}$$

To calculate the maximum displacement according to the ratio of layers' thickness, it is sufficient to find the derivation roots of Eq. (8) with respect to r. The resulting derivation is shown in Eq. (9).:

$$dz\big/_{dr} = 3.(\alpha_1 - \alpha_2).l_b^2.\Delta T.(1+r)^2(1-2r) \tag{9}$$

The roots of Eq. (9) are 0.5 and -1. The negative value is an invalid result because thickness cannot be negative. So, the positive value is the correct result, thereupon the thickness of the insulator must be two times larger than the thickness of the metallic layer to achieve the maximum displacement for the microcantilever detector.

5. RESULTS AND DISCUSSION

We calculate Heat transfer coefficient (β), Thermomechanical ($\Re_T$), Power ($\Re_P$), Temperature (S_t), Displacement (S_d), and Black body temperature (S_{dt}) sensitivities and Time constant (τ) to extra study.

the Thickness ratio of Al and SiO_2: ΔT and t have inverse correlation according to Eq. (4) and Eq. (2). Therefore, temperature decreases by increasing of t_{Al}. According to Fig. 1, the Calculations results show that maximum bending occurs while t_{Al} is equal to 0.5µm which is half of t_{SiO2} . So, ΔT, H, and S_t do not have a sensible change when t_{Al} changes, and Δz, $\Re_T$, $\Re_P$, S_d, and S_{dt} are maximum that t_{AL} is 0.5µm.

Effect of silicon dioxide layer's thickness: According to Fig. 1, Calculations of ΔT with respect to changes of t_{SiO2} are done by considering the thickness ratio, in which t_{Al} is half of t_{SiO2}. Results show that ΔT and Δz increase when t_{SiO2} decrease. Also, the following values are optimized by comparing to our previous work respectively, when t_{SiO2} is 500nm and 100nm:

(1) ΔT (1.61 and 3.25) time; (2) Δz (4.13 and 41) time; (3) H (1.5 and 3.2) time; (4) $\Re_T$ (2.55 and 12.8) time; (5) $\Re_p$ (4.2 and 42) time; (6) S_t (3.22 and 1.6) time; (7) S_d (41.13 and 41.62) time; (8) S_{dt} (4.14 and 41.5) time; (8) τ (1.06 and 2.64) time.

Effect of decrement of arms' width: According to Fig. 1, Calculations of G with respect to changes of W are done by considering the thickness ratio, in which t_{Al} is half of t_{SiO2}. Results show that ΔT and Δz increase when W decreases. Also, the following values are optimized by comparing to our previous work respectively, when the detector dimension (W, t_{SiO2}, t_{Al}) is (5µm, 0.5µm, 0.25µm) and (1µm, 0.1µm, 0.05µm): (1) ΔT (3.72 and 4.72) time; (2) Δz (47.7 and 54) time; (3) H (3.7 and 4.12) time; (4) $\Re_T$ (12.8 and 12.8) time; (5) $\Re_p$ (48.46 and 54) time; (6) S_t (4.2 and 3.71) time; (7) S_d (47.67 and 48.54) time; (8) S_{dt} (54 and 47.8) time; (8) τ (2.8 and 2.5) time.

6. CONCLUSIONS

In this paper, ΔT, Δz, and the sensitivity of the IR detector are increased by optimizing its geometric dimensions. It has been proven that Δz, $\Re_T$, $\Re_P$, S_t, and S_{dt} are increased by 27%, 28%, 26%, and 26%, respectively, when the thickness of the absorbing layer has been selected double of the thickness of the metal layer. In addition, the calculation results show that ΔT, Δz, H, $\Re_T$, $\Re_P$, S_t, S_d, S_{dt}, and τ are improved by 4.24, 54, 12.4, 12.8, 54, 4.2, 54.48, 54 and 1.5, respectively, times higher than with respect to Ref. [6] in the vacuum environment

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