Design, simulation and validation of a novel uncooled infrared focal plane array

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Received 31 October 2005; received in revised form 14 March 2006; accepted 22 March 2006
Available online 11 May 2006

Abstract
This paper describes a novel single-layer bi-material cantilever microstructure without silicon (Si) substrate for focal plane array (FPA) application in uncooled optomechanical infrared imaging system (UOIIS). The UOIIS, responding to the radiate infrared (IR) source with spectral range from 8 to 14 μm, may receive an IR image through visible optical readout method. The temperature distribution of the IR source could be obtained by measuring the thermal–mechanical rotation angle distribution of every pixel in the cantilever array, which is consisted of two materials with mismatching thermal expansion coefficients. In order to obtain a high detection to the IR object, gold (Au) film is coated alternately on silicon nitride (SiNx) film in the flection beams of the cantilevers. And a thermal–mechanical model for such cantilever microstructure is proposed. The thermal and thermal–mechanical coupling field characteristics of the cantilever array structure are optimized through numerical analysis method and simulated by using the finite element simulation method. The thermal–mechanical rotation angle simulated and thermal–mechanical sensitivity tested in the experiment are $2.459 \times 10^{-3}$ and $3.322 \times 10^{-4}$ rad/K, respectively, generally in good agreement with what the thermal–mechanical model and numerical analysis forecast, which offers an effective reference for FPA structure parameters design in UOIIS.

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Keywords: Cantilever; FPA; UOIIS; IR; Optical readout; Finite element

1. Introduction
Infrared (IR) imaging sensors have already been available to military users for over two decades; their applications in the industrial and civil sectors from remote sensing, fire fighting to biomedical diagnostics have steadily increased in recent years [1].

As we known all objects in nature can radiate IR whose wavelength have three peak spectrums such as 1–3, 3–5 and 8–14 μm. IR detectors can be generally classified into two categories: photonic and thermal. The photonic devices require cooling of the detector to 77 K to reduce the thermal noise. For many military and most civil applications, however, high costs, large weight and size of the additional cooling systems limit their development and a clear requirement exists for a thermal imaging technology offering reasonable performance at low cost in a compact lightweight easy-to-use package. The thermal IR imaging detectors can meet the requirements mentioned above. Traditionally, these two categories of IR detectors all need a signal readout IC, and with the increasing of pixels, the cost and the technology difficulty of readout IC increase more rapidly.

Manalis et al. [2] presented micro-fresnel zone plate IR detector with pixel size 96 μm × 96 μm and optical readout system in Stanford University in 1997, and proved an IR imaging detector without readout IC by micro-machine structures. Mao et al. [3] and Zhao et al. [4] reported focal plane array (FPA) composed of the bi-material cantilevers anchored on the substrate, using different optical readout parts in 1999 and in 2002, respectively. Besides these, Datskos et al. [5] discussed performances of a SiNx/Al microcantilever uncooled infrared detector with optical readout by numerical method in Oak Ridge National Laboratory.
Li [6] simulated performances of an uncooled double-cantilever microbolometer with capacitive readout.

In this paper, a novel single-layer bi-material cantilever microstructure for FPA application in uncooled optomechanical infrared imaging system (UOIIS) will be discussed. The novel microstructure is a new freestanding single-cantilever without Si substrate, and its performances will be discussed by both methods: numerical analysis and finite element simulation.

2. Principles of uncooled optomechanical IR imaging system

The principle of IR imaging system based on optomechanical effect is that the bi-material cantilevers bend after absorbing infrared radiation; simultaneously an optical readout measures the deformations of every cantilever of FPA, and projects a visible imaging result.

Fig. 1 shows the schematic diagram of the uncooled optomechanical IR imaging system. This system consists of three main parts: IR lens, FPA and optical readout. In the main part FPA, each pixel is a cantilever microstructure containing two bi-material flection beams. Two materials selected should have a large mismatch in thermal expansion coefficients, which will result in big deformation of the cantilever when absorbing the incoming IR radiation. Besides, one of the materials must fully absorb IR of 8–14 μm spectral range, and the other is a great reflector in the visible spectrum for optical readout. Owing to these requirements, low-pressure chemical vapor deposited (LPCVD) low-stress silicon nitride (SiNₓ) and gold (Au) are selected in the bi-material cantilever structure. The thermal expansion coefficients of SiNₓ and Au are 0.8 × 10⁻⁶ and 14.2 × 10⁻⁶ K⁻¹, respectively. Since the thermal conductivity of Au (296 W/(m K)) is much bigger than that of SiNₓ (5.5 W/(m K)), it is important to reduce the thermal loss and obtain high thermal deformation of the structure. So in the
eflection beams of cantilever Au film is coated alternately on SiNₓ film. Compared with double-layers structure presented by Zhao et al. [4], this novel design of single-layer microstructure suspending on gridding frames greatly simplifies its fabrication avoiding sacrificial layer process. In addition, it increases the thermal–mechanical sensitivity and accordingly decreases noise-equivalent temperature difference (NETD) of the whole system compared to previous fabricated structure in our group [7,8]. Subjected to some fabrication bottleneck in our previous fabricated structure, Au film could but be coated wholly on SiNₓ film. Delightfully that bottleneck has been solved successfully by our group now and the novel single-layer microstructure design has practical significance.

3. FPA design and physical characters

The thermal and mechanical properties of SiNₓ, Au and Si are given in Table 1. The SiNₓ/Au cantilever layer thermally isolates from the silicon supporting frames through the contacted SiNₓ layer with them. Fig. 2 shows the schematic diagram of the heat transfer model of pixel. The heat transfer mechanisms between the cantilever and environment can be categorized as: (i) the heat conduction between the bi-material cantilevers and silicon supporting frames through the supporting beams (legs); (ii) the heat exchange between the bi-material cantilevers and environment by thermal radiation; (iii) the heat conduction between the bi-material beams and silicon supporting frames through the air; (iv) the heat convection of the bi-material cantilever with the air.

Table 1
Thermal and mechanical properties of SiNₓ, Au and Si

<table>
<thead>
<tr>
<th>Material</th>
<th>Density, ρ (×10⁻³ kg/m³)</th>
<th>Young’s modulus, E (GN/m²)</th>
<th>Thermal conductivity, K (W/(m K))</th>
<th>Expansion coefficient, α (×10⁻⁶ K⁻¹)</th>
<th>Heat capacity, c (J/(kg K))</th>
<th>Emissivity, ε (8–14 μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiNₓ</td>
<td>2.40</td>
<td>180</td>
<td>5.5 ± 0.5</td>
<td>0.8</td>
<td>691</td>
<td>0.8</td>
</tr>
<tr>
<td>Au</td>
<td>19.30</td>
<td>73</td>
<td>296</td>
<td>14.2</td>
<td>129</td>
<td>0.01</td>
</tr>
<tr>
<td>Si</td>
<td>2.33</td>
<td>100</td>
<td>135</td>
<td>2.6</td>
<td>700</td>
<td></td>
</tr>
</tbody>
</table>
3.1. Thermal characters [4,9,10]

Fig. 3 shows the part dimensions of FPA that can be initially determined under our fabrication abilities. The designed pixel area is 200 \( \mu \text{m} \times 200 \mu \text{m} \), the supporting frame width 10 \( \mu \text{m} \), the supporting beam width 3 \( \mu \text{m} \), the space adjacent to reflection pad 3 \( \mu \text{m} \) and other spaces 3 \( \mu \text{m} \). Supporting beam deflection number is \( n^4 \).

The system is initially at ambient temperature \( T_a \), absorbing IR incident flux \( q_s \), then the absorbed IR incident flux \( q_s \), the temperature of the bi-material cantilevers \( T_c \) will follow:

\[
\frac{\rho Vc}{Vc} \frac{dT_c}{dt} = -G_{\text{Total}} (T_c - T_a) + q_s \tag{1}
\]

where \( \rho \) is the density of the material, \( V \) the volume of the film, \( c \) the heat capacity and \( G_{\text{Total}} \) is the total thermal conductance of the cantilever structure. The temperature change induced in the microcantilever by a temperature change of a distant blackbody source will follow [9]:

\[
H = \frac{8T_c}{hT_s} = \frac{1}{G_{\text{Total}}} A_{\text{abs}} \tau_{\text{opt}} \pi \frac{dL}{dT_a} \tag{2}
\]

where \( A_{\text{abs}} \) is the pixel IR absorption area; \( \tau (=0.4) \) is the transmissivity of the IR optical system; \( \varepsilon \) is the total emissivity due to a distant blackbody source (to human being, \( \varepsilon = 0.98 \) at temperature 300 K); \( F_{\text{im}} (=0.7) \) is \( F \) number of the IR imaging lens; the numerical value of \( dL/dT_a \) in 8–14 \( \mu \text{m} \) wavelength range for a blackbody at temperature 300 K is 0.63 W/(m\(^2\) K sr).

It can be seen from Eq. (2) that the lower total thermal conductance of the cantilever structure, the higher temperature change of the cantilevers. The total thermal conductance of the cantilever structure contains all the heat transfer mechanisms mentioned above:

\[
G_{\text{Total}} = G_{\text{leg}} + G_{\text{rad}} + G_{\text{air}, \text{cov}} + G_{\text{air}, \text{cond}} \tag{3}
\]

Heat convection of the bi-material cantilevers with the air is much smaller than those at atmosphere pressure, so \( G_{\text{air}, \text{cov}} \) is neglected. Total thermal conductance of the cantilever structure can be expressed as:

\[
G_{\text{Total}} = G_{\text{leg}} + G_{\text{rad}} \tag{4}
\]

The leg’s conductance can be expressed as:

\[
G_{\text{leg}} = \left[ \sum_i \left( \frac{L}{AK} \right) \frac{SiN_{i},Au,i}{SiN_{i},SiN_{i},i} \right]^{-1} \tag{5}
\]

where \( A \) is the cross-sectional area of the leg, \( K \) the thermal conductivity of the leg material and \( L \) is the length of the leg, subscript \( i (=1 \text{ and } 2) \) the two materials.

The radiative thermal conductance:

\[
G_{\text{rad}} = 4\sigma \left[ A_{\text{SiN}_1,\text{Au}} (\varepsilon_{\text{SiN}_1} + \varepsilon_{\text{Au}}) + A_{\text{SiN}_2,\text{SiN}_2} \right] T_a^3 \tag{6}
\]

where \( A_{\text{SiN}_1,\text{Au}} \) and \( A_{\text{SiN}_2} \) are the areas of \( \text{SiN}_1/\text{Au} \) layer and \( \text{SiN}_2 \) layer, respectively, \( \varepsilon_{\text{SiN}_1} \) and \( \varepsilon_{\text{Au}} \) are the emissivities, respectively, \( \sigma \) the Stefan–Boltzmann constant (=5.67 \times 10^{-8} \text{ W/(m}^2\text{ K}) \) and \( T_a \) is the ambient room temperature (~300 K).

3.2. Thermal–mechanical characters [4,10] and FPA dimension design

In order to make numerical analysis convenient, FPA in Fig. 3 can be equivalent to Fig. 4. In the bi-material structure parts, the deflection of the freestanding cantilever under the temperature change \( \Delta T \) meets the thermal–mechanical equation:

\[
\frac{d\theta}{dx} = \frac{d^2z}{dx^2} = 6(\alpha_1 - \alpha_2) \left( \frac{n + 1}{K} \right) \left( \frac{1}{h_2} \right) \Delta T(x) \tag{7}
\]

\[
z = 0; \quad \frac{dz}{dx} = 0 \quad \text{at} \quad x = 0
\]

where \( (\alpha_1 - \alpha_2) \) is the thermal expansion coefficient difference of \( \text{Au} \) and \( \text{SiN}_2 \); \( K \) the structure parameter given as \( K = 4 + 6n + 4n^2 + \phi n^3 + 1/\phi n \), \( n \) the thickness ratio of \( \text{Au} \) and
SiNₓ film \((n = h₁/h₂)\), \(\psi\) the Young’s modulus ratio of Au and SiNₓ \((\phi = E₁/E₂)\).

Considering the thermal conductivity of Au \((296 \text{ W/(m K)}\)) is much bigger than that of SiNₓ \((5.5 \text{ W/(m K)}\)), assume that the temperature distribution in the bi-material reflection pad and bi-material beams is uniform while in single-SiNₓ supporting beams is linear.

\[
\Delta T(x) = \begin{cases} 
\frac{x}{L_{\text{SiN}_x}} \Delta T_c (m l_{\text{SiN}_x} + m l_{\text{SiN}_x, Au}) & x \leq (m + 1) l_{\text{SiN}_x} + m l_{\text{SiN}_x, Au}; \\
\frac{(m + 1) l_{\text{SiN}_x}}{L_{\text{SiN}_x}} \Delta T_c (m l_{\text{SiN}_x} + m l_{\text{SiN}_x, Au}) & x \leq (m + 1) l_{\text{SiN}_x} + (m + 1) l_{\text{SiN}_x, Au}; \\
\Delta T_c (n^* l_{\text{SiN}_x} + n^* l_{\text{SiN}_x, Au}) & x \leq n^* l_{\text{SiN}_x} + n^* l_{\text{SiN}_x, Au} + L_{\text{pad-y}} \end{cases} 
\]  

where \(\Delta T_c\) is the temperature change of reflection pad, \(l_{\text{SiN}_x}\), and \(l_{\text{SiN}_x, Au}\) the length of each single-SiNₓ supporting beam and bi-material supporting beam, respectively (see Fig. 4). \(n^*\) the flection number and \(L_{\text{SiN}_x,} (= n^* l_{\text{SiN}_x})\) is the whole length of the single-SiNₓ supporting beam.

The detailed deformation of cantilever structure is showed in Fig. 5. Single-SiNₓ beams without Au-coated above do not deform, and keep staying in the tangential surface cross with the end of deformed SiNₓ/Au beams.

The thermal–mechanical sensitivity can be expressed using the maximum thermal–mechanical rotation angle as:

\[
S_{T}^* = \frac{\Delta \theta_{\text{max}}}{\Delta T_c} = \frac{\sum_{i=1}^{n} \theta_i}{\Delta T_c} = 3(n^* + 1)(\alpha_1 - \alpha_2) \left( \frac{n + 1}{h_2 K} \right) l_{\text{SiN}_x, Au} 
\]  

It can be seen that the factors influencing the thermal–mechanical sensitivity are many, such as the thermal expansion coefficient difference of Au and SiNₓ, the thickness ratio of Au film and SiNₓ film, the Young’s modulus ratio of Au and SiNₓ, the thickness of SiNₓ film, flection number \(n^*\) and so on. When those parameters except \(n\) are determined, \(S_T(S_T^*) \sim (n + 1)/K\) (see Fig. 6). The cantilevers can get high thermal–mechanical sensitivity when \(0.75 < n < 0.95\), but because of our fabrication limit, \(n\) cannot be optimized; \(n\) is designed to be 0.3 to be discussed as follows.

First determine the thickness of SiNₓ film. The penetration depth within the SiNₓ film for incident infrared radiation with mean wavelength at \(\lambda_0 = 10 \text{ µm}\) will be 0.8 µm. Under the consideration of the fabrication simplicity, SiNₓ film intensity and thermal–mechanical sensitivity of the cantilever structure, the SiNₓ film thickness is designed to be 1 µm. The Au film thickness is designed to be 0.3 µm to the best of our fabrication abilities.

From all detailed discussion above, \(n^*\) is the last key parameter to be designed. \(n^*\) is closely relative to some other performances of the IR imaging system to be discussed as follows.

### 3.2.1. \(n^*\) parameter design

The flection number \(n^*\) is important for synthetical performances of the IR imaging system. It can influence the thermal image grey change induced by temperature change of the IR source, which obey the law as follows:

\[
\frac{\Delta I}{\Delta T_S} = \frac{\Delta I}{\Delta \theta} \frac{\Delta \theta}{\Delta T_C} \frac{\Delta T_C}{\Delta T_S} = \gamma SH 
\]  

<table>
<thead>
<tr>
<th>Pixel area ((\mu m^2))</th>
<th>Infrared absorption (reflection) pad area, (A_{\text{pad}} (\mu m^2))</th>
<th>Cantilever length, (L_{\text{leg}} (\mu m))</th>
<th>Cantilever width, (d (\mu m))</th>
<th>SiNₓ thickness, (h_2 (\mu m))</th>
<th>Au thickness, (h_1 (\mu m))</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 × 200</td>
<td>16 × 184</td>
<td>2618</td>
<td>3</td>
<td>1</td>
<td>0.3</td>
</tr>
</tbody>
</table>
where \( \gamma = \Delta I / \Delta \theta \) is optic detection sensitivity. It is a constant when \( \Delta \theta \) is small (see Fig. 13), so Eq. (10) can be expressed as:

\[
\frac{\Delta I}{\Delta T_S} = \frac{\Delta I_{\text{max}}}{\Delta \theta_{\text{max}}} \frac{\Delta T_C}{\Delta T_S} = \gamma \frac{S^*_T H}{(n^* + 1)}
\]

where \( S^*_T H \) is closely related to \((n^* + 1)(A_{ab}/G_{\text{Total}})\) (1 \( \leq n^* \leq 7 \)).

Fig. 7 shows the influence of flection number \( n^* \) to the performances of the IR imaging system. It can be seen from Fig. 7 that the IR imaging system can get high pixel temperature change when \( 5 \leq n^* \leq 7 \), and can obtain high thermal–mechanical rotation angle and high thermal image grey when \( n^* = 7 \). As long as the visible light projecting onto FPA is enough strong, the area of the reflection pad does not matter. In our design \( n^* \) is 7, \( L_{\text{pad-y}} = 184 \mu \text{m} \) and the whole cantilever length \( L_{\text{leg}} \) is 2618 \( \mu \text{m} \).

Table 2 shows the bi-material cantilever microstructure design parameters.

From the discussion above, the leg’s conductance is calculated to be \( 2.348 \times 10^{-8} \text{ W/K} \) and the radiative thermal conductance is \( 9.212 \times 10^{-8} \text{ W/K} \). The total thermal conductance of the cantilever structure is 1.156 \( \times 10^{-7} \text{ W/K} \), which is limited near to the radiative thermal conductance. The lower total thermal conductance can enhance the pixel temperature change and cantilever thermal deformation under a certain IR absorption. It can be calculated that when the IR resource change 1 K, the pixel temperature change is \( 6.390 \times 10^{-2} \text{ K} \), and when FPA changes 1 K, the thermal–mechanical rotation angle is \( 5.346 \times 10^{-3} \text{ rad/K} \).

The bi-material cantilever structure performances parameters are showed in Table 3.

### 3.3 Finite element simulation

Basing on the data from Table 2, the thermal and thermal–mechanical characters are simulated using the finite element simulation method. Considering the cantilever is very thin bi-material microstructure, 3D four-nodes thermal shell element and eight-nodes linear layered structural shell element are chose. The thermal exchange between the two thin layers of SiNx and Au is so small that thru-thickness thermal conduction can be

<table>
<thead>
<tr>
<th>Bi-material cantilever microstructure performance parameters</th>
<th>Leg’s conductance, ( G_{\text{leg}} ) (W/K)</th>
<th>Radiative thermal conductance, ( G_{\text{rad}} ) (W/K)</th>
<th>Thermal sensitivity of FPA, ( H )</th>
<th>Thermal–mechanical sensitivity of FPA, ( S^*_T ) (rad/K)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( 2.348 \times 10^{-8} )</td>
<td>( 9.212 \times 10^{-8} )</td>
<td>( 6.390 \times 10^{-2} )</td>
<td>( 5.346 \times 10^{-3} )</td>
</tr>
</tbody>
</table>
Fig. 10. (a) Thermal–mechanical rotation angle distributions under different $n^*$ values ($2 \leq n^* \leq 7$) and (b) graph of simulated thermal mechanical sensitivities ($S^*_T$) under different $n^*$ values ($2 \leq n^* \leq 7$).

ignored, so in four-nodes thermal shell element only in-plane thermal conduction is considered. Eight-nodes linear layered structural shell element is used for layered applications of a shell model. It is used to calculate the structural deformation under the thermal expansion.

Grid division is showed in Fig. 8. In area where stress may be concentrated, grids are divided to be denser than those in other areas to decrease the calculated errors.

When simulating the thermal characters, considering the fixed points of the supporting cantilever are connected with the silicon frame, the temperature changes over there are defined to be zero as the boundary conditions. IR heat flux is loaded to the surface of the cantilevers, and the temperature distribution can be obtained as showed in Fig. 9. It can be seen that the temperature distribution basically accords with the theory assumption. The temperature distributions in the bi-material reflection pad and bi-material beams is basically uniform while in single-Si$_3$N$_4$ supporting beams the temperature distribution is linear.

When simulating the thermal–mechanical characters, considering the fixed points of the supporting cantilever are connected with the silicon frame, the displacements over there are defined to be zero as the boundary conditions. Under different $n^*$ values ($2 \leq n^* \leq 7$), the thermal–mechanical rotation angle distributions under thermal expansion are showed in Fig. 10(a). It can
Fig. 11. Photographs of fabricated FPAs.

Fig. 12. Photographs of human hand (b) using FPA with two flection legs (a).

Table 4

<table>
<thead>
<tr>
<th>Thermal image grey change, $\Delta I/\Delta T_S$ (grey/(m K))$^a$</th>
<th>Optic detection sensitivity, $\gamma = \Delta I/\Delta \theta$ (deg$^{-1}$)$^a$</th>
<th>Thermal–mechanical sensitivity of UOIIS, $S^\ast_T \times H$ (rad/K)$^a$</th>
<th>Thermal sensitivity of FPA, $H^b$</th>
<th>Thermal–mechanical sensitivity of FPA, $S^\ast_T \times H$ (rad/K)$^b$</th>
<th>Thermal–mechanical sensitivity of UOIIS, $S^\ast_T \times H$ (rad/K)$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>58.14</td>
<td>10034</td>
<td>$3.322 \times 10^{-4}$</td>
<td>$5.110 \times 10^{-2}$</td>
<td>$2.005 \times 10^{-3}$</td>
<td>$1.025 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

$^a$ Tested.

$^b$ Calculated.

be seen that the rotation angle distribution are uniform in the reflection pad, which is the need for IR imaging system to get a high-quality imaging result. Fig. 10(b) shows the graph of simulated results, in which the maximum simulated rotation angle is $2.459 \times 10^{-3}$ rad/K when $n^\ast = 7$, basically identical to what the thermal–mechanical model forecasts. It also can be seen that the maximum thermal–mechanical rotation angles linearly increase with the increase of $n^\ast$ value, which is identical to what Fig. 7 displays.

4. FPA microfabrication and performances test

FPAs with above dimensions under different flection legs ($2 \leq n^\ast \leq 7$) are fabricated. According to the fabrication results, FPAs with from three to seven flection legs are distorted. For example, it can be seen from Fig. 11(a and b) that flection legs inter-touch, while FPA with two flection legs avoid distortion (see Fig. 12(a)).

Fig. 13. Graph of grey change to FPA rotation angle change.
FPAs with optimized dimensions cannot be fabricated under the existed experiment condition. The reason making the flection legs inter-touch may be the release of remainder stress in SiN_{x}/Au film, which cannot be well controlled. Joyfully, FPA with two flection legs is fabricated successfully, and an image of human hand under 23.2 °C background is obtained (see Fig. 12(b)). The grey changes detected in CCD induced by absorption of IR human hand is measured to be 58.14 grey/(mK). The optic sensitivity (γ = Δl/Δθ) measured is 10034 deg^{-1} (see Fig. 13). Calculated performances of FPA with two flection legs by using above thermal–mechanical model and its tested performances are summarized in Table 4.

5. Conclusion

It can be seen from the discussion above that the simulated thermal–mechanical angle 2.459 × 10^{-3} rad/K by finite element simulation method is basically identical to numerical analysis result 5.346 × 10^{-3} rad/K from the thermal–mechanical model. The small difference in two values is mainly due to the errors between every simulation shells which are used to simplify the practical case. The thermal–mechanical sensitivity tested in the experiment is 3.322 × 10^{-4} rad/K, generally in good agreement with what the thermal–mechanical model forecast (1.025 × 10^{-4} rad/K). Two validations improve the practicality of the thermal–mechanical model, which can offer an effective reference for FPA structure parameters design in UOII.

The cantilever material chosen and structure dimensions are directly influence the thermal and thermal–mechanical properties. In order to optimize the FPA structure, materials of large mismatch in thermal expansion coefficients and low thermal conductivities are chosen. Bigger IR absorption pad and narrower–thinner–longer supporting beams all together can make higher cantilever temperature increment and bigger thermal–mechanical sensitivity.

Acknowledgement

Supported by National Natural Science Foundation of China (no. 60576053).

References


Biography

Shi Sha-li received the BS degree in applied physics from Wuhan University (WHU), Wuhan, China, in 2002. She is currently working towards the PhD degree in Micro-processing and Nano-technology Department at IME CAS. Her research interests include design and fabrication of MEMS.