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# Characterization of thermal expansion coefficient of LPCVD polycrystalline SiC thin films using two section V-beam actuators

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**Abstract**

In this paper we present the characterization of the coefficient of thermal expansion (CTE) of in-situ doped polycrystalline SiC thin films, obtained by low pressure chemical vapor deposition (LPCVD). The material is characterized using V-beam actuators on which the temperature coefficient of resistance (TCR) and the in-plane displacement versus current are measured. A CTE value of 4.3 ± 0.4 ppm/K is obtained in the temperature region of 20 °C to 300 °C. This value is used in a finite element modeling (FEM) simulation of vertical SiC-$SiO_2$ bimorph beams. For an actuator length of 700 µm, width of 100 µm and layer thickness of 2 µm, a displacement up to 200 µm can be obtained.


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*Keywords:* coefficent of thermal exoansion, silicon carbide, actuators

## 1. Introduction

Among all MEMS actuators, electrical comb drive and electro-thermal V and U beams are widely used for in-plane motion. However, they cannot easily achieve displacement above 100 µm [1] in a single actuator configuration. On the other hand, a bimorph beam provides high displacement in out-of-plane motions. A bimorph consists of two horizontal layers of material with a large difference in coefficient of thermal expansion (CTE). To use the advantages of bimorphs for in-plane motion, layers should be stacked vertically, like depicted in Fig. 1. To realize this configuration, layers with the desired thermal and electrical properties that can be patterned in a high-aspect ratio should be considered. The good combination of mechanical, electrical and thermal properties makes SiC a promising candidate for bimorph applications. Further, low pressure chemical vapor deposition (LPCVD) of SiC is suitable for the controlled filling of high aspect ratio trenches, thus allowing the fabrication of vertical bimorph actuators in a silicon substrate.


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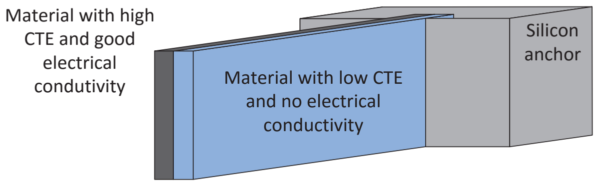


Fig. 1. Vertically stacked layers for an in-plane motion electro-thermal bimorph actuator.

To make an accurate simulation model of any actuator, it is essential to have the correct physical parameters of the materials used. For electro-thermal actuators, the most important relevant material property is the coefficient of thermal expansion. In literature, a large variation of values is reported for this parameter [2], [3]. Therefore, it is crucial to properly characterize the CTE of the LPCVD SiC layer to accurately model the device and determine the optimal fabrication process.

For the purpose of CTE extraction, LPCVD SiC two-section V-beam actuators are fabricated using surface micromachining. The electro-thermal characterization of these V-beam actuators is done by measuring the temperature dependency of resistance (TCR characterization) and the horizontal displacement versus input current [4]. Based on these measurements, a FEM model was built in order to evaluate the CTE for the SiC layer. Using the obtained CTE value, a FEM model of the SiC-$SiO_2$ bimorph actuator was built. Verification of the model is done by measuring the displacement of the fabricated SiC-$SiO_2$ bimorphs up to temperature of 200 °C.

## 2. Two section V-beam actuators for CTE characterization

The two section V-beam actuator system design is illustrated in Fig. 2(a). The system has a shuttle, which is on one side suspended with two hinges and on the other with two V-shaped beams. Both beams and hinges are anchored at one end. The actuators, hinges and anchors are made of conductive, in-situ doped SiC. Therefore, the V-beam anchors also serve as electrical contact pads for the actuators.

The actuator fabrication process is presented in Fig. 2(b1) – Fig. 2(b7). Both sacrificial and hard mask $SiO_2$ layer were deposited using plasma enhanced chemical vapour deposition (PECVD), while 1.5 μm thick layer of in-situ n-type doped SiC is deposited using $C_2H_2$ and $SiH_2Cl_2$ as precursors for LPCVD deposition. The SiC layer is etched down to the sacrificial layer in a HBr/Cl plasma and the full device is released in vapour HF to prevent stiction of the structure to the substrate. Finally, an optical image of the final device is given in Fig. 2(b8).

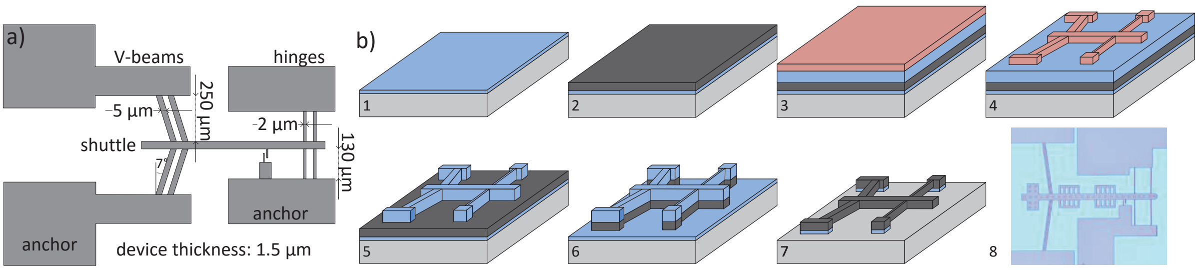


Fig. 2. (a) Actuator system design and geometry parameters. (b) Fabrication flow for SiC two-section V-beam actuators: (1) PECVD deposition of 3 μm thick $SiO_2$ sacrificial layer (2) LPCVD deposition of 1.5 μm thick SiC device layer (3) PECVD deposition of 5 μm thick $SiO_2$ hard mask layer and photoresist coating (4) UV exposure and photoresist development (5) $SiO_2$ hard mask dry etching (6) SiC dry etching (7) Device release and hard mask removal in vapor HF. (8) Fabricated SiC two section V-beam actuator.

### *2.1. TCR characterization*

The Thermal Coefficient of Resistivity (TCR) of the deposited SiC layer was characterized. The V-beam actuator resistance was measured over the temperature range of 20$^{O}$C – 200 $^{O}$C in steps of 50 $^{O}$C on a probe station with a thermally controlled chuck. These measurements were performed with limited power to avoid any self-heating that could influence the result.

The TCR was initially calculated using the formula: $R(T)=R_0[1+\alpha(T-T_0)]$, where $R_0$ is the resistance at reference temperature $T_0$ and $\alpha$ is the TCR. As the measured resistance appears to follow a 2nd degree polynomial behaviour (Fig. 3(a)), we can substitute the constant $\alpha$ with a linear function, $\alpha = f(T)$, as shown on Fig. 3(b), effectively turning the linearized resistance formula above to a 2nd degree approximation. As reported in [4] this polynomial approximation gives a good agreement to measured values up to 700 $^{O}$C and we assumed to be the case in our layer as well.

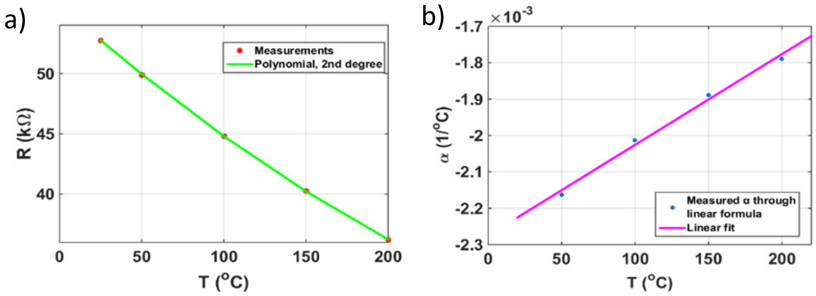


Fig. 3. (a) Resistance measurements and (b) TCR approximation.

## *2.2. Actuators in-plane displacement*

The fabricated actuator was characterized with the configuration shown in Fig. 4. A current source supplied current in 0.5 mA steps. The voltage across the pads was measured (4-probe Kelvin measurement method) and the device resistance was calculated. As the current heated the V-beams through Joule heating, the small SiC expansion was mechanically amplified by the shape of the structure. The displacement of the tip from its rest position was optically measured using a high magnification microscope.

The displacement measurement was done with the technique presented in [5]. A high-speed camera tracks the light intensity profile of a stationary thin fin attached to the substrate and a moving fin attached to the actuator. Curves are fitted to those profiles as seen in Fig. 4(b) and an accurate displacement *d* can be calculated between them. The displacement measurement is combined with the resistance measurement to provide all the necessary data to calculate the CTE (Fig. 4(c)). The procedure is repeated a few times and the results are averaged.

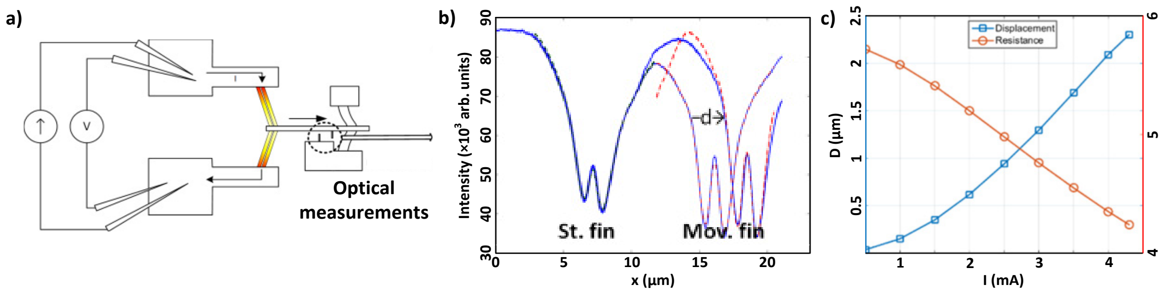


Fig. 4. (a) Actuator and resistance measurement setup, (b) displacement measurement and (c) final data extracted.

## *2.3. FEM model for CTE extraction*

From the data measured in section 2.3, a FEM model was constructed to calculate the CTE of SiC, which included simulation of thermal conduction and thermal expansion. First, the resistance values at different actuation current levels were used to calculate the average temperature along the V-beams and set into the model ($T_{meas}$). Heat transfer was simulated with conduction paths through the anchors and the air to the substrate. Although air is a good thermal insulator, the distance of the structure from the substrate was very small (3 μm) and hence the air thermal conduction could not be omitted. The thermal simulation assumptions can be seen in Fig. 5(a).

The SiC layer exhibited a gradient stress component that caused the thin actuator structure to buckle. This caused unexpected non-linear out of plane motion when current was applied and essentially introduced a variable offset in the measured horizontal displacement at different current levels. The buckling was measured with a white light interferometer and was accounted for in the model by including the gradient stress value that resulted in the same amount of buckling. However, at low actuation currents, any unaccounted errors in the motion or temperature are proportionally larger, resulting in high CTE mismatch from the apparent trend (Fig. 5(b)). For the temperature range of 50 °C to 300 °C, extracted CTE has a value of 4.3 ± 0.4 ppm/K.

In order to verify the obtained CTE value for our LPCVD SiC layers, a FEM model of SiC-$SiO_2$ bimorph actuators was compared with the fabricated bimorph devices for a working temperature of 200 °C. The results are presented in Table 1. The good agreement observed indicates the accuracy of the CTE value.

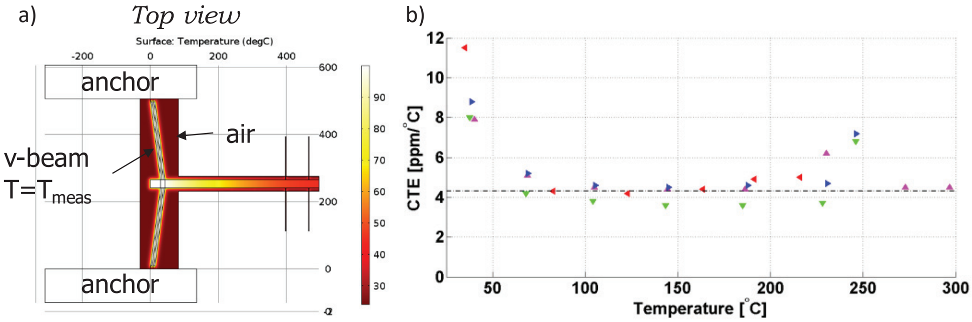


Fig. 5. (a) Finite element model and its results for 4 different samples. (b) Coefficient of thermal expansion versus temperature.

Table 1. Comparison of simulated ($d_s$) and measured ($d_m$) displacement of a SiC-$SiO_2$ bimorph actuator

| Bimorph length $L$ | Simulated displacement $d_s$ | Measured displacement $d_m$ |
|---|---|---|
| 700 µm | 36.45 µm | 39.4 µm |
| 600 µm | 22.23 µm | 24.2 µm |
| 500 µm | 26.18 µm | 30.2 µm |

## 3. Conclusion

In this paper we presented the CTE characterization of in-situ doped polycrystalline SiC thin films, using electro-thermal MEMS actuators. We showed it is possible to electro-thermally characterize this material up to 200 °C using a probe station for TCR and optical microscope displacement measurements on two-section V-beam actuators. Using the same FEM model we calculated that for a temperature of 800 °C it is possible to achieve displacement of 200 µm, thus indicating the potential applicability of in-situ doped SiC for MEMS actuator fabrication, when large displacements are needed.

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