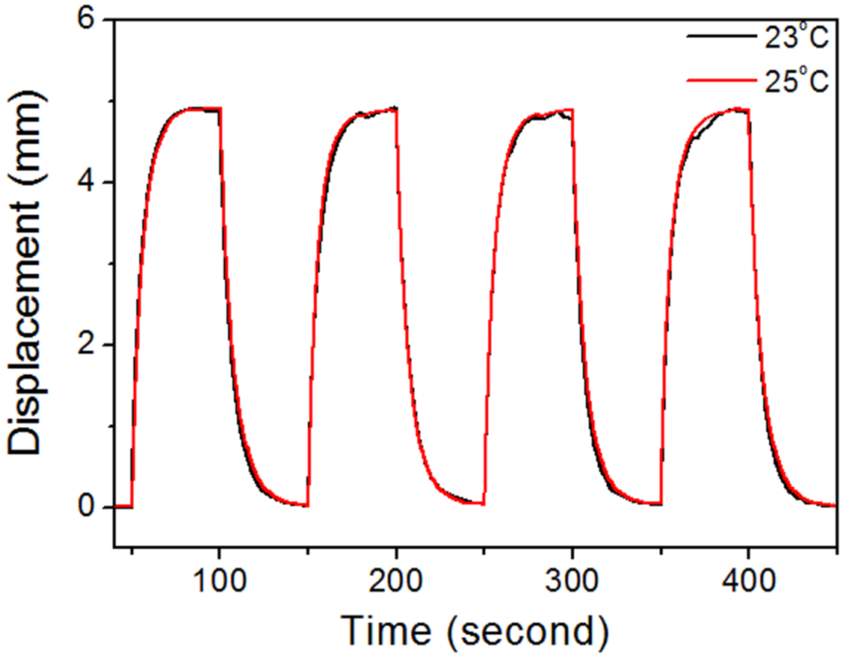

Fig. S1 0.01Hz square wave voltage (0~4V) actuated displacement of the sG/PDMS bimorph with different environmental temperature of 23℃ and 25℃.

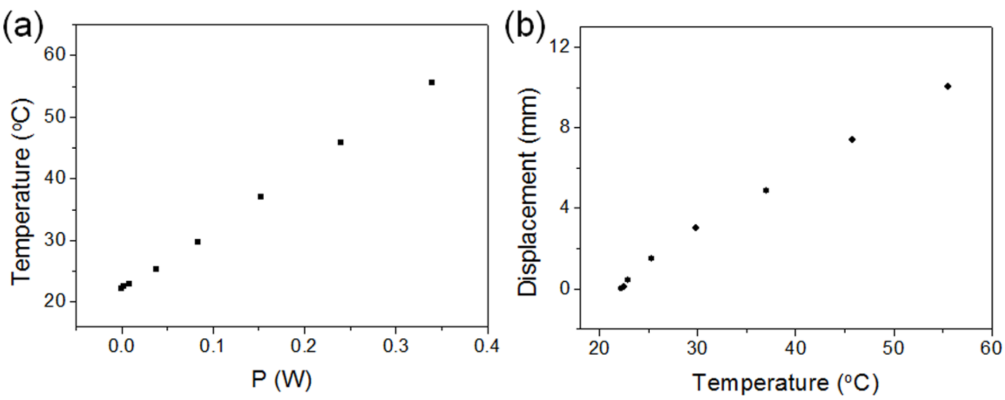

Fig. S2 (a) Generated temperature of the bimorph actuator versus the input electric power. (b) Maximum displacement of the bimorph actuator versus the generated temperature.

From the experiment result we could see that although the displacement is increased with the decrease of the PDMS thickness, the generated displacement of the bimorph actuator is reversed for the thickness below 130um. Hence, the equation for bimorph cantilever deflection as a function of the thickness and Young's Moduli of the two materials is used to explain the actuator behavior. In order to simplify the actuator behavior process, a simple bimorph cantilever consisted of two layers is created, as shown in figure S3. We assume that a certain temperature change is applied on the bimorph, and the different thermal expansion forces induced moment could cause the bending deformation of the bimorph cantilever. Here l and w are the length and width of the bimorph, respectively, and t_1 and t_2 are the thickness of the two layers. The equation derivation is as follows:

Due to the applied temperature load, the original thermal expansion forces for the two layers are,

$$F_1 = A_1 E_1 \varepsilon_{T1} = w t_1 E_1 k_1 \Delta T \tag{1}$$

$$F_2 = A_2 E_2 \varepsilon_{T2} = w t_2 E_2 k_2 \Delta T \tag{2}$$

Where E_1 and E_2 are the Young's modulus of the two layers, A_1 and A_2 are the sectional areas, k_1 and k_2 are the CTE of the two layers, ΔT is the temperature change of the bimorph cantilever, and F_1 and F_2 are the thermal expansion force of the two layers.

The axial forces F_1 and F_2 can cause a combined deformation to the bimorph, an axial tensile deformation plus a pure bending deformation. Assuming that the equivalent forces caused the axial tensile deformations for the two layers are F_1' and F_2' respectively, and the transfer force at the interface from the PDMS layer to the sG layer is ΔF. Then we have the following force relationships,

$$F_1' = F_1 + \Delta F \tag{3}$$

$$F_2' = F_2 - \Delta F \tag{4}$$

And the total equivalent moment induced the pure bending deformation can be calculated from the transfer force,

$$M = \Delta F \cdot \left(\frac{t_1 + t_2}{2} \right) \tag{5}$$

The moment M causes pure bending deformations for the two layers, and then it can be divided into two parts for the two layers respectively,

$$M = M_1 + M_2 \tag{6}$$

And M1 and M2 are satisfied with the following two conditions. The first condition is that the curvatures of the two layers are the same. That is,

$$\frac{M_1}{E_1 I_1} = \frac{M_2}{E_2 I_2} \tag{7}$$

Where I_1 and I_2 are the moments of inertia of area of the two layers respectively. The second condition is that the strain at the interface between the two layers is continuous.

$$\frac{F_1'}{t_1 w E_1} + \frac{M_1}{E_1 I_1} \cdot \frac{t_1}{2} = \frac{F_2'}{t_2 w E_2} + \left(-\frac{M_2}{E_2 I_2} \frac{t_2}{2} \right) \quad (8)$$

Using Eq. (1)~(8), we can get the moment M_2 as follows,

$$M_2 = (k_2 - k_1)\Delta T \frac{1}{\frac{2}{t_1+t_2}\left(\frac{1}{t_1 w E_1} + \frac{1}{t_2 w E_2}\right)\left(1 + \frac{E_1 I_1}{E_2 I_2}\right) + \frac{t_1+t_2}{2E_2 I_2}} \quad (9)$$

And the curvature of the bending bimorph can be obtained,

$$\frac{1}{\rho} = \frac{M_2}{E_2 I_2} = (k_2 - k_1)\Delta T \frac{1}{\frac{2}{t_1+t_2}\left(\frac{1}{t_1 w E_1} + \frac{1}{t_2 w E_2}\right)(E_2 I_2 + E_1 I_1) + \frac{t_1+t_2}{2}} \quad (10)$$

Then the tip displacement of the bending bimorph is,

$$D \approx \frac{1}{\rho}\frac{l^2}{2} = (k_2 - k_1)\Delta T l^2 \cdot \frac{1}{\frac{4}{t_1+t_2}\left(\frac{1}{t_1 w E_1} + \frac{1}{t_2 w E_2}\right)(E_2 I_2 + E_1 I_1) + t_1 + t_2} \quad (11)$$

Where I_1 and I_2 are,

$$I_1 = \frac{1}{12} w t_1^3 \quad (12)$$

$$I_2 = \frac{1}{12} w t_2^3 \quad (13)$$

Using Eq. (12) and (13) in Eq. (11), we can get

$$D \approx \frac{(k_2 - k_1)\Delta T l^2}{t_1} \cdot \frac{1}{\frac{1}{3(1+x)}\left(1 + \frac{E_1}{E_2} \cdot \frac{1}{x}\right)\left(1 + \frac{E_2}{E_1} x^3\right) + (1+x)} \quad (14)$$

Where x is defined as,

$$x = \frac{t_2}{t_1} \quad (15)$$

From the Eq. (14) we could get that the displacement as a function of the thickness of the layers is not monotonic. The displacement with PDMS thickness of 80μm is indeed lower than the displacement with PDMS thickness of 130μm. Considering the temperature change, this trend of the displacement versus thickness from the equation is nearly consistent with the observed experiment result.

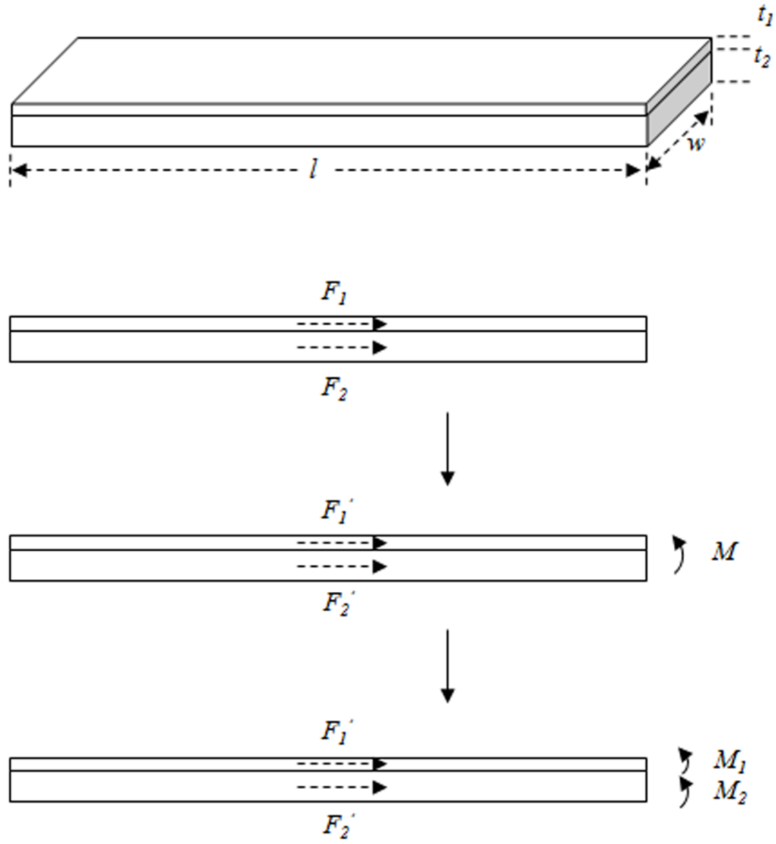

Fig. S3 Schematic diagram of force analysis of the thermal expansion induced bending deformation of the bimorph

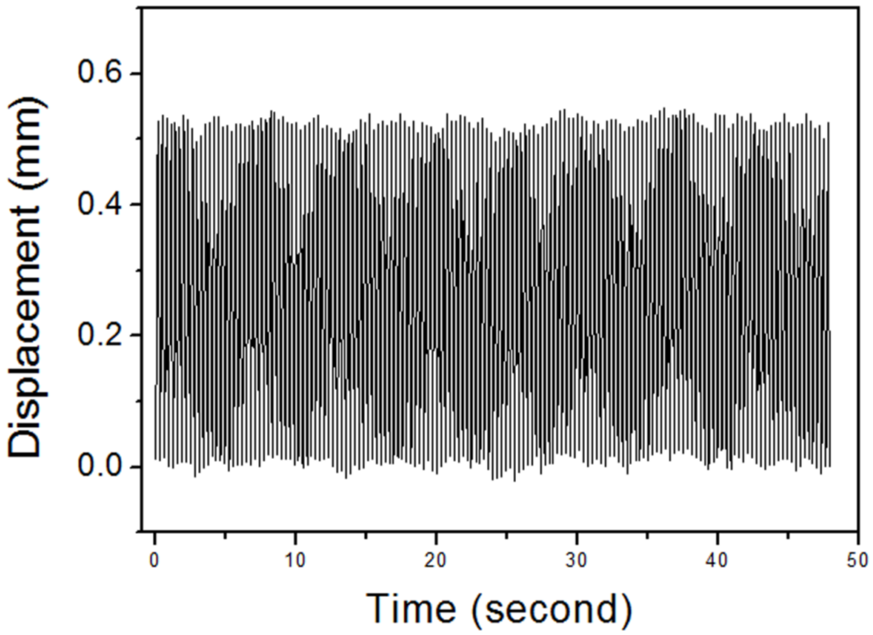

Fig. S4 Vibration displacement of the sG/PDMS bimorph under the 5Hz square wave voltage (0~10V).

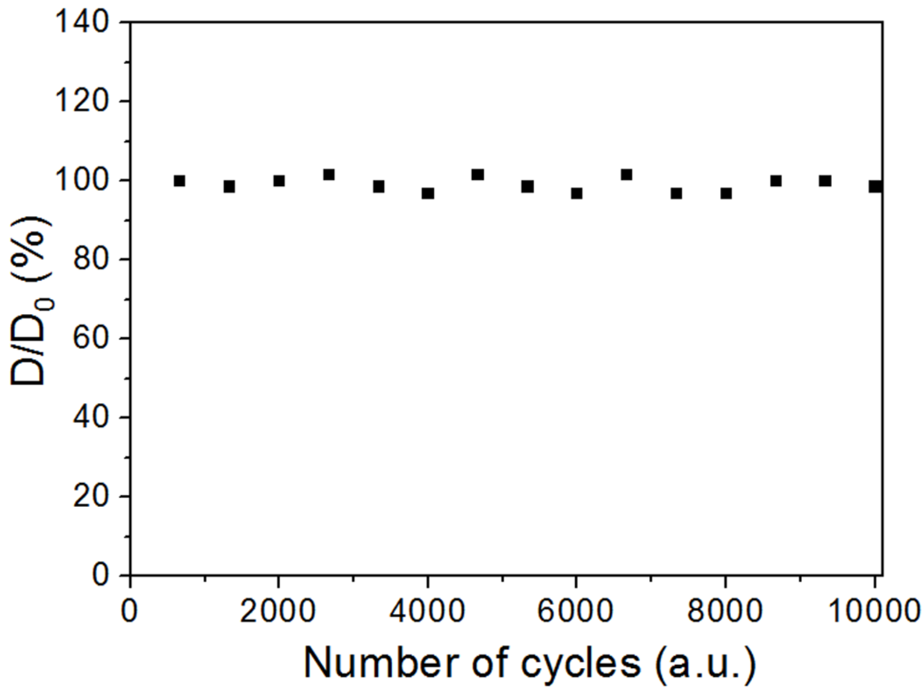

Fig. S5 Cycle life of the sG/PDMS bimorph with the 0.5Hz square wave voltage (0~5V) for about 10000 cycles. D_0 represents the initial displacement value.

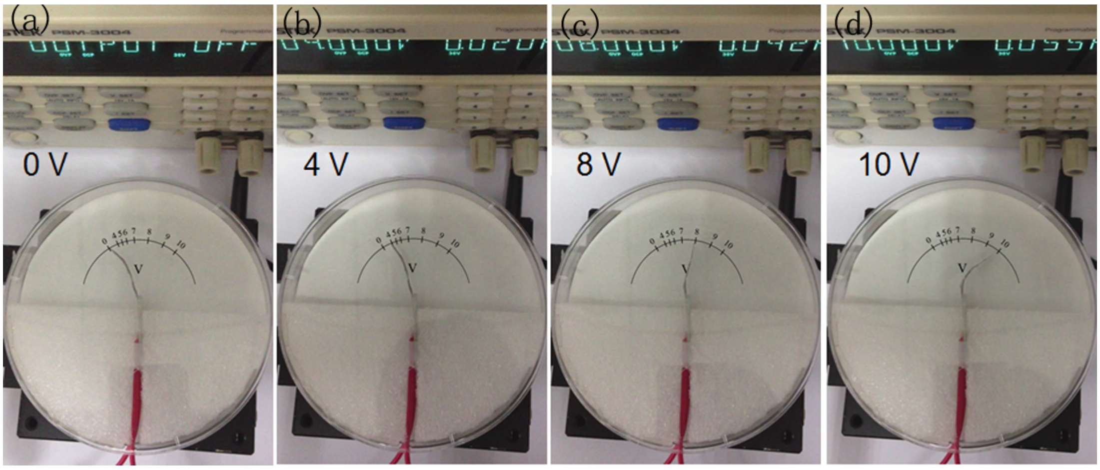

Fig. S6 A prototype voltmeter based on sG/PDMS bimorph actuator can measure the voltage ranging from 0V to 10V: (a) 0V, (b) 4V, (c) 8V, (d) 10V. The upper part of the images is a power supply, and the green numbers on its screen display corresponding output voltage.