Supplementary material

High-performance optical projection controllable ZnO nanorod arrays microweighing sensor

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1 Theoretical relationship between the output current and structure size

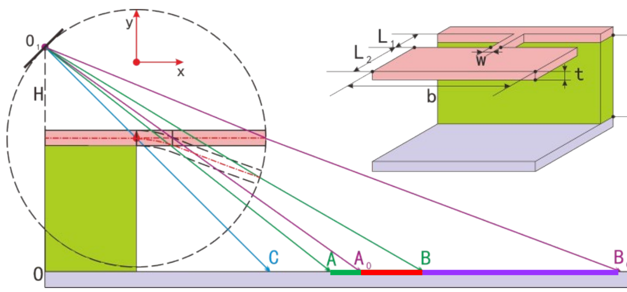

Figure S1 Simplified geometrical model of the optical projection controllable microweighing sensor.

The schematic illustration and geometrical model of the optical projection controllable microweighing sensor are shown in Figure S1. The microcantilever (MC) would produce a downward deflection when external weight applied on it. The projected area (*S*) of the MC on the ZnO photosensitive layer is given by the following equation,

$$S = b \times L_{projection} = b(|\vec{OB}| - |\vec{OA}|) \quad (1)$$

where $L_{\text{projection}}$ is the length of projected area boundary in x axis; *b* is the width of the guide structure of MC (10 mm); $|\vec{OA}|$ and $|\vec{OB}|$ are the boundary of MC projected area, as shown in Figure S1. The values of $|\vec{OA}|$ and $|\vec{OB}|$ at any bending angles of MC can be given as follows:

$$|\vec{OA}| = \frac{(H+t+h)(L_0 + L_1\cos\theta)}{H+t+L_1\sin\theta} \quad (2)$$

$$|\vec{OB}| = \frac{(H+t+h)\left[(L_1+L_2)\cos\theta\right]}{H+(L_1+L_2)\sin\theta} \quad (3)$$

where *H* is the height between the UV light source and the upper surface of the MC; *t*, *h* are the thickness (25 μm) and height of the MC, respectively; L_0 is the horizontal distance between the UV light source and the geometric center of MC; L_1 is the length of the beam of MC (6 mm); L_2 is the length of the guide structure of MC (6 mm); θ is the bending angle of the MC.

Integrating equations 1–3, the projected area of the MC can be obtained as follows:

$$S = b(H+t+h)\left[\frac{L_0 + (L_1+L_2)\cos\theta}{H+(L_1+L_2)\sin\theta} - \frac{L_0 + L_1\cos\theta}{H+t+L_1\sin\theta}\right] \quad (\theta \le \alpha) \quad (4)$$

where α is the incident angle of UV light source. We can find that the projected area S of the MC is only related to the bending angle θ when the dimensions of optical microweighing sensor are determined. Here, it should be noted that θ must be less than incident angle of UV light source during the tests, otherwise the theoretical formula is not applicable. The reason can be explained as that the bending angles of MC aren't able to be detected once it surpasses the illuminating area. Assuming that the photocurrent per unit area of photosensitive layer is I_0 with a certain light intensity, the equation 4 can be further represented as follow:

$$I = bI_0\left(H+h+t\right)\left[\frac{L_0+\left(L_1+L_2\right)\cos\theta}{H+\left(L_1+L_2\right)\sin\theta}-\frac{L_0+L_1\cos\theta}{H+t+L_1\sin\theta}\right] \quad (\theta\leq\alpha) \tag{5}$$

The bending angle of the MC θ is given by

$$\theta = \frac{F\left(L_1+L_2\right)^2}{2EI} \tag{6}$$

where F is the weight applied on the MC, E is Young's modulus and I is the area moment of the cross section with respect to the neutral axis of the MC. Equation 6 confirms that the bending angle of MC is related to the external applied weight.

2 Simulation results about the deformation and weights

Equations 1-6 are based on the consistent deformation of MC. If the deformation of MC is not coordinated, the actual projected areas would cause error with the theoretical projected areas. Hence, the uniform and consistent deformation of MC is very important for the performance of presented optical projection controllable microweighing sensor. The deformation of MC was simulated (parameters of simulation is shown in Table S1) and the results are shown in Figure S2, which indicated that the deformation of MC is uniform when different weights are applied on the surface (the loads are 3.3 mN (10°), 6.4 mN (20°), 10.1 mN (30°), 15.3 mN (40°), 22.5 mN (50°), 31.2 mN (60°), 41.7 mN (70°), 51.6 mN (80°), respectively).

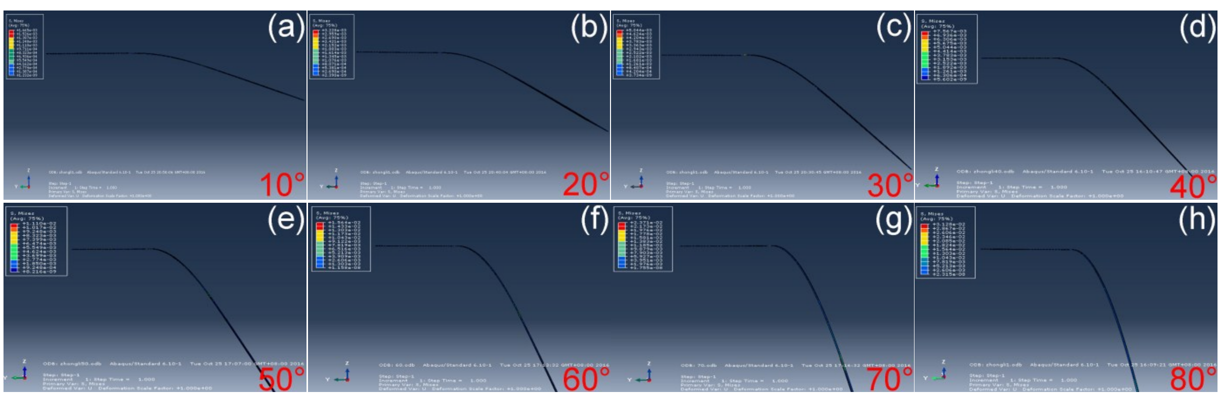

Figure S2 Relationship between the bending angle of MC and external applied weight. (a) θ =10°, (b) θ =20°, (c) θ =30°, (d) θ =40°, (e) θ =50°, (f) θ =60°, (g) θ =70°, (h) θ =80°.

Table S1 Physical properties and structure parameters of MC (Kapton film)

Thickness	Tensile modulus	Poisson's ratio	Density	b	L_1	L_2	w
25 μm	2.5 GPa	0.34	1.42 g/cm^3	10 mm	6 mm	6 mm	4 mm

The relationship between the deflection of MC and external applied weight can be confirmed with the deflection formulas[1] of MC as follows:

$$d = W(L_1 + L_2)^3 / 3EI \tag{7}$$

$$W = F(L_1 + L_2 / 2) \tag{8}$$

and

$$I = wt^3 / 12 \tag{9}$$

$$d = (L_1 + L_2)\sin\theta$$

where E is the tensile modulus of MC (2.5 GPa); w is the width of the MC beam (4 mm); F is the load applied on surface of the MC. Integrating equations 1–3, the relationship between the weight and displacement of MC can be obtained as

$$\sin\theta = \frac{4F\left(L_1 + L_2 / 2\right)(L_1 + L_2)^2}{Ewt^3} \tag{10}$$

3 Theoretical calculation of the adjustable range of UV light source

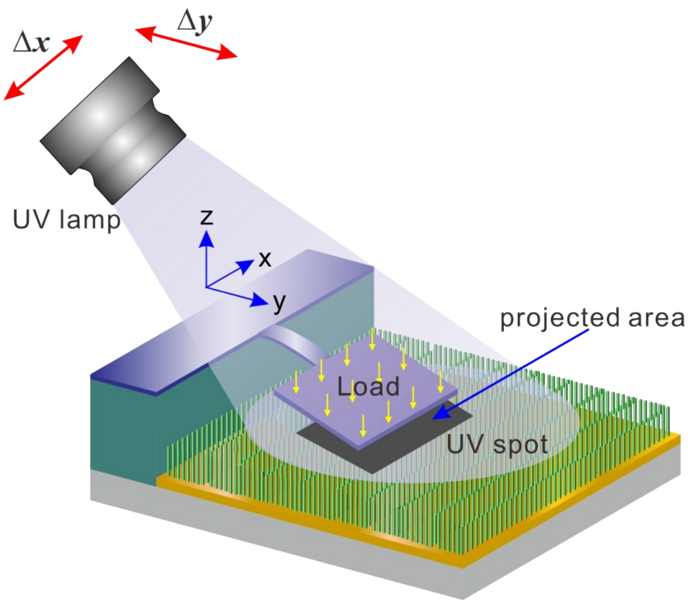

Figure S3 Schematic illustration of the adjustment of UV light source.

The detection of present optical projection controllable microweighing sensor does not require repetitive optical correction and the position of the UV light source can be adjusted within a wide range. The adjustable range (Δx and Δy) of UV light source in x and y axis can be calculated as follows (Figure S3):

$$\Delta x = \frac{D_x - b}{2} \tag{11}$$

$$\Delta y = \frac{D_y - L_2}{2} \tag{12}$$

where D_x, D_y are the UV spot minor axis and major axis on the horizontal plane of MC, respectively, which are related to the divergence angle (θ_{uv}) and radius (w(z)) of UV spot. The θ_{uv} and w(z) can be obtained by Gaussian theory[2],

$$w(z) = w_0\sqrt{1+\left(\frac{\lambda z}{\pi w_0{}^2}\right)^2} \tag{13}$$

$$2\theta_{uv} = \frac{2\lambda^2 z}{\pi w_0}\left(\pi^2 w_0{}^4 + z^2\lambda^2\right)^{-1/2} \tag{14}$$

Integrating equations 13-14, the D_x, D_y can be estimated as follows:

$$D_x = 2w_0\sqrt{1+\left(\frac{\lambda z}{\pi w_0{}^2}\right)^2} \tag{15}$$

$$D_x = 2w_0\sqrt{1+\left(\frac{\lambda z}{\pi w_0{}^2}\right)^2} \tag{16}$$

where w_0 is the diameter of UV light beam at the exit surface (22 mm); λ is the wavelength of UV light source (365 nm); z is the distance between the UV light source and MC. Equations 15 and 16 indicate that D_x, D_y are controlled by z, however, α can also affect the D_y. Hence, Δx and Δy can be written as

$$\Delta x = w_0\sqrt{1+\left(\lambda z / \pi w_0\right)^2} - b/2 \tag{17}$$

$$\Delta y = \frac{w_0\sqrt{1+\left[\lambda\left(z - w_0\tan\alpha\sqrt{1+(\lambda z/\pi w_0{}^2)^2}\right)/\pi w_0{}^2\right]^2}}{\sin\left(\alpha-\theta_{uv}\right)} - L_2/2 \tag{18}$$

The values of $\lambda z/\pi\omega_0$ and $\lambda(z - \omega_0 tan\alpha\sqrt{1+\left(\frac{\lambda z}{\pi\omega_0^2}\right)^2})$ are close to zero in near-field, Δx and Δy can be further simplified as

$$\Delta x = \omega_0 - b/2 \tag{19}$$

$$\Delta y = \frac{\omega_0}{sin\alpha} - L_2/2 \tag{20}$$

Reference

1. R. Roark and A. Sadegh, *McGraw-Hill*, 2003, **43**, 173.
2. P. Goldsmith, *IEEE Press*, 1998, **5**, 192.