Supporting Information

S1 Experimental observation of microtubules

In the experiments, MC-3T3-E1 cells were cultured on glass slides for 2 h. The cells were fixed with 4% paraformaldehyde. After the cell membranes were broken with 1% Triton-X100 in PBS, the cells were blocked in blocking buffer (containing 5% bovine serum albumin in PBS) for 1 h at room temperature. The slides were then incubated with primary antibodies against α-tubulin (1:200; Origene) and with a secondary antibody, Dylight-594 anti-rabbit IgG (1:400; Earthhox). Finally, the cell nuclei were visualized by DAPI (1:1,000; Sigma) and viewed under a Leica TCS SP5 confocal microscopy system. The fluorescence images were selected randomly. Microtubules (red areas) with a buckled configuration were observed in cells, as shown in Fig. 1a.

S2 Substrate stiffness

In this section, the substrate stiffness is explored for the system in which an infinite long fiber is embedded in the substrate. Given that the fiber would buckle in the xz plane, the deflection of the fiber can be expressed as

$$w = A\cos kz \tag{S1}$$

where A is the amplitude and $k = 2\pi/\lambda$ is the wavenumber, with λ being the wavelength. The fiber is assumed to be a slender beam. The normal traction $-T_x$ of the substrate to the fiber is given by

$$-T_x = E_{\mathrm{f}} I w_{,zzzz} = E_{\mathrm{f}} I k^4 A\cos kz = \beta\cos kz \tag{S2}$$

where $E_{\mathrm{f}} I$ is the bending stiffness of the fiber and $\beta = E_{\mathrm{f}} I k^4 A$. The normal traction T_x on the surface of the substrate imposed by the fiber is assumed to be uniform over the width W of the fiber cross section. For a cylindrical or tubular fiber, this width is $W = 2r$, where r is the outer radius of the fiber. Finite element simulations show the distribution of T_x along the width for a fiber embedded in substrate (Fig. S1). For a thin film resting on a compliant substrate, Jiang *et al.* [1] assumed that the normal traction was uniform over the width; Cao *et al.* [2] verified that this assumption is reasonable. The displacement field in the infinite substrate can be obtained from the integration of Kelvin's solution. Therefore, for the distributed load T_x given by eqn (S2), the normal displacement of the point $(0, y, z)$ can be obtained as

$$
\begin{aligned}
w_s(0,y,z) &= \int_{t_2=-W/2}^{W/2}\int_{t_1=-\infty}^{\infty} \frac{-\beta\alpha\cos kt_1}{W\sqrt{(y-t_2)^2+(z-t_1)^2}}\mathrm{d}t_1\mathrm{d}t_2 \\
&= -\frac{\beta\alpha}{W}\cos kz \times 2\int_{-W/2}^{W/2} Y_0(k\,|\,y-t_2\,|)\mathrm{d}t_2
\end{aligned} \tag{S3}
$$

where $\alpha = \dfrac{3-4\nu_s}{16\pi G_s(1-\nu_s)}$ according to Kelvin's solution and Y_n $(n=0,1,2,...)$ is the second kind modified Bessel function,[3] with Y_0 given by

$$
Y_0(k) = \int_0^{\infty} \frac{\cos kt}{\sqrt{t^2+1}}\mathrm{d}t \tag{S4}
$$

The strain energy per unit wavelength in the substrate under the load T_x can be solved from eqns (S2) and (S3) as

$$
\begin{aligned}
U_s &= \frac{k}{2\pi}\int_{y=-W/2}^{W/2}\int_{z=0}^{2\pi/k} \frac{\beta^2\alpha}{2W^2}\cos^2 kz \times 2\int_{t_2=-W/2}^{W/2} Y_0(k\,|\,y-t_2\,|)\mathrm{d}t_2\mathrm{d}z\mathrm{d}y \\
&= \frac{1}{2}\beta^2\alpha \times \rho(kW)
\end{aligned} \tag{S5}
$$

where

$$
\rho(kW) = \frac{2}{k^2W^2}\int_{t_2=-kW/2}^{kW/2}\int_{t_1=0}^{t_2+kW/2} Y_0(t_1)\mathrm{d}t_1\mathrm{d}t_2 \tag{S6}
$$

is a dimensionless function and kW is the dimensionless parameter. By introducing the substrate stiffness K, the strain energy in the substrate can be rewritten as

$$
U_s = \frac{1}{4}\frac{\beta^2}{K} \tag{S7}
$$

Eqns (S5) and (S6) yield the following substrate stiffness:

$$
K = \frac{1}{2\alpha}\frac{1}{\rho(kW)} \tag{S8}
$$

The function $\rho(kW)$, which is determined by the integration given in eqn (S6), cannot be obtained in explicit form. Here, a function $f = \dfrac{1}{-\ln(kW/5)}$ is found that can fit the function $1/\rho(kW)$ with high accuracy, as shown in Fig. S2. The relative error of the function f compared to the exact solution is less than 0.2% in the parameter range shown in Fig. S2. With this function, the substrate stiffness K is given by

$$K \approx \frac{1-\nu_s}{3-4\nu_s}\frac{8\pi G_s}{-\ln(kW/5)} \tag{S9}$$

For a cylindrical or tubular fiber with an outer radius of r, the substrate stiffness can be written as

$$K = \frac{1-\nu_{\mathrm{s}}}{3-4\nu_{\mathrm{s}}}\frac{8\pi G_{\mathrm{s}}}{-\ln(2kr/5)} \tag{S10}$$

For an incompressible material, eqn (S10) can be obtained from the strain energy of the substrate given by Jiang and Zhang. [4] Eqn (S10) is also consistent with the foundation stiffness adopted by Brangwynne *et al.*[5] and Su *et al.*[6] when $kr \to 0$.

For a rectangular fiber with b being the width, substrate stiffness can be written as

$$K = \frac{1-\nu_{\mathrm{s}}}{3-4\nu_{\mathrm{s}}}\frac{8\pi G_{\mathrm{s}}}{-\ln(kb/5)} \tag{S11}$$

(a)

(b)

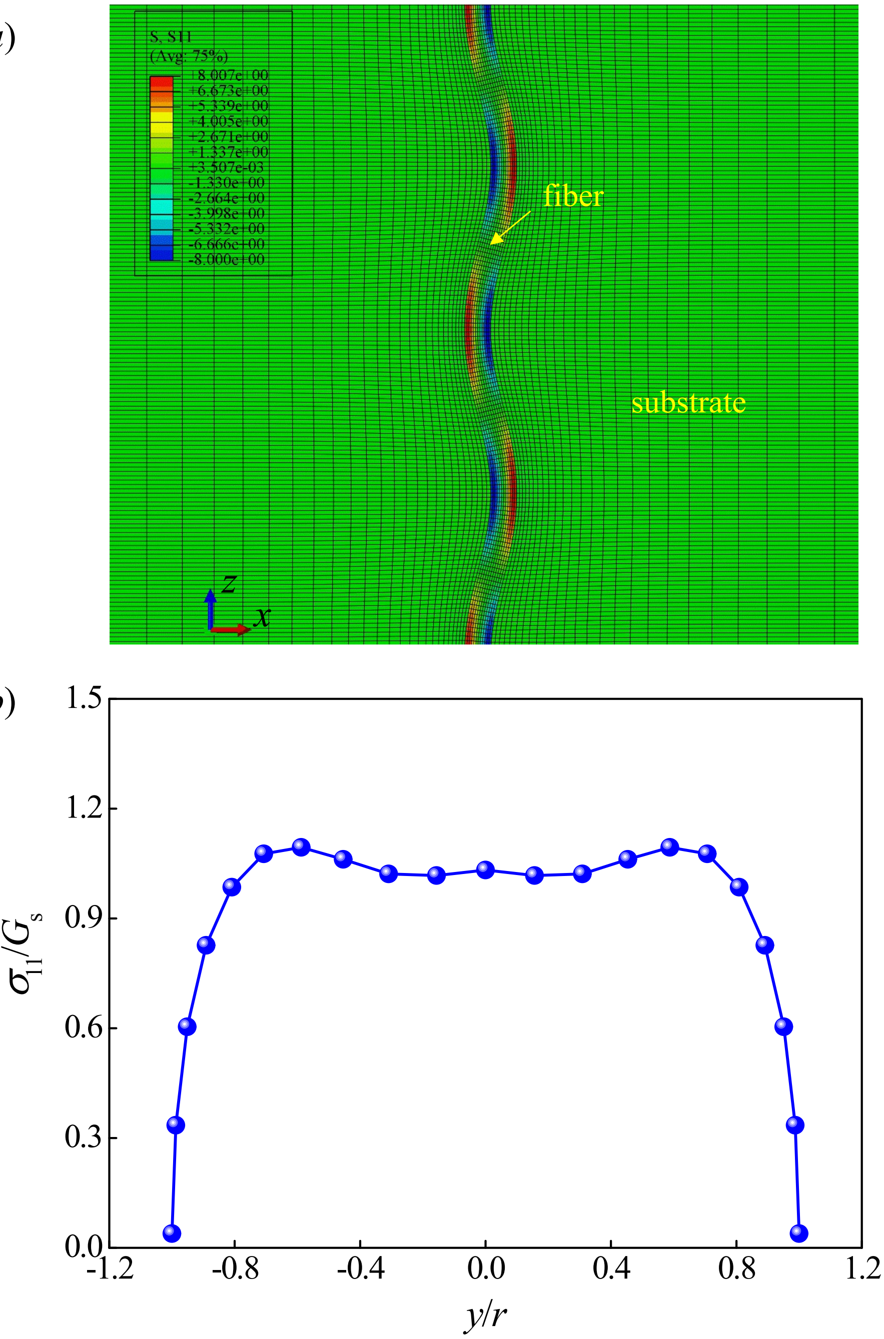

Fig. S1 (*a*) Contour of normal stresses σ_{11} at the interface between the fiber and substrate; (*b*) distribution of the normal stresses at the interface along the y direction at one buckling peak. In the simulations, the modulus ratio is $E_{\mathrm{f}}/E_{\mathrm{s}} = 445$. Poisson's ratios are both taken as 0.48. The corresponding wrinkling amplitude is r.

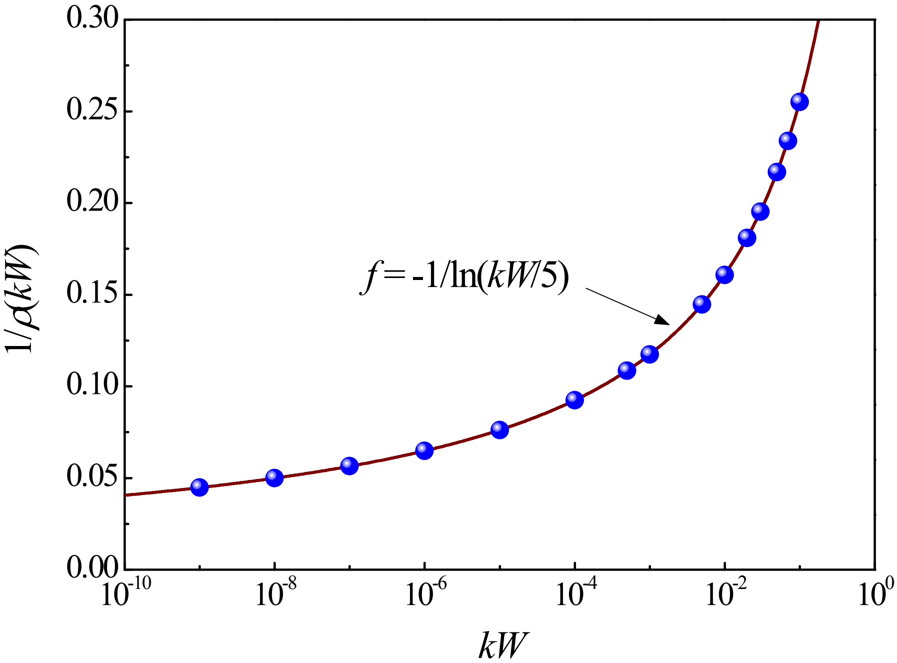

Fig. S2 Plot of the function $1/\rho(kW)$. The blue points represent the exact results that are given by numerical integration, and the line is the curve-fitting result using the function $f = -1/\ln(kW/5)$.

References

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