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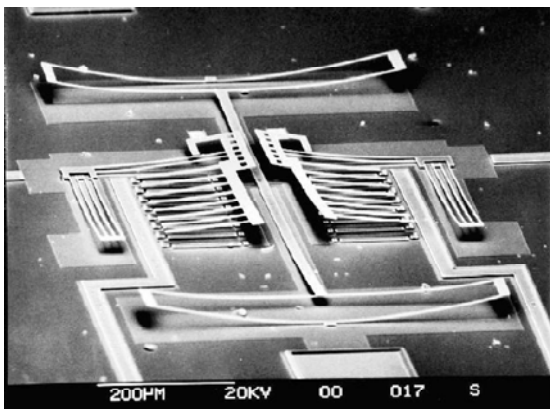
Stress Gradients in Cantilevers

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Vertical Stress Gradients

- Variation of residual stress in the direction of film growth
- Can warp released structures in z-direction



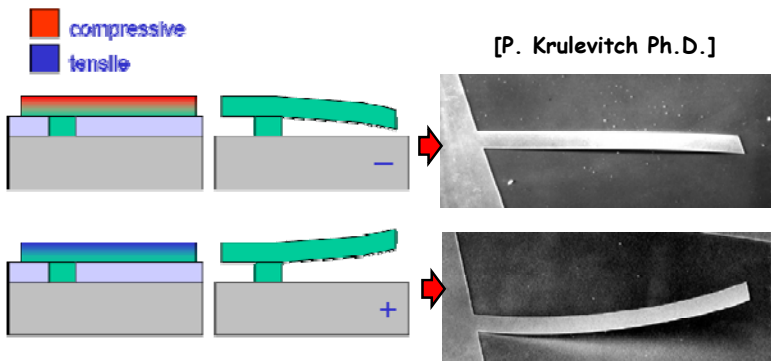
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Measurement of Stress Gradient

- Use cantilever beams
 - ↳ Strain gradient (Γ = slope of stress-thickness curve) causes beams to deflect up or down
 - ↳ Assuming linear strain gradient Γ , $z \sim \Gamma L^2/2$

[P. Krut'evitch Ph.D.]



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Folded-Flexure Suspensions

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Folded-Beam Suspension

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- Use of folded-beam suspension brings many benefits
 - Stress relief: folding truss is free to move in y-direction, so beams can expand and contract more readily to relieve stress
 - High y-axis to x-axis stiffness ratio

Folding Truss

Comb-Driven Folded Beam Actuator

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Beam End Conditions

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TABLE 4.1
Types of commonly used support conditions for beams and frames

Type of support	Displacement boundary conditions	Force boundary conditions
FREE	None	All, as specified
PINNED	$u = 0$ $w = 0$	Moment is specified
ROLLER (vertical)	$u = 0$	Transverse force and moment are specified
ROLLER (horizontal)	$w = 0$	Horizontal force and bending moment are specified
FIXED or CLAMPED	$u = 0$ $w = 0$ $dw/dx = 0$	None specified

[From Reddy, Finite Element Method]

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Common Loading & Boundary Conditions

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- Displacement equations derived for various beams with concentrated load F or distributed load f
- Gary Fedder Ph.D. Thesis, EECS, UC Berkeley, 1994

(a) Concentrated load.

cantilever	guided-end	fixed-fixed
$x = \frac{F_x L}{E h w}$	$x = \frac{F_x L}{E h w}$	$x = \frac{F_x L}{4 E h w}$
$y = 4 \frac{F_y L^3}{E h w^3}$	$y = \frac{F_y L^3}{E h w^3}$	$y = \frac{1}{16} \frac{F_y L^3}{E h w^3}$
$z = 4 \frac{F_z L^3}{E h w^3}$	$z = \frac{F_z L^3}{E h w^3}$	$z = \frac{1}{16} \frac{F_z L^3}{E h w^3}$

(b) Distributed load.

cantilever	guided-end	fixed-fixed
$x = \frac{f_x L}{E}$	$x = \frac{f_x L}{E}$	$x = \frac{f_x L}{4 E}$
$y = \frac{3}{2} \frac{f_y L^4}{E h w^3}$	$y = \frac{1}{2} \frac{f_y L^4}{E h w^3}$	$y = \frac{1}{32} \frac{f_y L^4}{E h w^3}$
$z = \frac{3}{2} \frac{f_z L^4}{E h w^3}$	$z = \frac{1}{2} \frac{f_z L^4}{E h w^3}$	$z = \frac{1}{32} \frac{f_z L^4}{E h w^3}$

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