EPFL

Paper 6 – Discussion

ME-426 – Micro/Nanomechanical Devices

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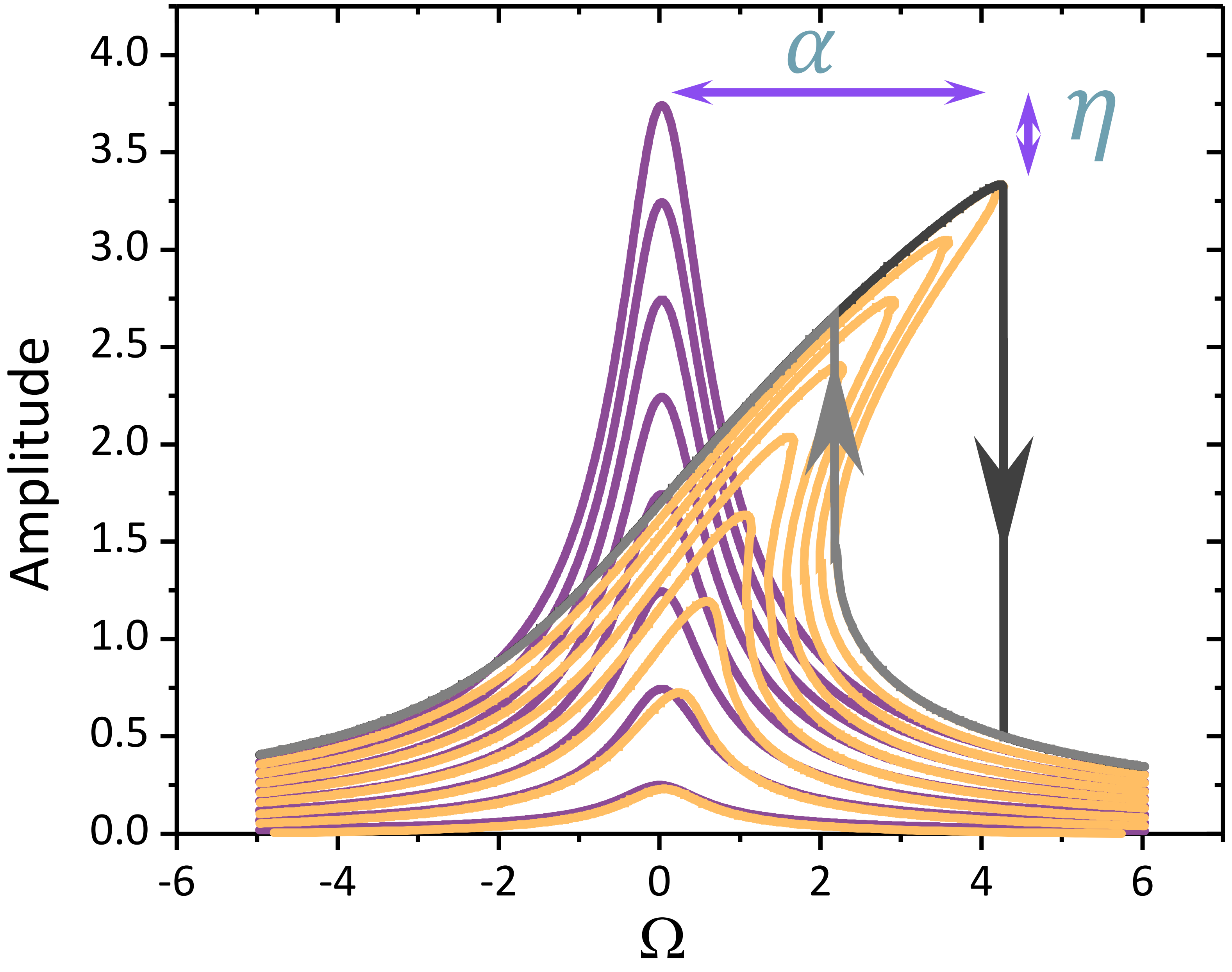
Questions

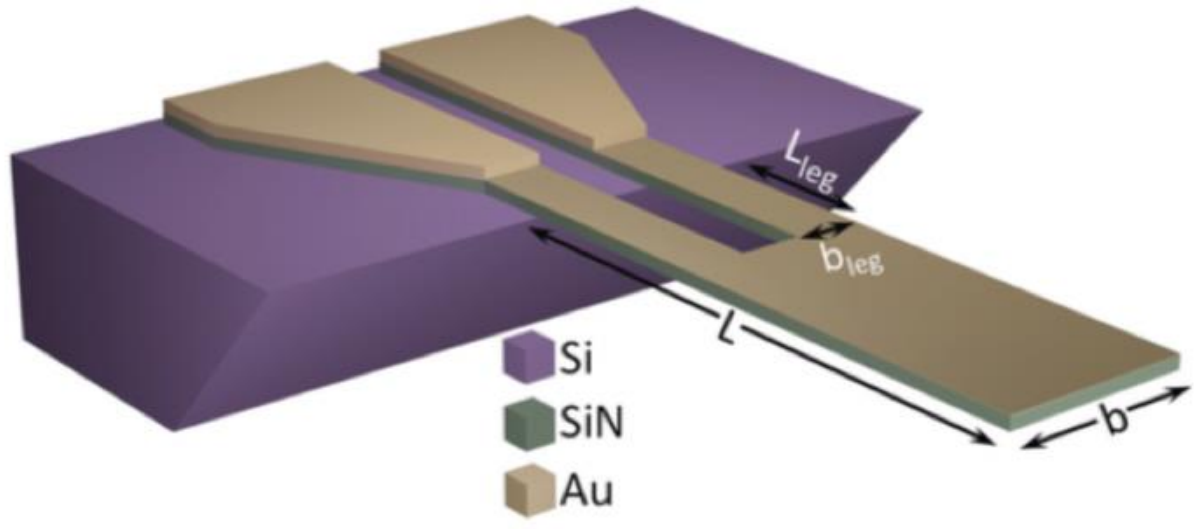
- What is the purpose of the experiment?
- How are the devices made?
- How do we know if a device has softening or stiffening NL?
- How is the device actuated and detected?
- Why do we need a calibration of the amplitude?
- Why the calibration was not important for the other papers?
- What is geometrical and inertial nonlinearity?
- What other types of nonlinearity could we find?
- Why does it depend on the aspect ratio?
- Why is there a huge difference from theory for the 1st and not for then 2nd mode?

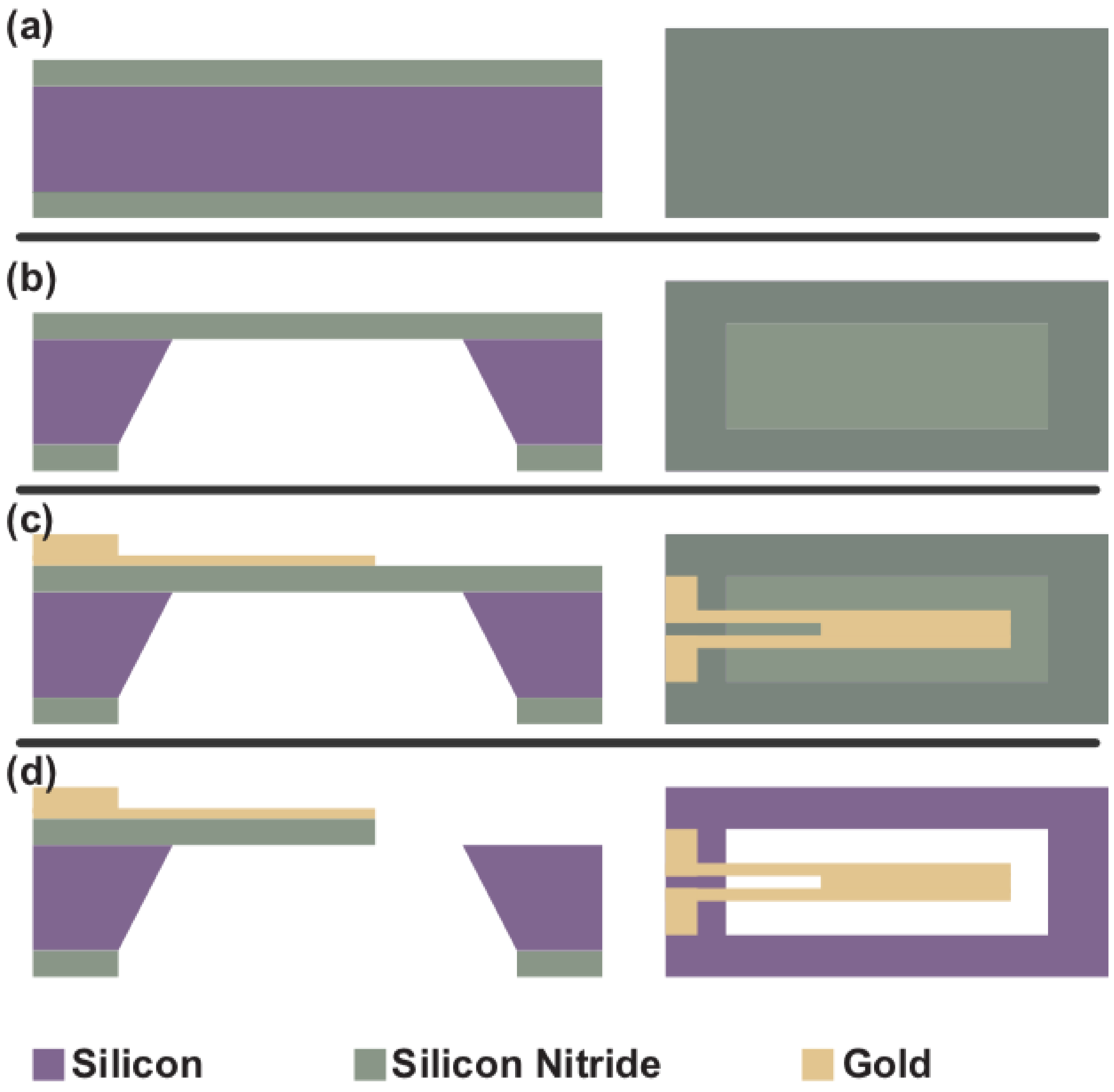
Discussion



$$|z|^2 = \frac{\left(\frac{G}{2m\omega_0^2}\right)^2}{\left(\frac{\omega-\omega_0}{\omega_0} - \frac{3}{8}\frac{\alpha}{m\omega_0^2}|z|^2\right)^2 + \left(\frac{1}{2Q} + \frac{1}{8}\frac{\eta}{m\omega_0^2}|z|^2\right)^2}$$

Discussion





Discussion

$$m_{\mathrm{eff}}\ddot{x} + \frac{m_{\mathrm{eff}}\omega_{\mathrm{R}}}{Q}\dot{x} + k_{\mathrm{eff}}x + \frac{\beta_{\mathrm{geom}}}{L^2}x^3 + \frac{\beta_{\mathrm{iner}}}{L^2}\left(x\dot{x}^2 + x^2\ddot{x}\right) = G\cos(\omega t)$$

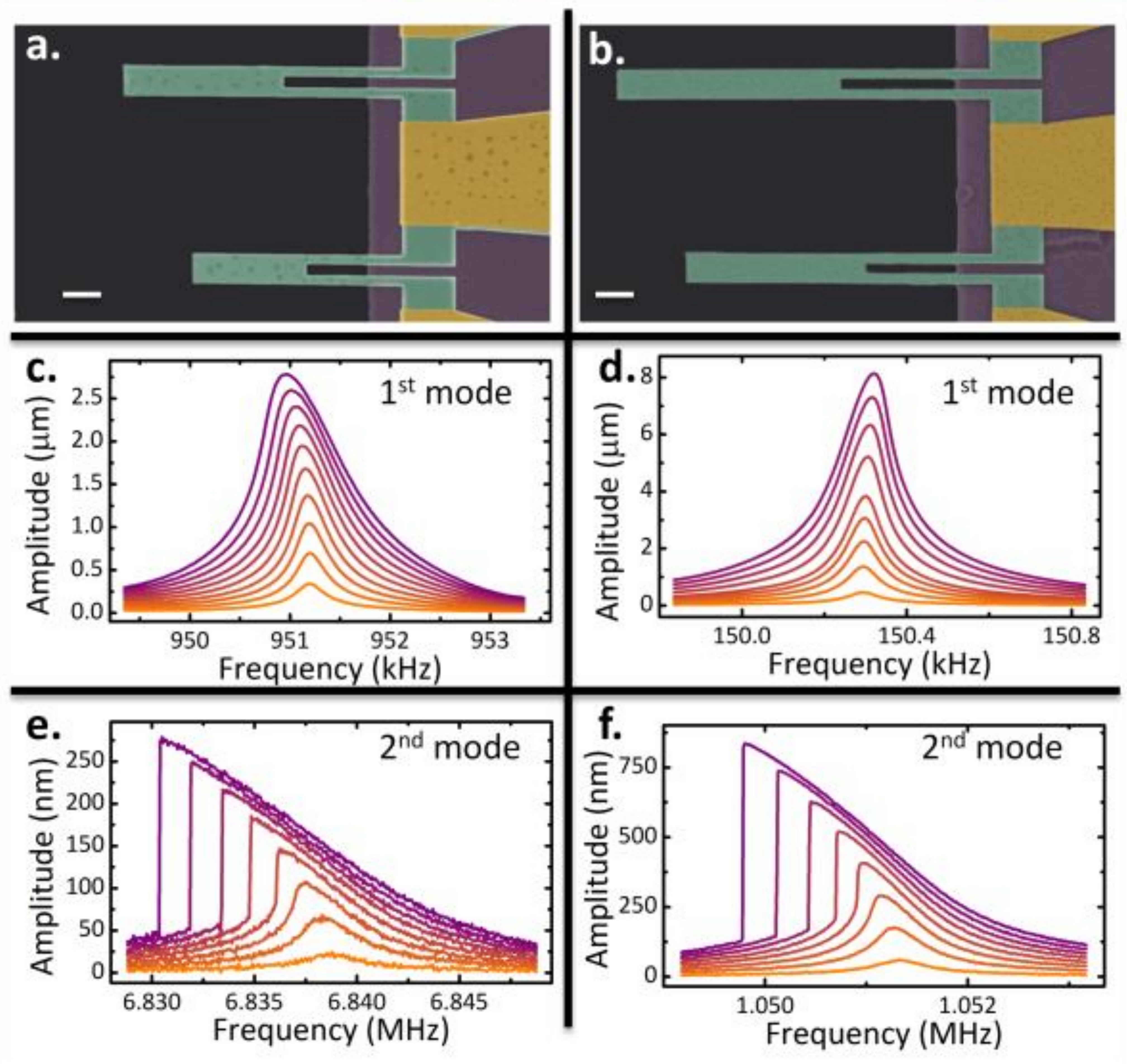
$$m_{\mathrm{eff}} = \int_0^1 \mu(\xi)\phi(\xi)^2\,\mathrm{d}\xi\,, \qquad k_{\mathrm{eff}} = \int_0^1 \langle EI\rangle(\xi)\phi''(\xi)^2\,\mathrm{d}\xi = m_{\mathrm{eff}}\omega_{\mathrm{R}}^2\,,$$

$$\boldsymbol{\beta_{\mathrm{geom}} = 2\int_0^1 \langle EI\rangle(\xi)\big(\phi'(\xi)\phi''(\xi)\big)^2\,\mathrm{d}\xi}\,, \qquad \boldsymbol{\beta_{\mathrm{iner}} = \int_0^1 \mu(\xi)\left(\int_0^{\xi}\phi'(\zeta)^2\,\mathrm{d}\zeta\right)^2\mathrm{d}\xi}\,,$$

$$\hat{\alpha} = \frac{\beta_{\mathrm{geom}}}{k_{\mathrm{eff}}} - \frac{2}{3}\frac{\beta_{\mathrm{iner}}}{m_{\mathrm{eff}}}$$

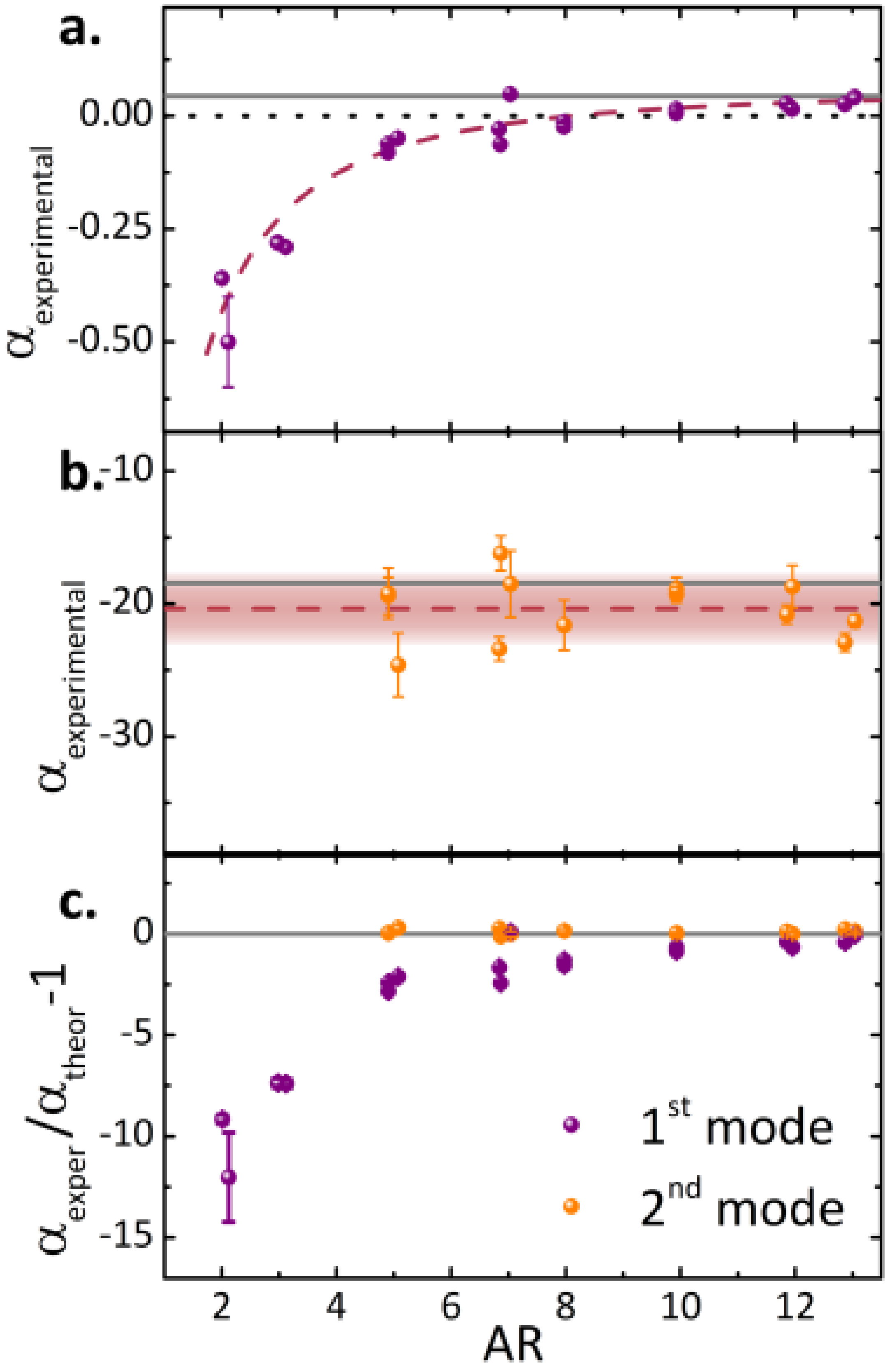
$$x^2(\omega) \approx \frac{\left(\frac{G}{2k_{\mathrm{eff}}}\right)^2}{\left(\frac{\omega-\omega_{\mathrm{R}}}{\omega_{\mathrm{R}}} - \frac{3}{8}\frac{\alpha}{L^2}x^2(\omega)\right)^2 + \left(\frac{1}{2Q}\right)^2}$$

Discussion



a.
b.
c.
1st mode
Amplitude (μm)
2.5
2.0
1.5
1.0
0.5
0.0
950
951
952
953
Frequency (kHz)
d.
1st mode
Amplitude (μm)
8
6
4
2
0
150.0
150.4
150.8
Frequency (kHz)
e.
2nd mode
Amplitude (nm)
250
200
150
100
50
0
6.830
6.835
6.840
6.845
Frequency (MHz)
f.
2nd mode
Amplitude (nm)
750
500
250
0
1.050
1.052
Frequency (MHz)

Discussion



a.
0.00
-0.25
-0.50
$\alpha_{experimental}$
b.
-10
-20
-30
$\alpha_{experimental}$
c.
0
-5
-10
-15
$\alpha_{exper}/\alpha_{theor}-1$
1st mode
2nd mode
2
4
6
8
10
12
AR