EPFL

Paper 5 – Discussion

ME-426 – Micro/Nanomechanical Devices

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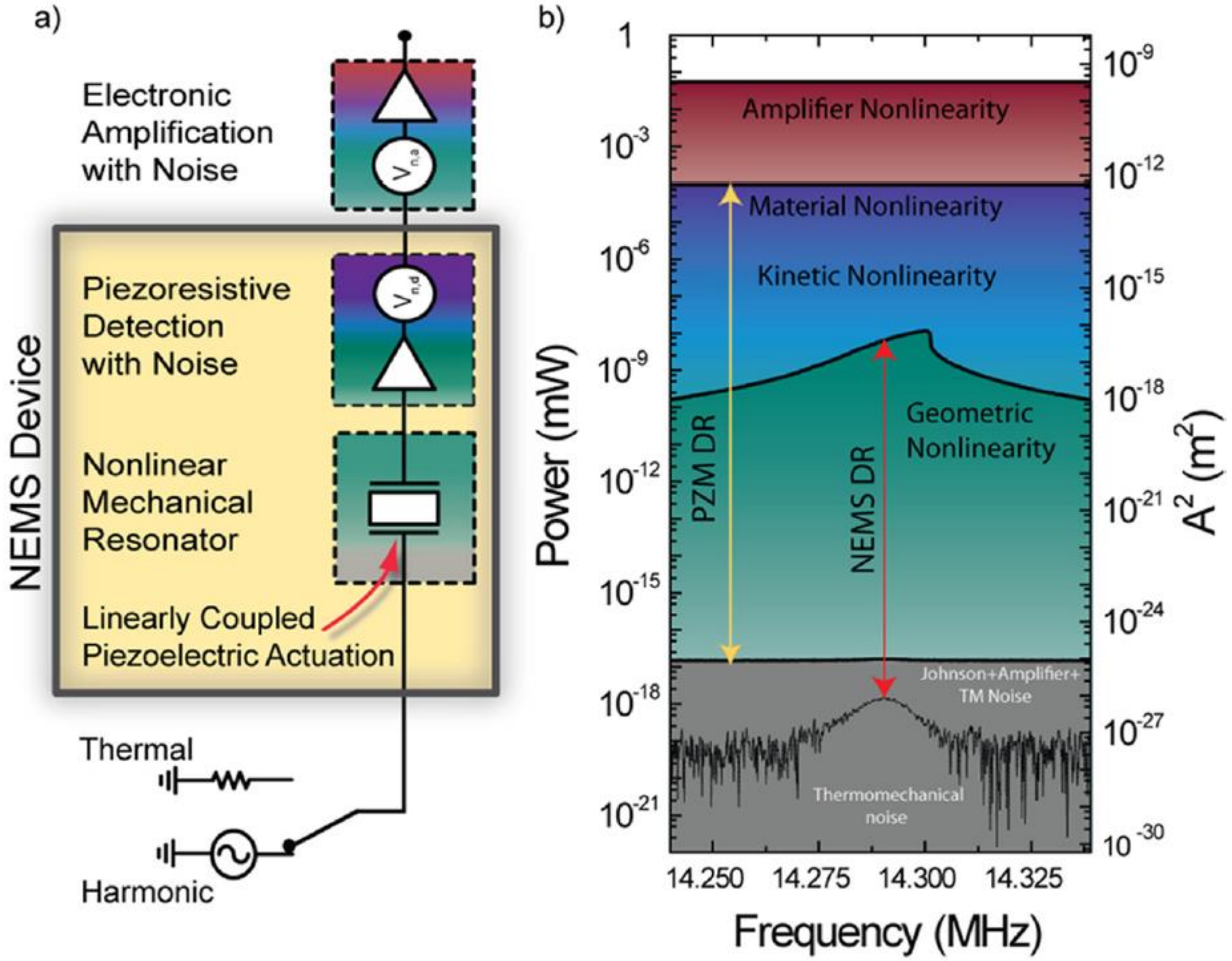
Questions

- How are the devices made?
- How is the device actuated and detected?
- Where is the nonlinearity coming from?
- Why not optical detection?
- How can Euler-Bernouilli determine the coupling constants?
- How can we separate the different noise contributions?
- Why is the signal to noise ratio larger in the inter-modal coupling?

Discussion

Discussion



a)
Electronic Amplification with Noise
NEMS Device
Piezoresistive Detection with Noise
Nonlinear Mechanical Resonator
Linearly Coupled Piezoelectric Actuation
Thermal
Harmonic
b)
Amplifier Nonlinearity
Material Nonlinearity
Kinetic Nonlinearity
Geometric Nonlinearity
PZM DR
NEMS DR
Johnson+Amplifier+ TM Noise
Thermomechanical noise
Power (mW)
A^2 (m^2)
Frequency (MHz)
14.250
14.275
14.300
14.325
1
10^{-3}
10^{-6}
10^{-9}
10^{-12}
10^{-15}
10^{-18}
10^{-21}
10^{-9}
10^{-12}
10^{-15}
10^{-18}
10^{-21}
10^{-24}
10^{-27}
10^{-30}

Discussion

$$\Delta\Omega_p \equiv \frac{\Delta\omega_p}{\omega_p} = \lambda_{pq} A^2_{\max,q} \tag{2}$$

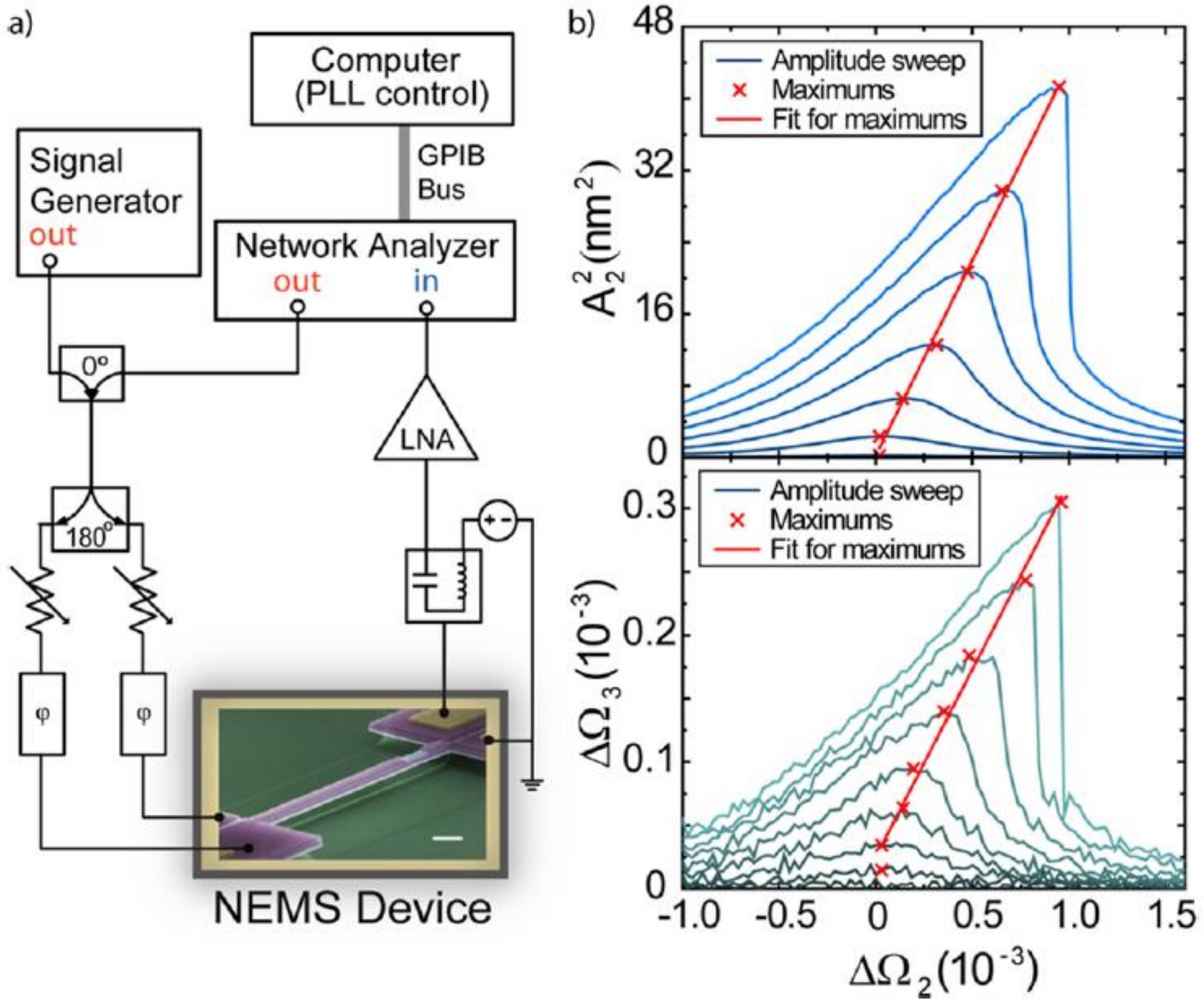
where $\Delta\Omega_p$ is the fractional frequency shift of mode p, and $A_{\max,q}$ is the maximum RMS displacement of the frequency response of mode q. Note that the Einstein summation convention is not used throughout. Calculations of the nonlinear coefficients λ_{pq} using Euler–Bernoulli theory gives (see Supporting Information)

$$\lambda_{pq} = (2 - \delta_{pq})\frac{\tau_p}{8}\left(\frac{X_{pp}X_{qq}}{2} + X^2_{pq}\right) \tag{3}$$

where

$$\tau_p = \frac{\eta_p}{1 + \eta_p X_{pp}\frac{TL^2}{E}}, \qquad \eta_p = \frac{tw}{I\int_0^1 \Phi_p \Phi_p^{(IV)} \mathrm{d}\xi}$$

Discussion



a)
Computer (PLL control)
GPIB Bus
Signal Generator
out
Network Analyzer
out
in
0°
180°
LNA
φ
φ
NEMS Device
b)
Amplitude sweep
Maximums
Fit for maximums
$A_2^2 (nm^2)$
48
32
16
0
$\Delta\Omega_3 (10^{-3})$
0.3
0.2
0.1
0
-1.0
-0.5
0
0.5
1.0
1.5
$\Delta\Omega_2 (10^{-3})$

Discussion

Table 1. Measured (Theoretically Calculated) Nonlinear Stiffness Coefficients λ_{pq} (10^{-5} nm^{-2}) for the First Three Out-of-Plane Flexural Modes of the Doubly-Clamped NEMS Device[a]

	$q = 1$	$q = 2$	$q = 3$
$p = 1$	0.53 ± 0.01 (0.53)	1.76 ± 0.36 (1.45)	3.51 ± 0.47 (3.59)
$p = 2$	0.18 ± 0.01 (0.186)	1.16 ± 0.03 (1.16)	1.77 ± 0.13 (1.65)
$p = 3$	0.13 ± 0.01 (0.124)	0.35 ± 0.06 (0.445)	1.43 ± 0.07 (1.43)

Discussion