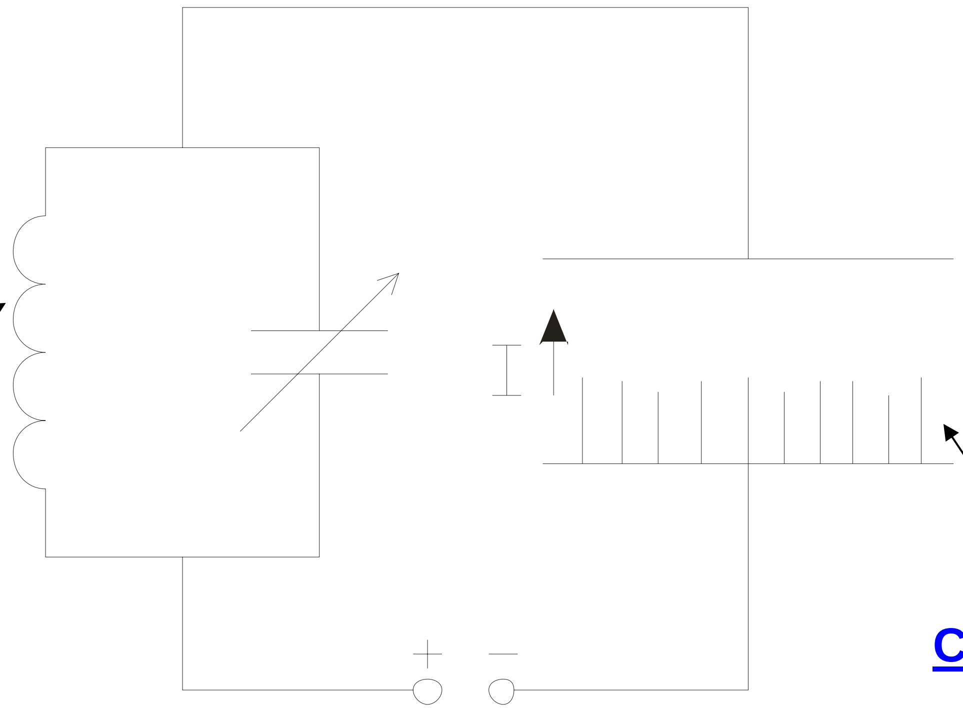
Resonance Frequencies, electrical noises and degradation phenomena in CNT-based sensors

Kate Alekseeva,
MIEE

Agenda:

- A sketch of a sensor;
- Resonance frequencies;
- Noises;
- Degradation phenomena

A sensor



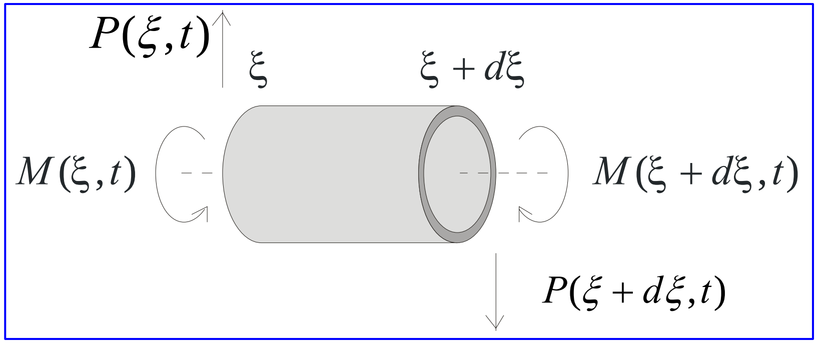
Resonance circuit

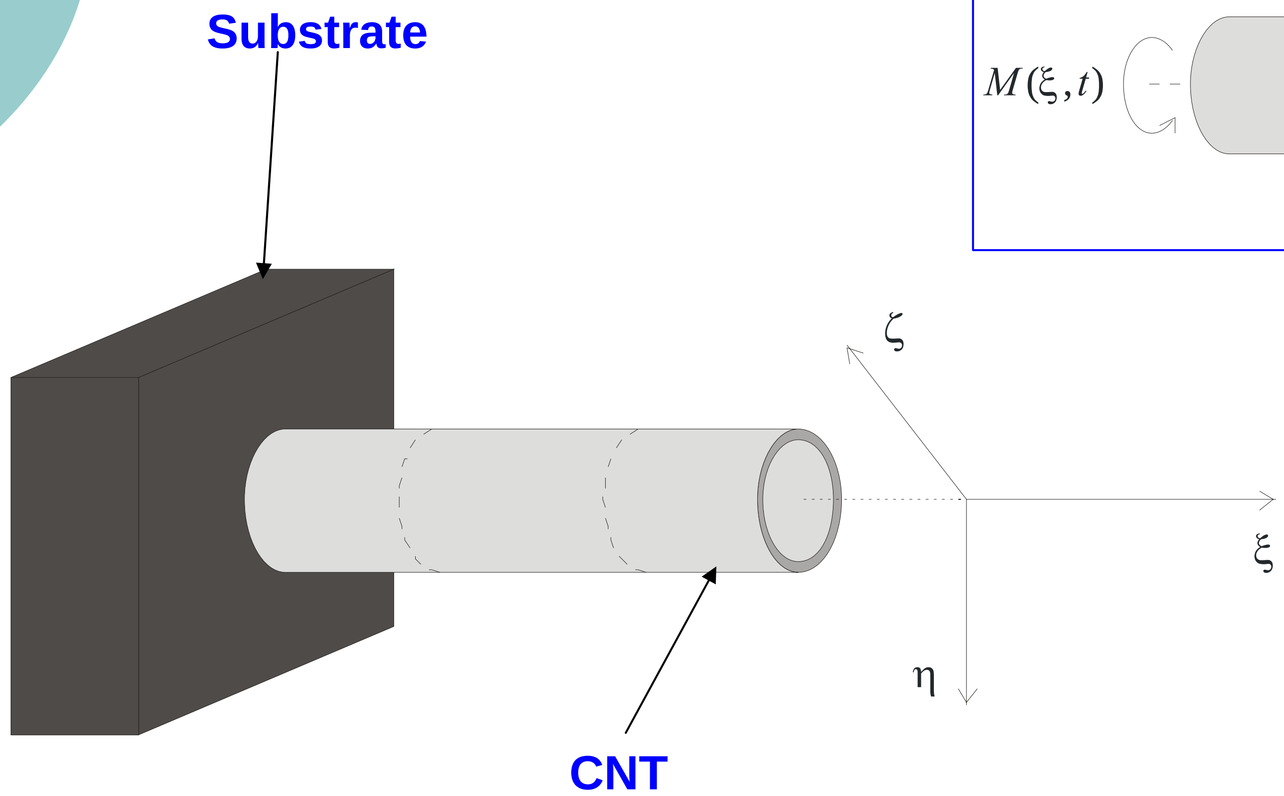
r

e

CNT's array

Self- Frequency

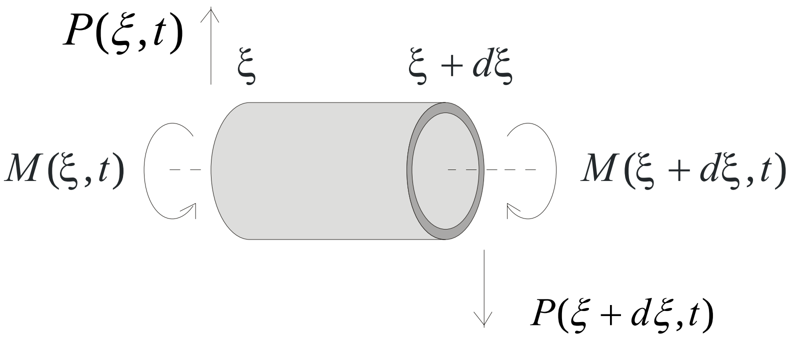




The equation of mechanical oscillations of the pointed piece is

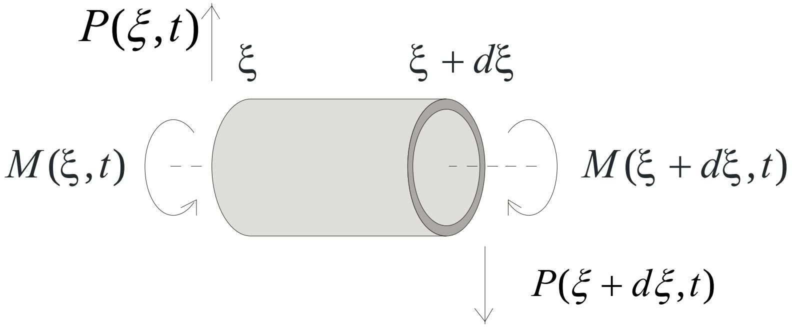
$$\boxed{m(\xi)d\xi\frac{\partial^2 y}{\partial t^2} = \frac{\partial P}{\partial \xi}d\xi}$$

$P(\xi, t)$ - a cutting force



a moment of normal efforts for the small deformations in the section:

$$\boxed{M(\xi,t) = EI\frac{\partial^2 y}{\partial \xi^2}}$$



A condition of rotation of the shank's element relatively the axis:

$$\boxed{M(\xi,t)-M(\xi+d\xi,t)-P(\xi,t)d\xi=J\frac{\partial^2\theta}{\partial t^2}}$$

$$\boxed{J\frac{\partial^2\theta}{\partial t^2}\approx 0}$$

The oscillation equation of the CNT

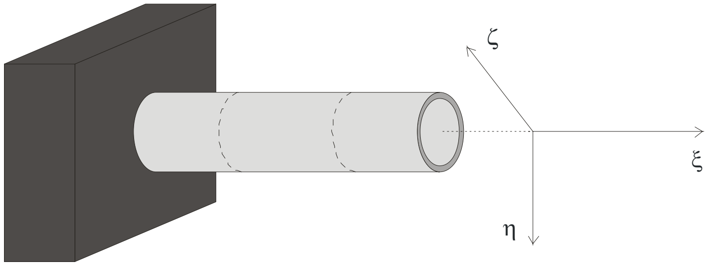
$$\boxed{\frac{\partial^2 y}{\partial t^2} + a^2 \frac{\partial^4 y}{\partial \xi^4} = 0}$$

$$a^2 = \frac{EI}{m}$$ - a physical parameter defining CNT's oscillations

Boundary conditions:

$$y(0,t) = y'(0,t) = 0$$

$$y''(0,t) = y'''(0,t) = 0$$



CTN’s self-frequencies

CNT’s parameters:

$$E = 10^{12}\frac{N}{m^2}$$

$$l = 5\mu m$$

$$\rho = 2000\frac{kg}{m^3}$$

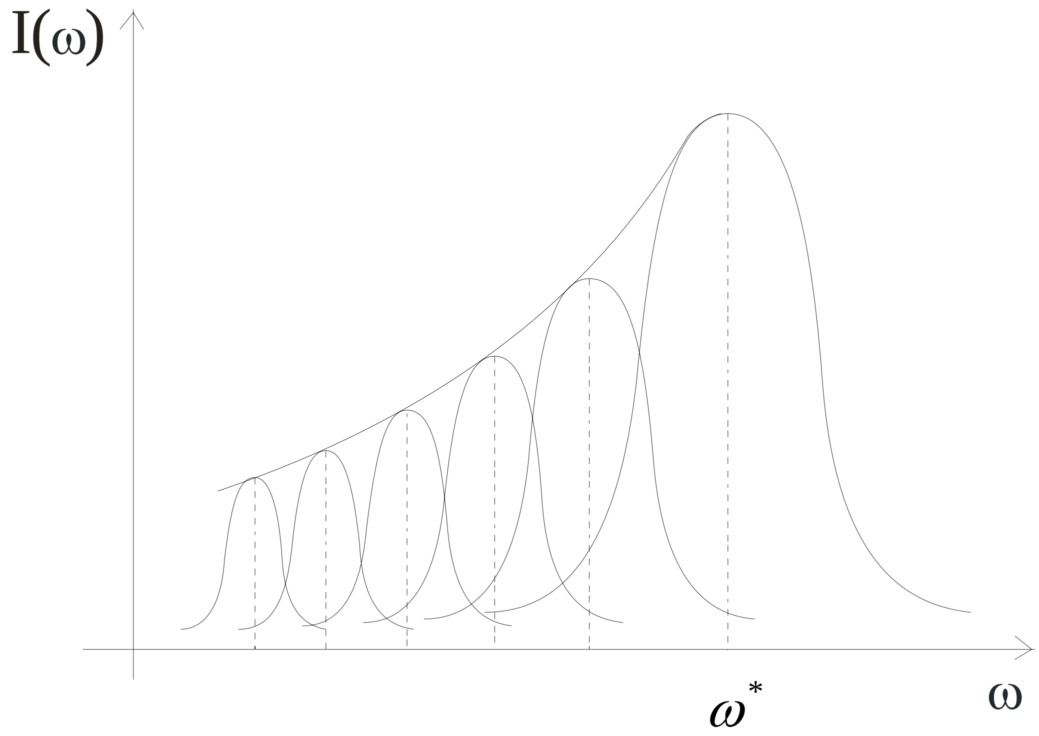
$$S = \pi(r_{ex}^2 - r_{in}^2) = 3.06\cdot 10^{-17}m^2$$

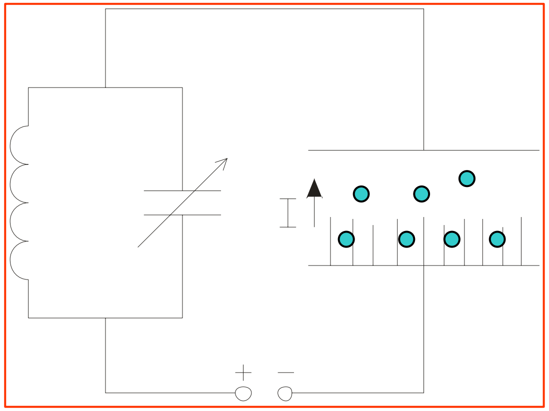
$$m = V\cdot\rho = 3.06\cdot 10^{-19}kg$$

$$\boxed{\omega \sim a^2}$$

j	ω_j ,GHz	f_j ,GHz
1	0.021	0,003
2	0,132	0,02
3	0,37	0,06
4	1,19	0,19
5	1,79	0,28
6	2,5	0,4

Resonance Curves





$$\boxed{\omega \sim a^2}$$

Noises

Temperature noise

$$\overline{(\Delta T)^2} = \frac{kT^2}{C}$$

$$\overline{(\Delta T)^2} = 0{,}00726K^2$$

Fluctuation Noise

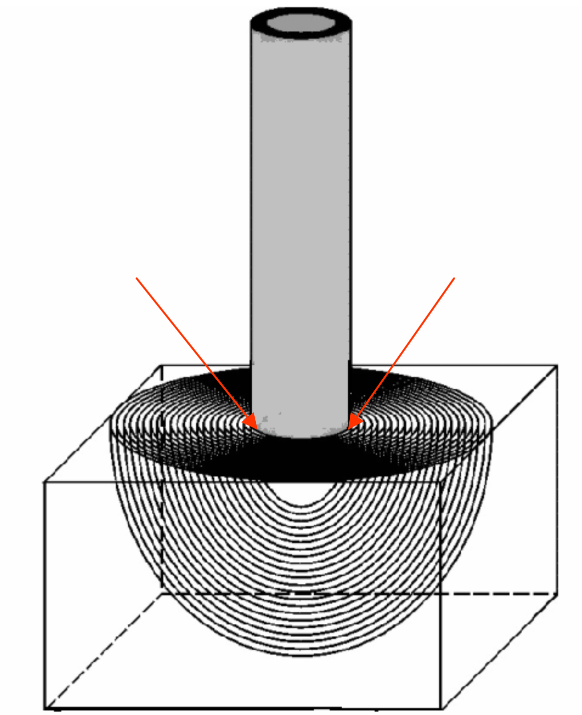
	ω_j, GHz	$\Delta i = \sqrt{2ei\Delta f}$, nA	P, nW
1	0.021	1	26
2	0.132	2,6	65
3	0.37	4,3	110
4	1.19	7,9	200
5	1.79	9,6	240

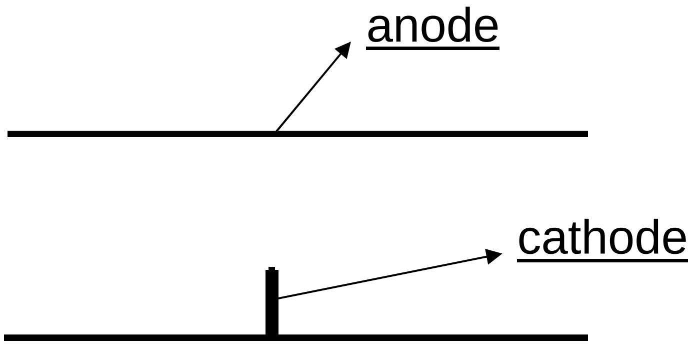
Thermal Noise

	ω_j, GHz	$\overline{V^2} = 4kT\left\{\int_{f_1}^{f_2} R(f)\cdot df\right\}\Delta f$, μV^2	P, pW
1	0.021	0.7	0.07
2	0.132	4.6	4.6
3	0.37	13	1.3
4	1.19	41	4.18
5	1.79	63	6.29

Degradation Phenomena

- **Local Overheating**
- **Ponderomotive Force**





Local overheating

$$\lambda_{CNT} \frac{dT \cdot S_1}{dx} + \varepsilon' \sigma \left(T_{pick}^4 - T_{base}^4 \right) S_2 = P,$$

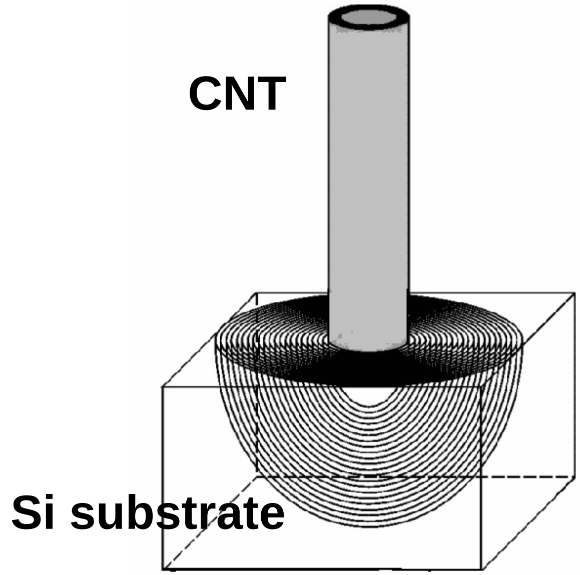
λ_{CNT} – Coefficient of thermal conductivity

ε' – emissivity factor;

S_1 – CNT's square;

S_2 – CNT's section square;

<u>Solution:</u>
U = 4V
T_{pick}=400K

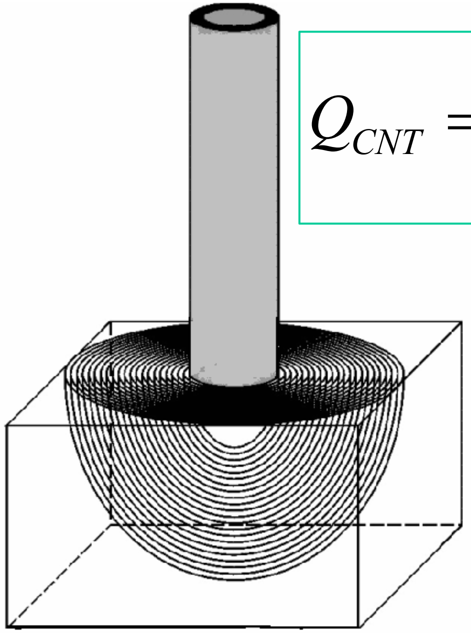


A probability of the overheating itself

The balance equation is

$$Q_{CNT} + Q_S = P$$

$$Q_{CNT} = \frac{\Delta T}{R_{T\_CNT}} = \frac{T_{pick} - T_{base}}{R_{T\_CNT}};$$



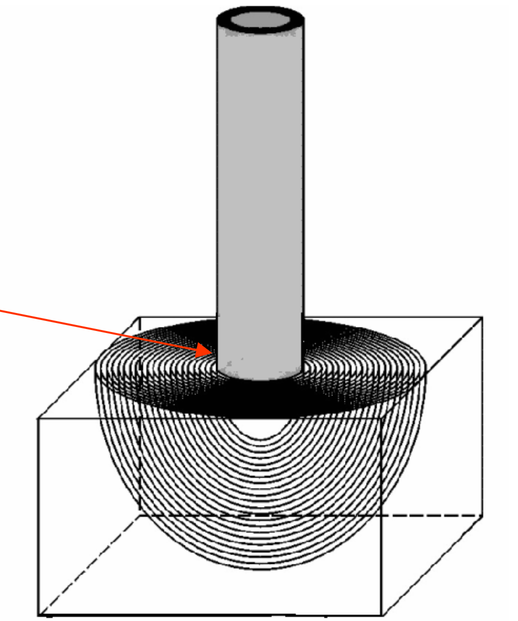
T_{sub}=300K

$$Q_{Si} = \frac{\Delta T}{R_{T\_Si}} = \frac{T_{base} - T_{sub}}{R_{T\_Si}},$$

To make a long story short

$$\boxed{T_{base} \approx 305K}$$

There is no overheating!



Ponderomotive Force

The force which acts on CNT $$F = q \cdot E,$$

***q* – nanotubes charge.**

$$q = C \cdot U,$$

$C \sim 2r_{ex}$ – **the capacity of cathode-anode system**

U – a voltage of cathode-anode system

$$\boxed{F = 4 \cdot 10^{-7}\, H}$$

To sum it up

- mechanical stress is about **1234.89МПа**, what is much more then possible yield stress of the used catalytic materials. Possible yield stress for nickel is $\sigma_{Ni} = 400\frac{MN}{m^2}$ for iron is $\sigma_{Ni} = 290\frac{MN}{m^2}$ Hence, the pressure limit for the system doesn’t have to exceed 15V for Ni catalytic layer and 8V for iron catalytic layer.

QUESTIONS?