Energy harvesting and storage from electromagnetic radiation sources

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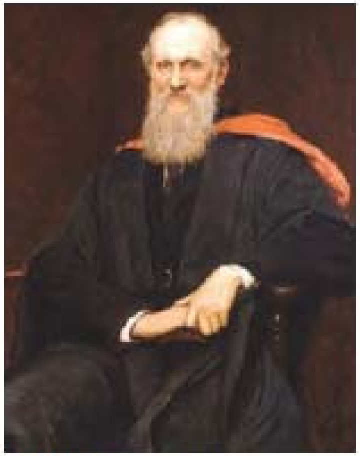
NiPS Summer School 2012. *Energy Harvesting at micro and nanoscale*, July 23-25, 2012
Erice (Sicily) - Italy

The University of Glasgow

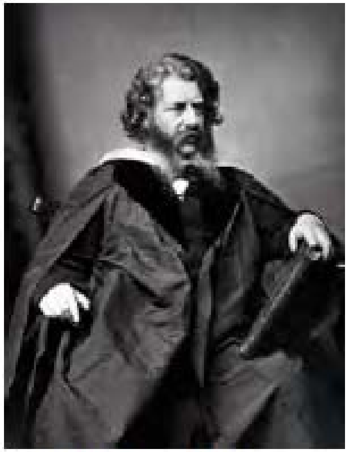
- Established in 1451
- 6 Nobel Laureates
- 16,500 undergraduates, 5,000 graduates and 5,000 adult students
- £130M research income pa

- 400 years in High Street
- Moved to Gilmorehill in 1870
- Neo-gothic buildings by Gilbert Scott

Famous Glasgow Scholars

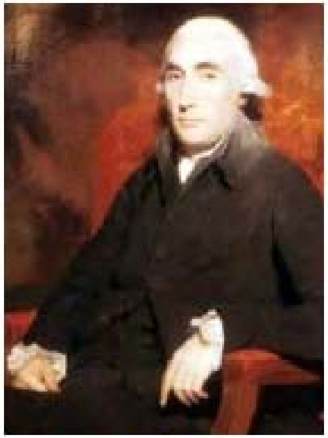

William Thomson
(Lord Kelvin)


James Watt


William John
Macquorn Rankine


Rev Robert Stirling


Rev John Kerr


Joseph Black


John Logie Baird


Adam Smith

Prof. Paco Serra

NiPS Summer School 2012

Signal = Energy + Information

Prof. Paco Serra

Outline

Energy available in the EM spectrum

RF energy harvesting. The MEMSTENNA concept.

Alternatives to Photovolatics:
  - Optical rectenna. From RF rectenna to optical rectenna
  - Opacmems devices

Storage

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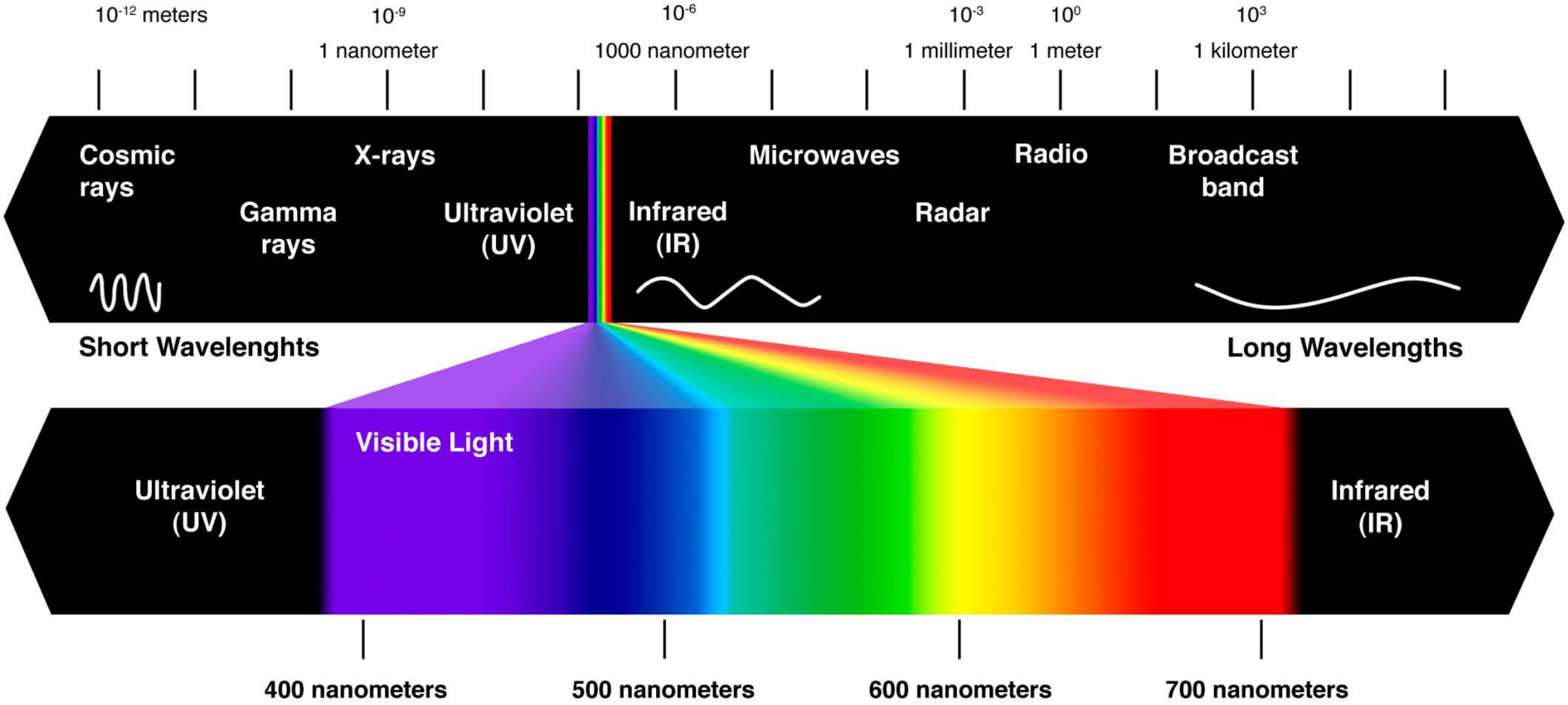
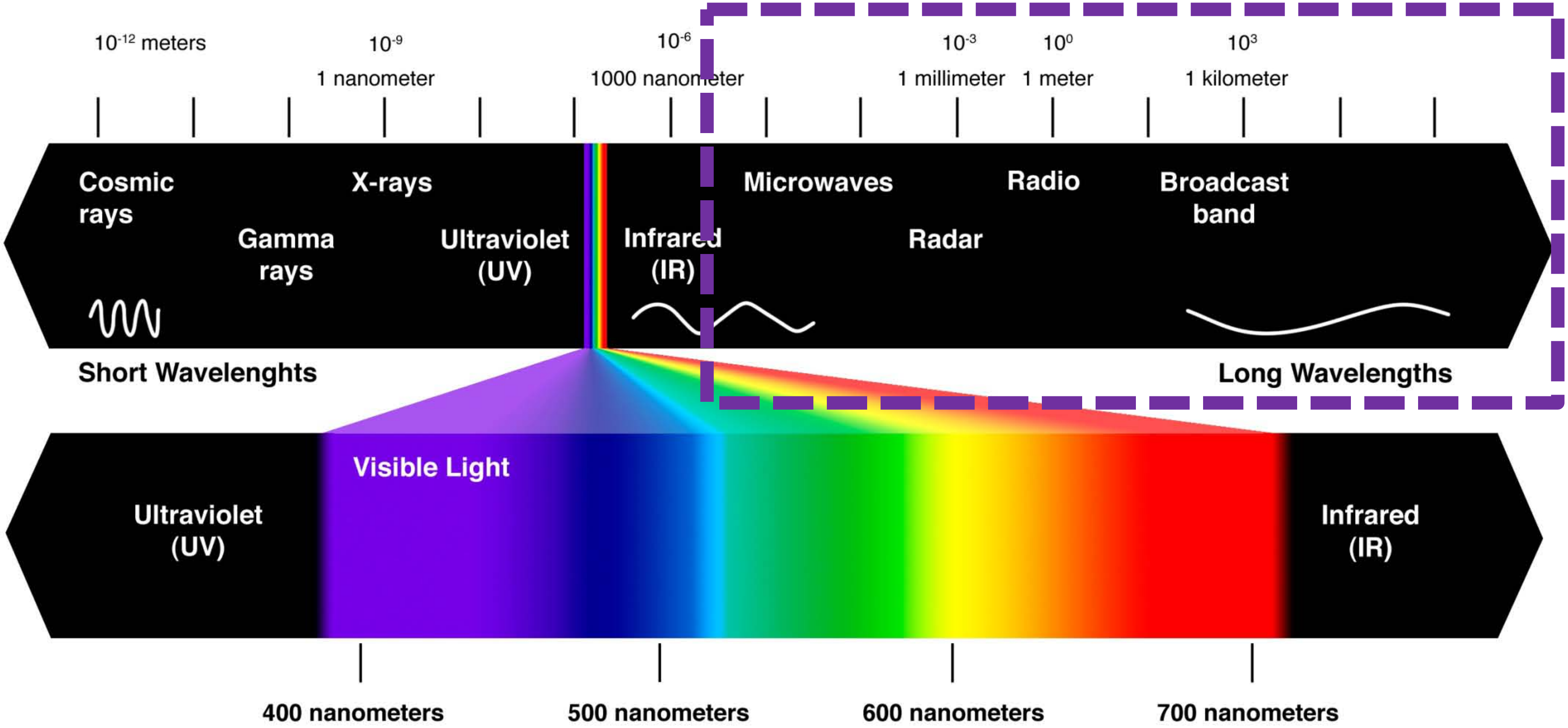
The electromagnetic spectrum



$$\boxed{c = \lambda \cdot \nu}$$

$$\boxed{E = h \cdot \nu}$$

The electromagnetic spectrum



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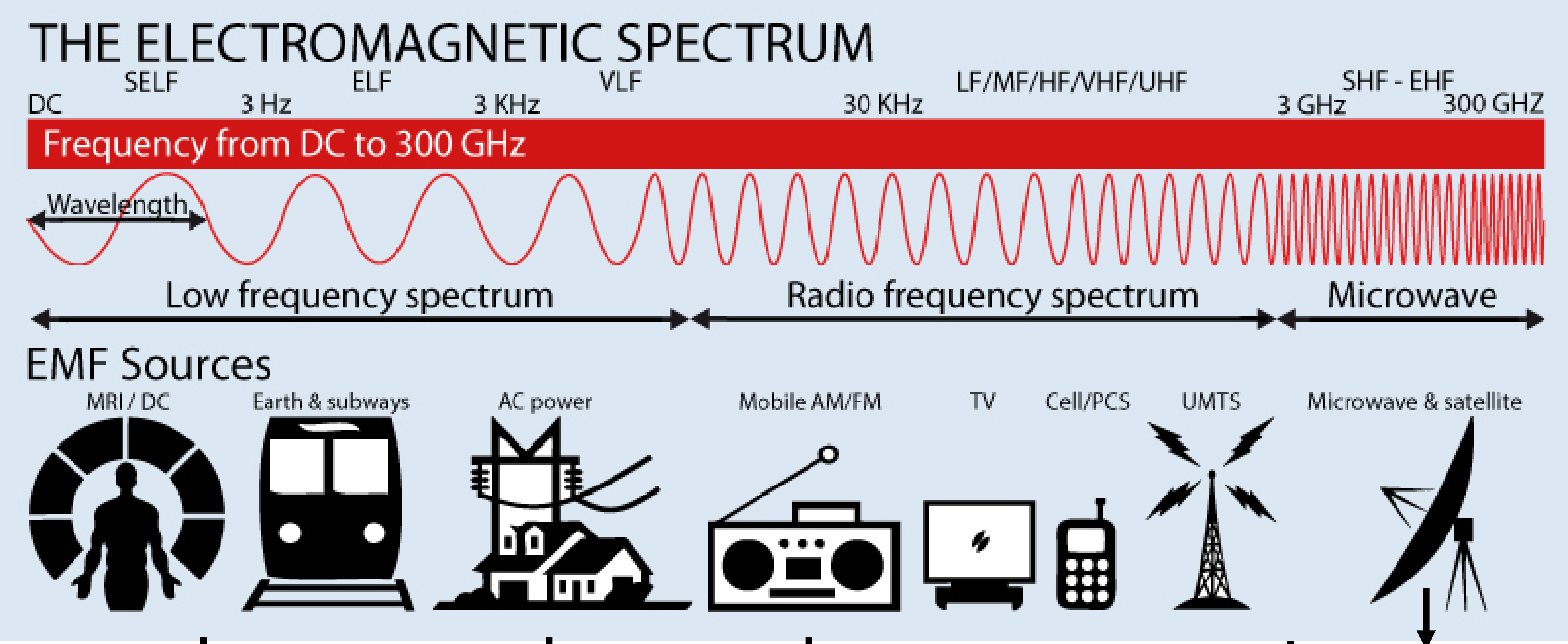

GPS: **10-100 aW**

GSM, UMTS -> 3G: **100mW-2W**

70 dBuV/m = **3.2mV/m** old UHF TV band

FM radio: **100kW** to achieve good reception at 50km

50 Hz, **100W-10kW**

ISM bands (900MHz-2.4GHz):
WIFI (**100mW**), Bluetooth (**2.5mW**), ZigBee (**<1mW**)

DC (no radiation)

Power density (W/cm^2)

GSM, UMTS -> 3G: **100mW-2W** → [1] → **8-160 nW/cm^2 (10m distance)**

70 dBuV/m = **3.2mV/m** old UHF TV band → [2] → **1.3 pW/cm^2**

FM radio: **100kW** to achieve good reception at 50km → [1] → **0.3 nW/cm^2 (50km distance)**

ISM bands (900MHz-2.4GHz):
WIFI (**100mW**), Bluetooth (**2.5mW**), ZigBee (**<1mW**) → [1] → **8 , 0.2 nW/cm^2 , <80pW/cm^2 (10m distance)**

[1]

$$P_r = \frac{P_i}{S_{esfera}} = \frac{P_i}{4\pi r^2} \quad [W/m^2]$$

[2]

$$|P_r| = \frac{1}{2}\frac{|E_f|^2}{\eta_0} \quad [W/m^2]$$

$$\eta_0 = 120\pi \simeq 377\,\Omega$$

Intrinsic vacuum impedance

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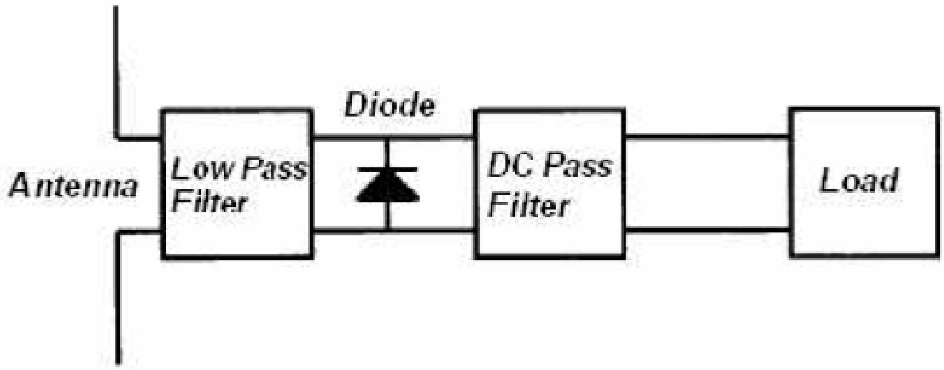
1014 IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 52, NO. 3, MARCH 2004

Recycling Ambient Microwave Energy With Broad-Band Rectenna Arrays

Joseph A. Hagerty, *Student Member, IEEE*, Florian B. Helmbrecht, *Student Member, IEEE*, William H. McCalpin, *Student Member, IEEE*, Regan Zane, *Member, IEEE*, and Zoya B. Popović, *Fellow, IEEE*

***Abstract*—This paper presents a study of reception and rectification of broad-band statistically time-varying low-power-density microwave radiation. The applications are in wireless powering of industrial sensors and recycling of ambient RF energy. A 64-element dual-circularly-polarized spiral rectenna array is designed and characterized over a frequency range of 2–18 GHz with single-tone and multitone incident waves. The integrated design of the antenna and rectifier, using a combination of full-wave electromagnetic field analysis and harmonic balance nonlinear circuit analysis, eliminates matching and filtering circuits, allowing for a compact element design. The rectified dc power and efficiency is characterized as a function of dc load and dc circuit topology, RF frequency, polarization, and incidence angle for power densities between 10^{-5}–10^{-1} mW/cm^2. In addition, the increase in rectenna efficiency for multitone input waves is presented.**



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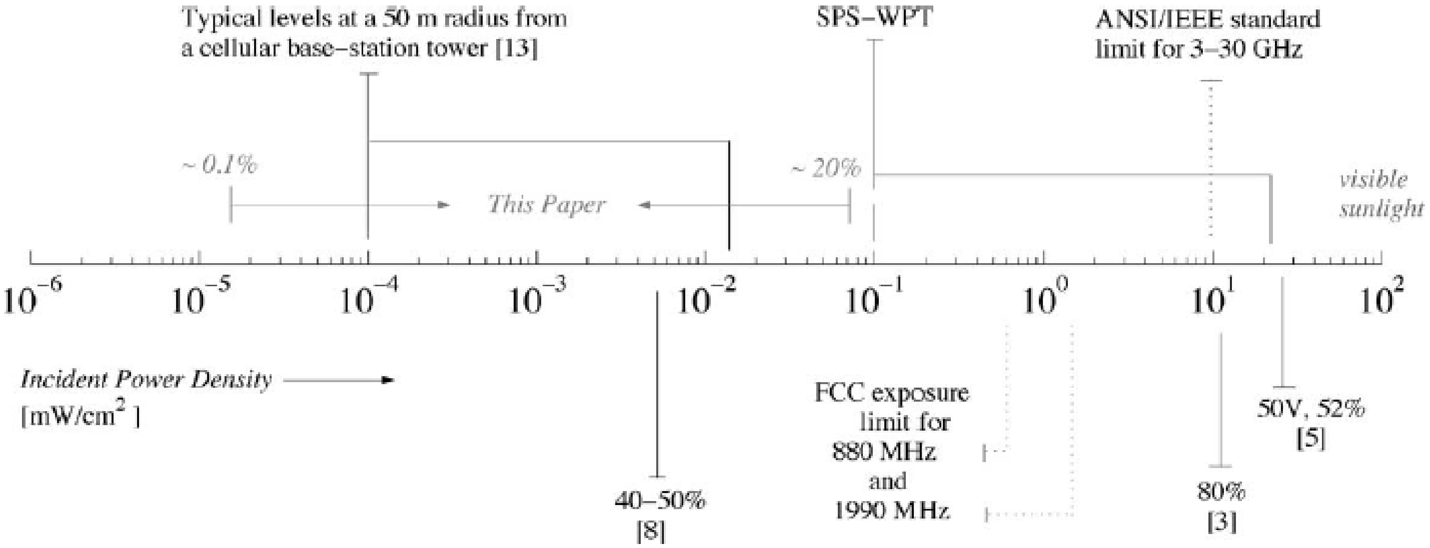

Fig. 1. Diagram of various microwave power sources and their typical power density levels. The power density operating points of several rectenna designs found in the literature and their corresponding efficiencies [3], [6], [8] are given. Also shown is the range of expected power densities used in the solar power satellite (SPS) and wireless power transmission (WPT) applications. The range of power densities measured in this paper is indicated for comparison. Measured ambient levels in our laboratory (no high-power equipment) are in the 10^{-6}–10^{-5}-mW/cm^2 range.

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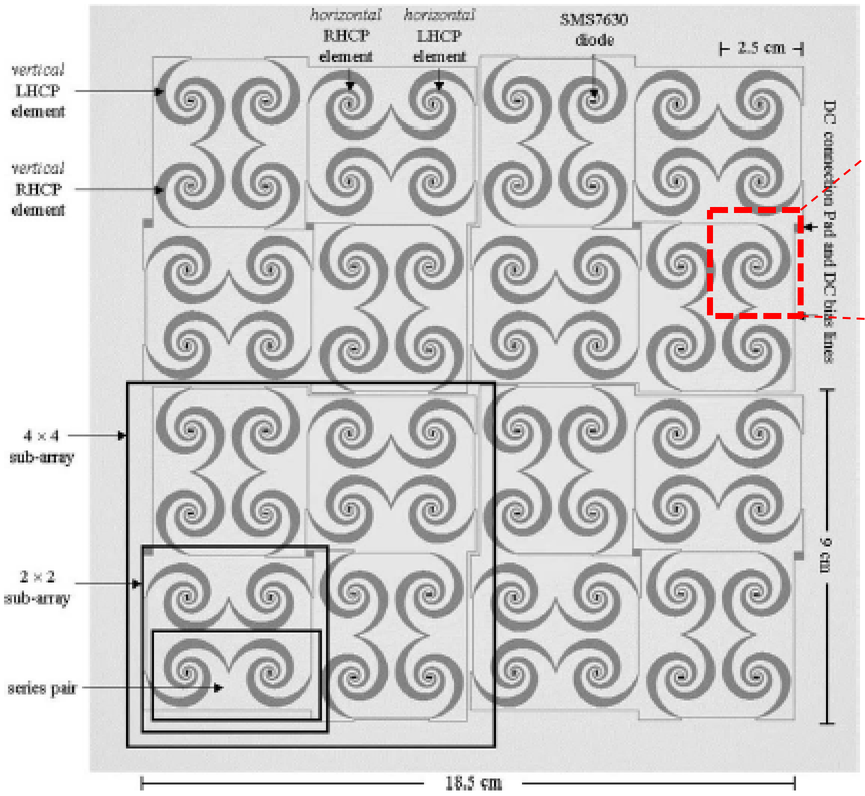

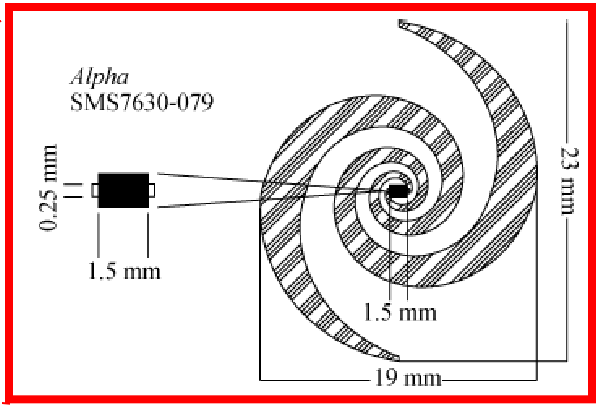

$$A = A_{\mathrm{eff}} = 25\ \mathrm{cm}^2 \tag{7}$$

we estimate incident power levels of

$$P_{\mathrm{RFmin}} = 250\ \mathrm{nW} \quad P_{\mathrm{RF\,max}} = 2.5\ \mathrm{mW}. \tag{8}$$

Assuming a dc–dc conversion efficiency of 90% and rectification efficiencies of

$$\eta(P_{\mathrm{RFmin}}) = 1\% \quad \eta(P_{\mathrm{RFmax}}) = 20\% \tag{9}$$

an average dc power output is obtained as

$$P_{\mathrm{dcmin}} = 2\ \mathrm{nW} \quad P_{\mathrm{dc\,max}} = 450\ \mu\mathrm{W}. \tag{10}$$

Drawbacks:

1) Dimensions of the rectenna in the cm scale: no integrable

2) “Natural” Source power densities very low: pW/cm^2 – nw/cm^2

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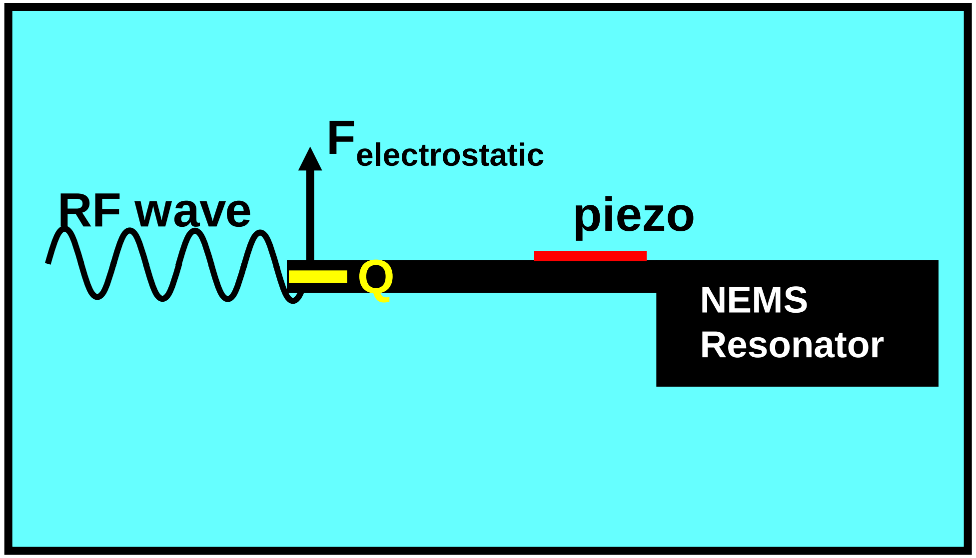
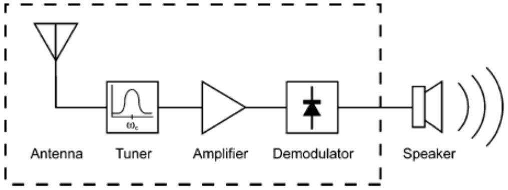
The MEMSTENNA concept



Nanotube Radio

K. Jensen, J. Weldon, H. Garcia, and A. Zettl*

Department of Physics, Center of Integrated Nanomechanical Systems, University of California at Berkeley, Berkeley, California 94720, and Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720



All-in-one nanotube radio

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3508−3511

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ABSTRACT

We have constructed a fully functional, fully integrated radio receiver from a single carbon nanotube. The nanotube serves simultaneously as all essential components of a radio: antenna, tunable band-pass filter, amplifier, and demodulator. A direct current voltage source, as supplied by a battery, powers the radio. Using carrier waves in the commercially relevant 40–400 MHz range and both frequency and amplitude modulation techniques, we demonstrate successful music and voice reception.

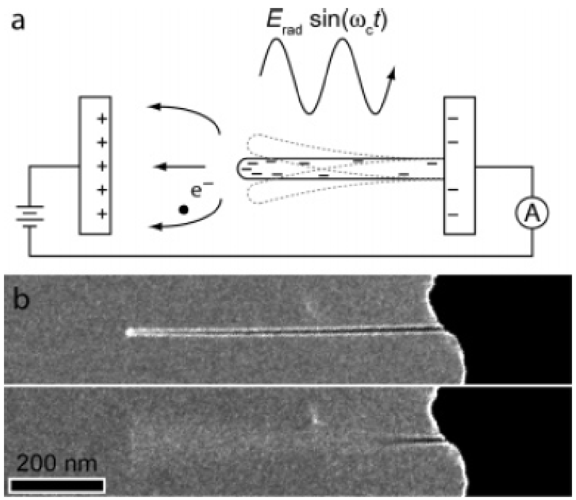
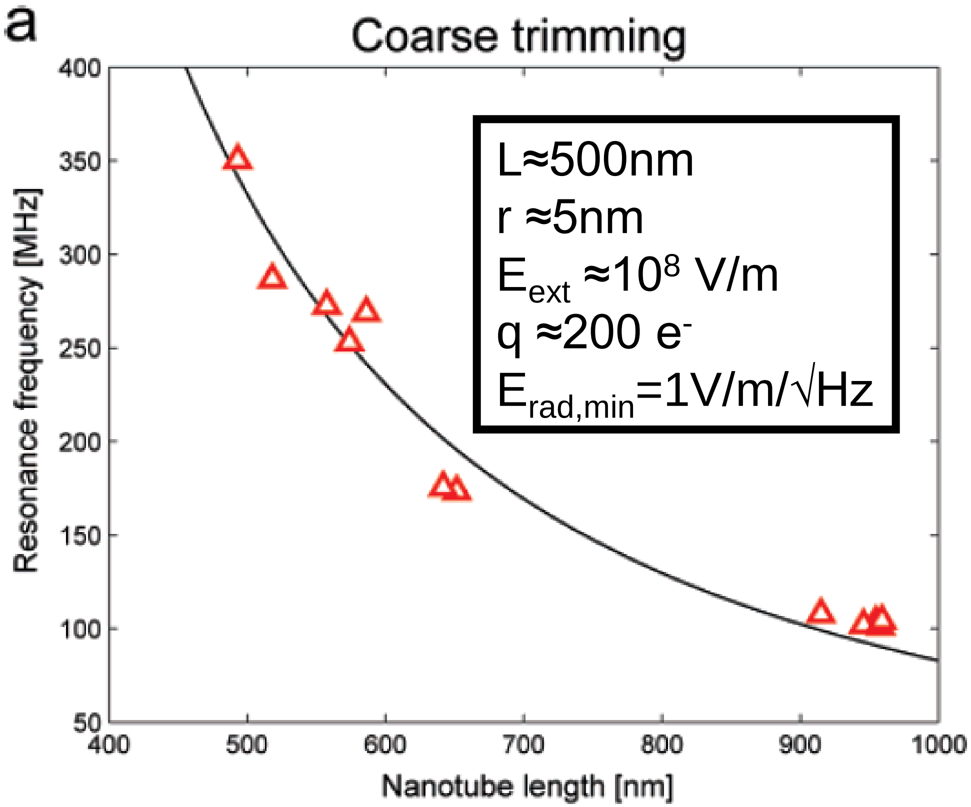
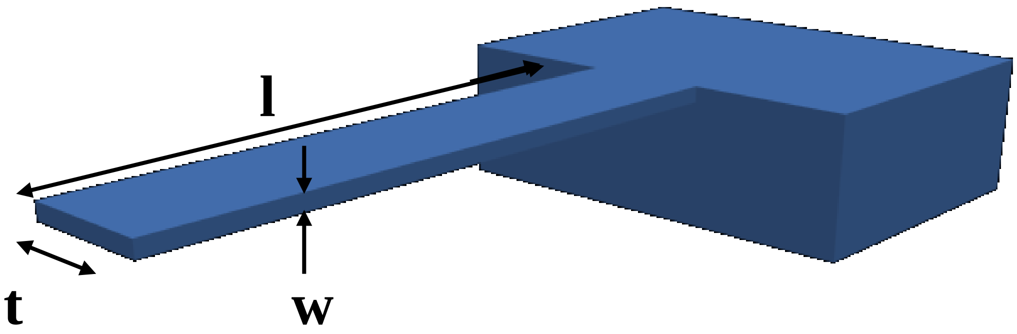


Figure 2. (a) Schematic of the nanotube radio. Radio transmissions tuned to the nanotube's resonance frequency force the charged nanotube to vibrate. Field emission of electrons from the tip of the nanotube is used to detect the vibrations and also amplify and demodulate the signal. A current measuring device, such as a sensitive speaker, monitors the output of the radio. (b) Transmission electron micrographs of a nanotube radio off and on resonance during a radio transmission.



L≈500nm
r ≈5nm
E_{ext} ≈10^8 V/m
q ≈200 e^-
$E_{rad,min}$=1V/m/√Hz

Some basics on NEMS. Mechanical characteristics



$$k = \frac{E}{4} \cdot \frac{w^3 \cdot t}{l^3} \qquad \text{(N/m)}$$

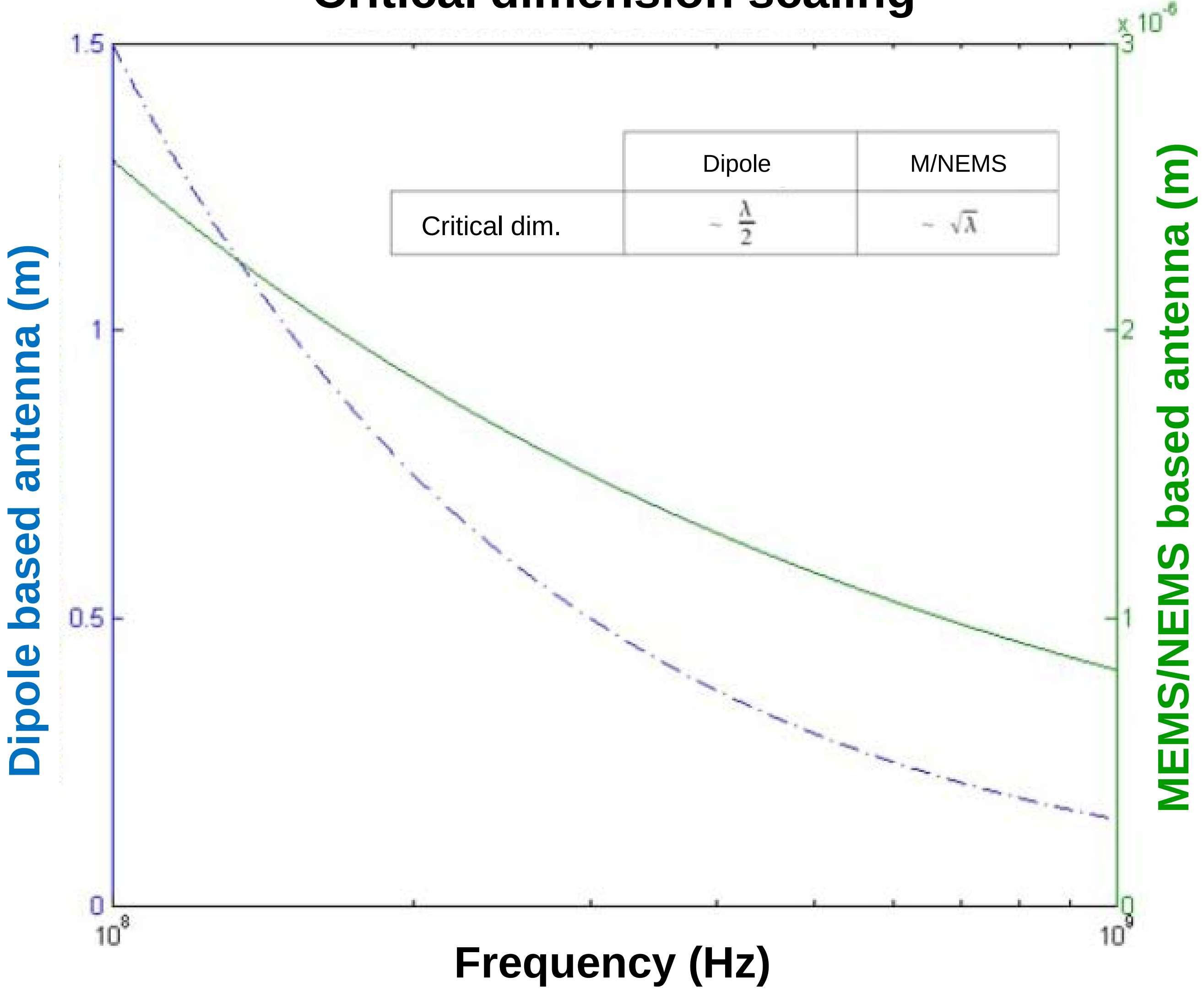
$$f_{res} = 0.162 \cdot \sqrt{\frac{E}{\rho} \cdot \frac{w}{l^2}} \qquad \text{(Hz)}$$

Young modulus: E_{Si}=1.79·1011 N/m^2
Density: ρ_{Si}=2.33·103 kg/m^3

$$m = \frac{k}{f_{res}^{\;2}} \qquad \text{(kg)}$$

	l(um)	t(um)	w(um)	k(N/m)	fres(kHz)	m(gr)
MEMS	450	50	2	0.2	14	10^{-6}
	125	30	4	44	364	$3 \cdot 10^{-7}$
NEMS	10	0.48	0.1	0.02	$1.4 \cdot 10^{3}$	10^{-11}

Critical dimension scaling



	Dipole	M/NEMS
Critical dim.	$\sim \frac{\lambda}{2}$	$\sim \sqrt{\lambda}$

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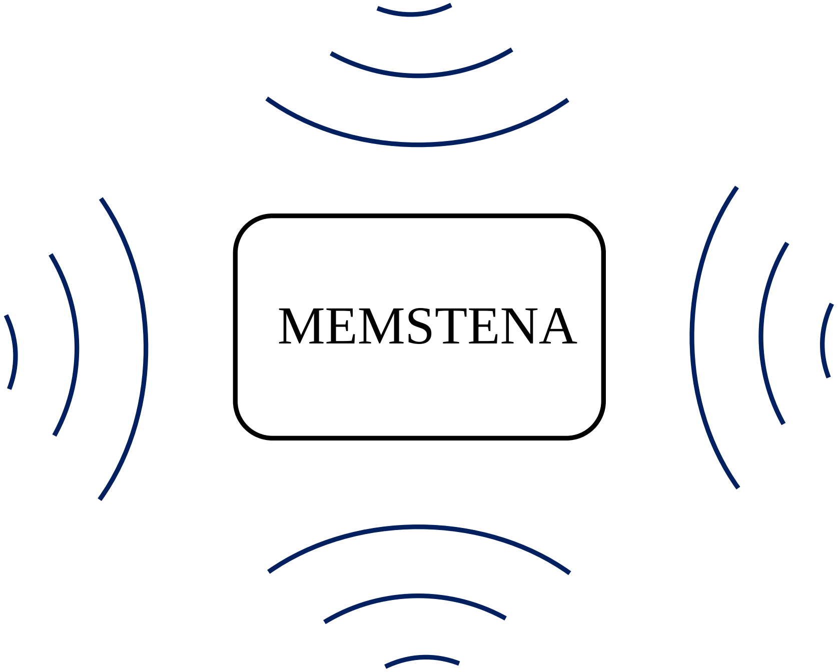
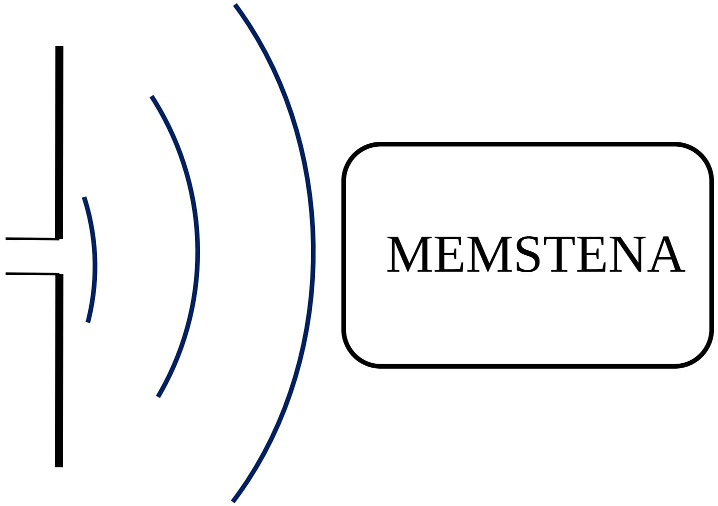
Need for “artificial/dedicated” RF sources



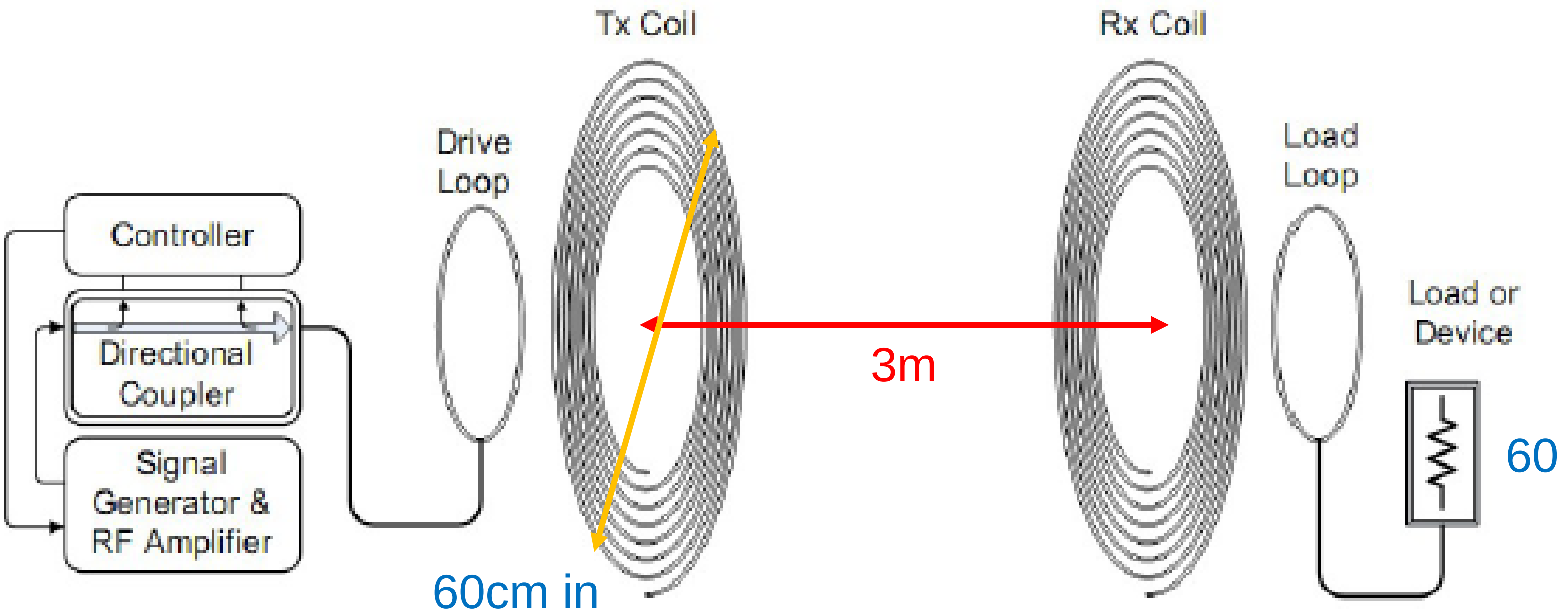
MEMSTENA

Energy is harvested from **“natural”** RF sources



Energy is harvested from **“artificial”** specially designed RF sources

WiTricity (MIT)

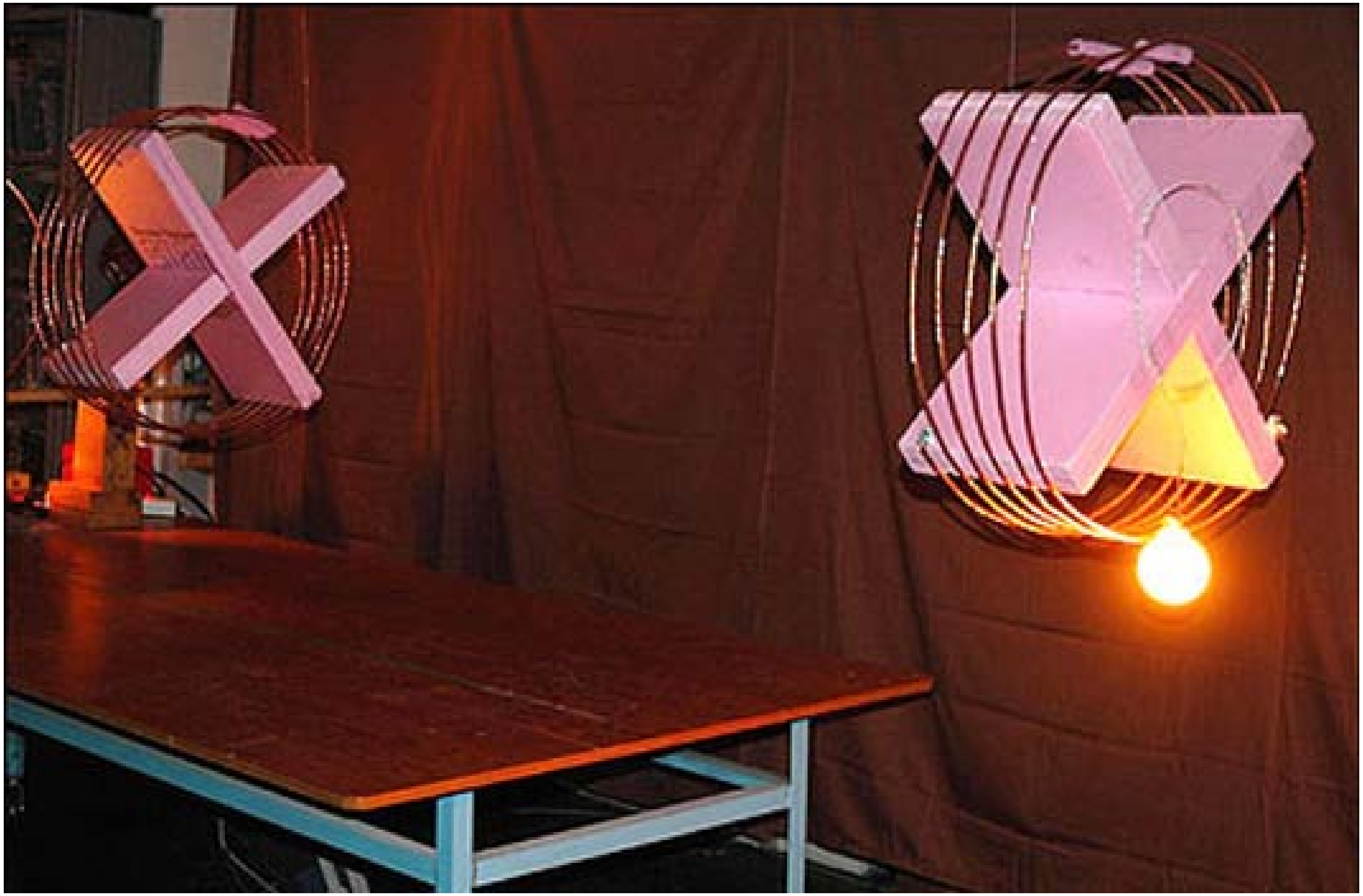


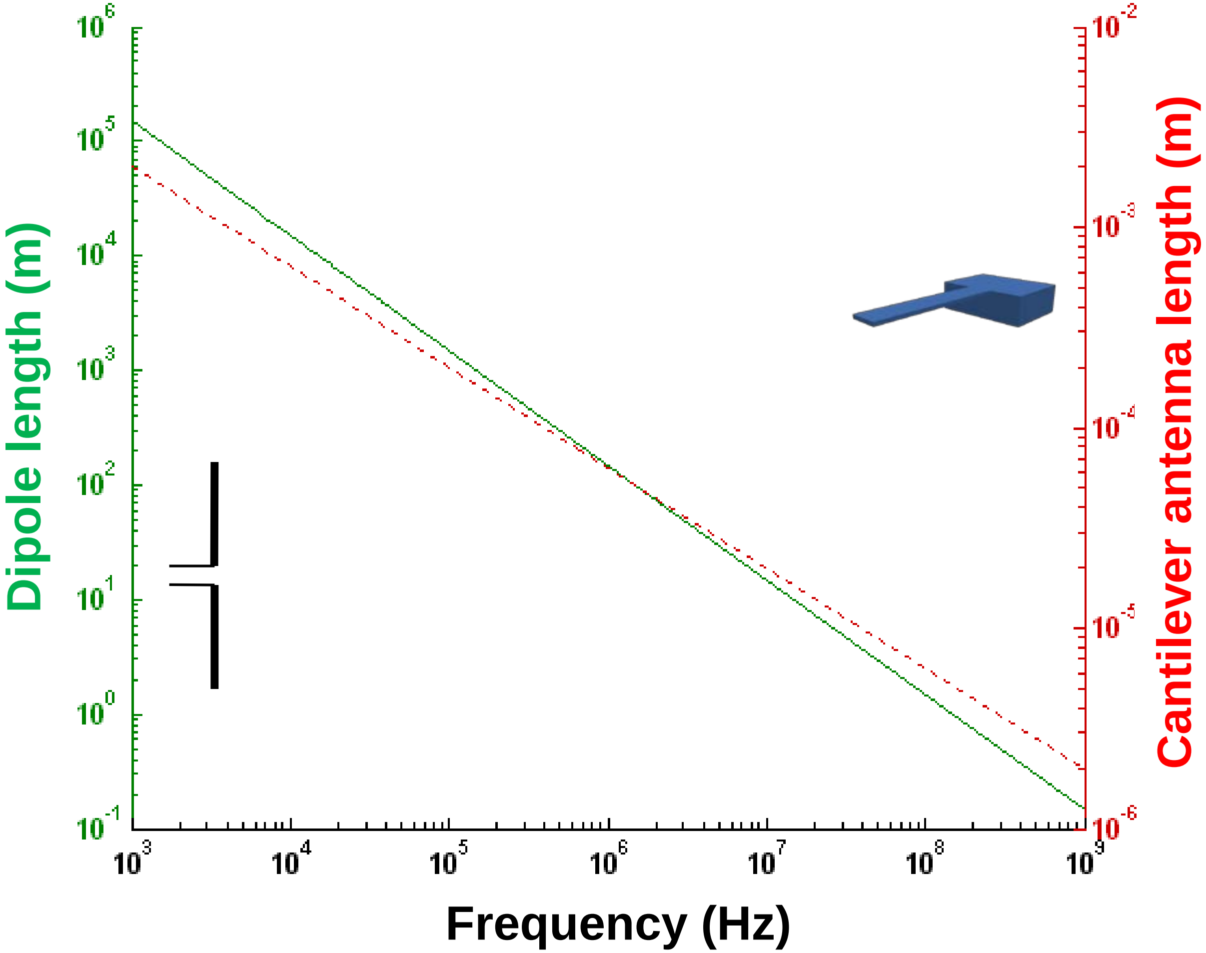
60W bulb

60cm in diameter

90% efficiency energy transfer
9.9MHz (λ=30m)

WiTricity (MIT)





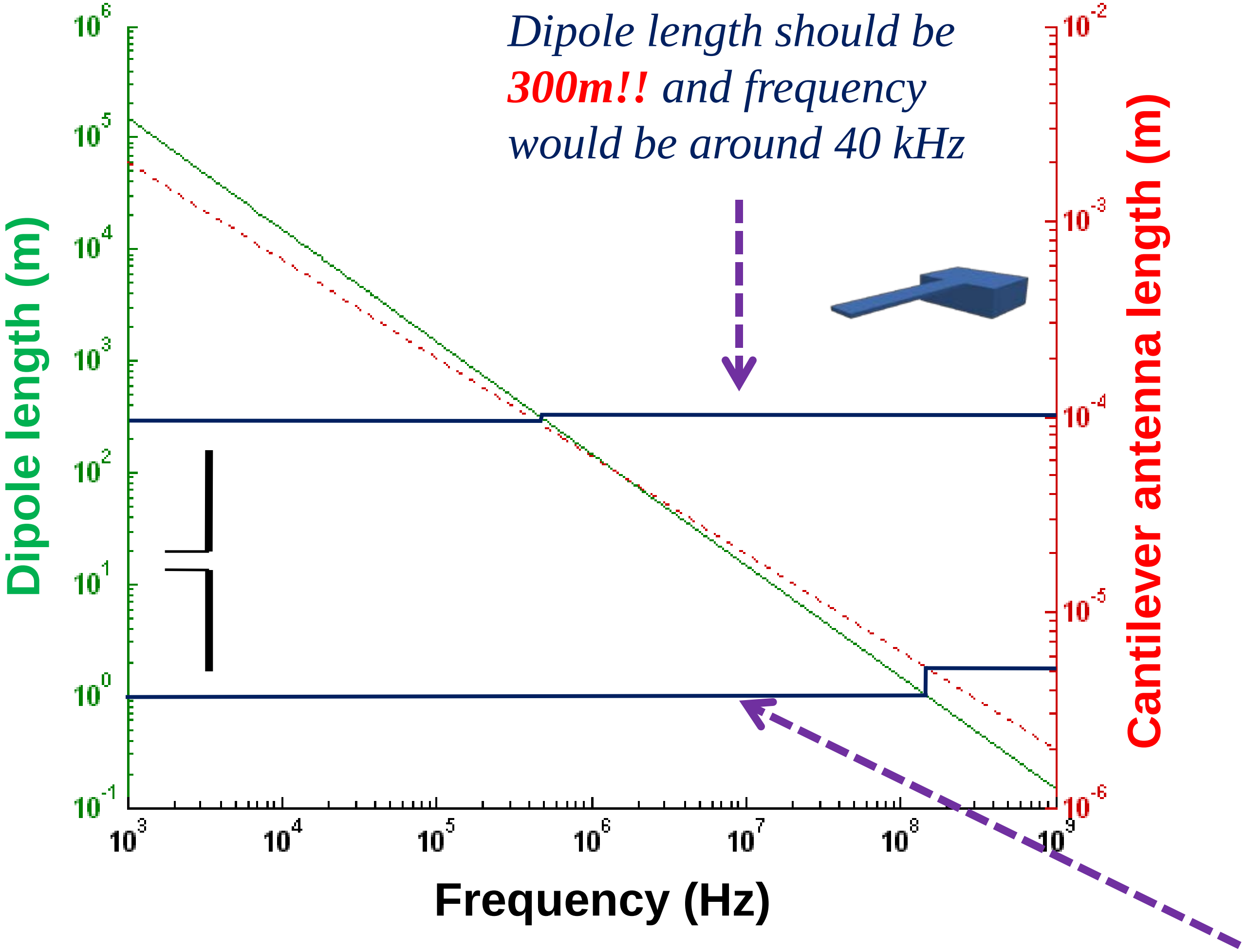
- $\lambda/2$ dipole
- Cantilever thickness and width:

$$t = 3\mu m$$

$$w = 30\mu m$$

For a cantilever 100 µm long:

Dipole length should be ***300m!!*** *and frequency would be around 40 kHz*



For a 1m dipole:

Cantilever length should be ***5µm!!*** *and frequency would be around 100 MHz*

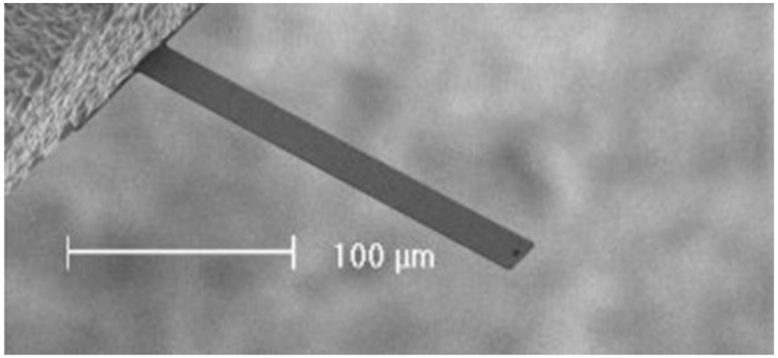

Pau Bramon

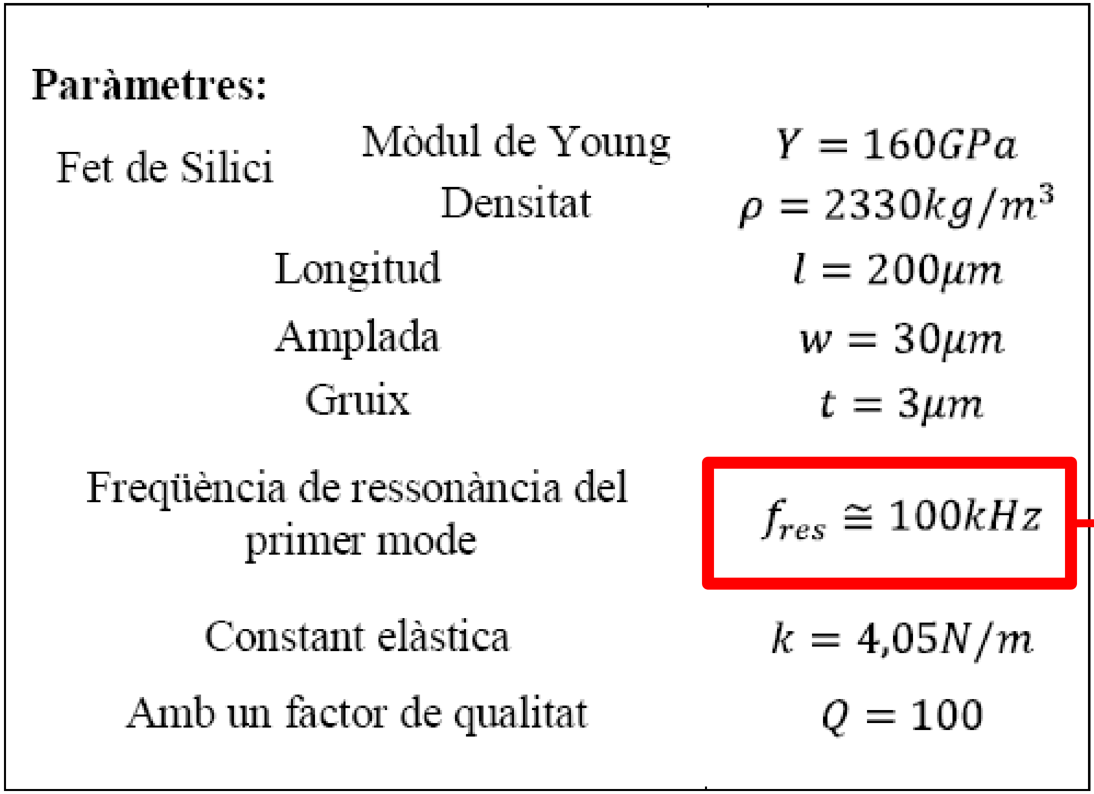
Exercise:

Consider a dipole antenna L=1m.
Consider a commercial cantilever (AFM) l=200um.

Q1) Would it be possible to demonstrate the MEMSTENNA concept with these two elements?

Q2) Which would be the order of magnitude of the mechanical energy harvested by the MEMSTENNA?



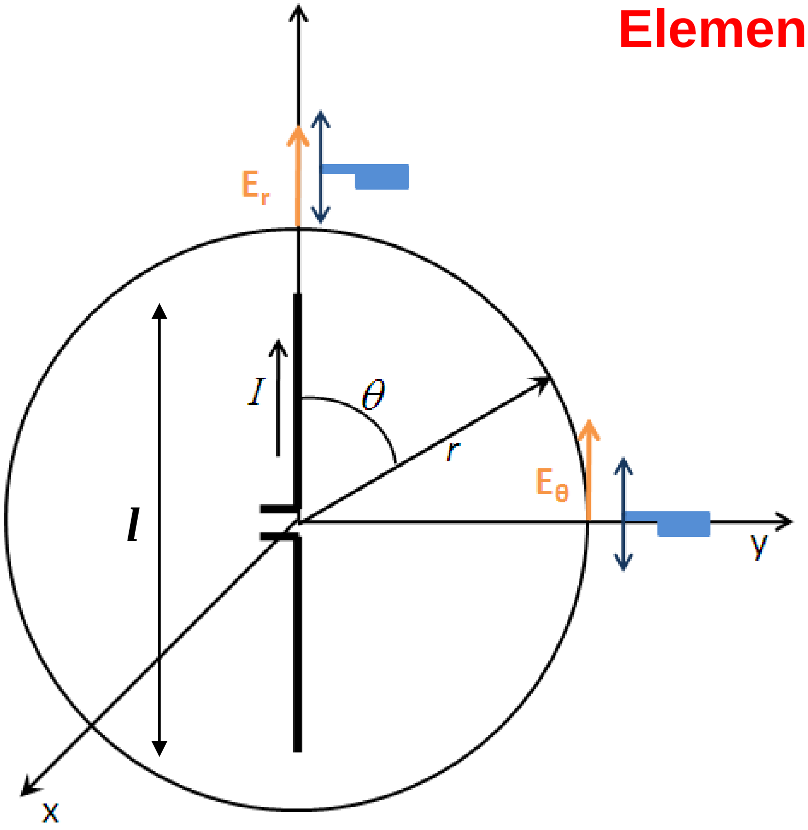


Paràmetres:

Fet de Silici	Mòdul de Young	$Y = 160GPa$
	Densitat	$\rho = 2330kg/m^3$
Longitud		$l = 200\mu m$
Amplada		$w = 30\mu m$
Gruix		$t = 3\mu m$
Freqüència de ressonància del primer mode		$f_{res} \cong 100kHz$
Constant elàstica		$k = 4{,}05N/m$
Amb un factor de qualitat		$Q = 100$

$\rightarrow$ λ=3km

Elemental Dipole / Near field conditions



- Wavelength>> Dipole length $\lambda \gg l$
- Uniform current distribution

MEMSTENNA placed close the dipole antenna

$r \ll \lambda$ $r \sim l$

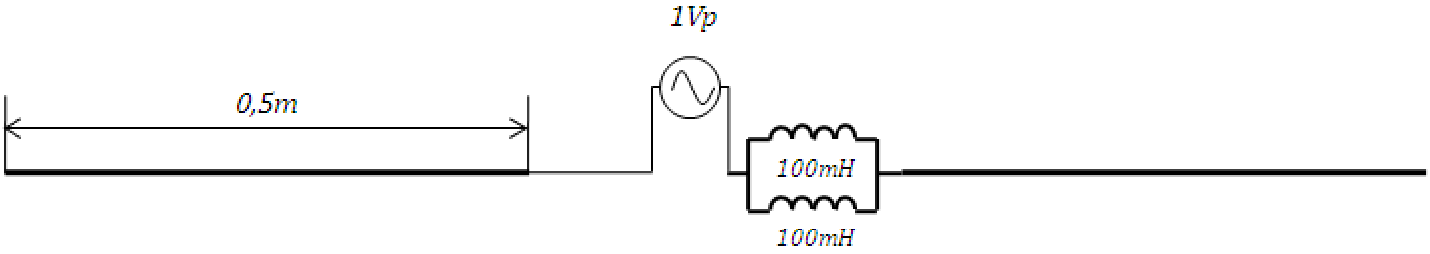
$$|E\theta| = \eta \frac{I\, l\, \lambda}{16\pi^2 r^3} \sin\theta$$

$$|Er| = \eta \frac{I\, l\, \lambda}{8\pi^2 r^3} \cos\theta$$

$kr \ll 1$

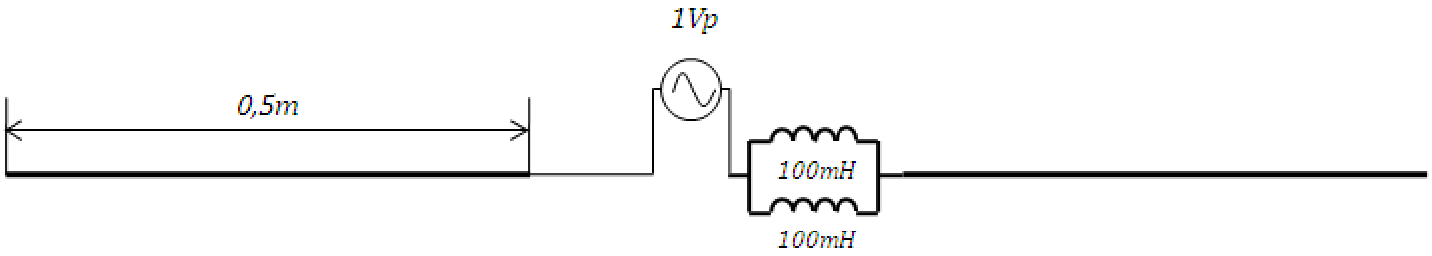
Quasiestatic electric fields

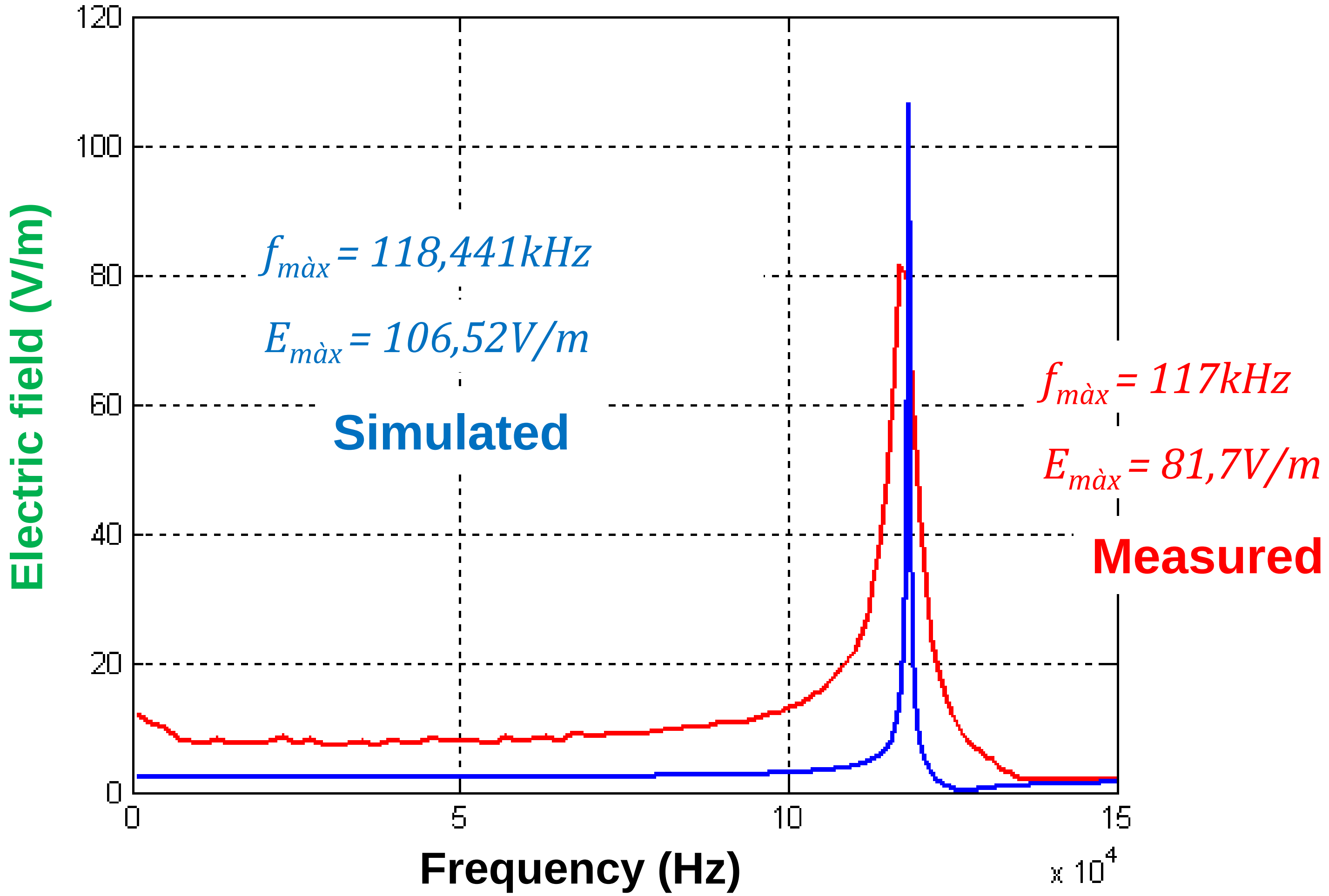
An elemental dipole antenna has to be designed to operate at f=100kHz



Autoinductaces are calculated to have a selfresonance around 100kHz

Electric field is measured 20cm away from the dipole antenna.





$f_{màx} = 118{,}441kHz$

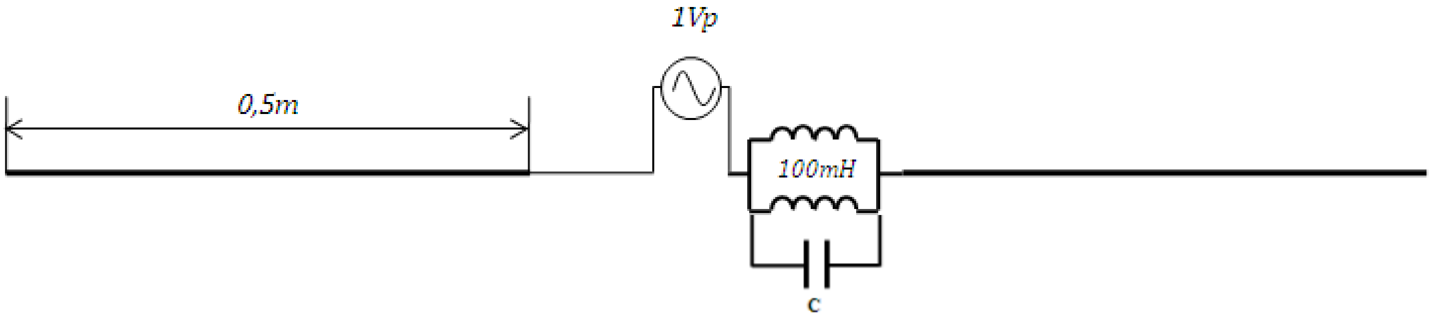
$E_{màx} = 106{,}52V/m$

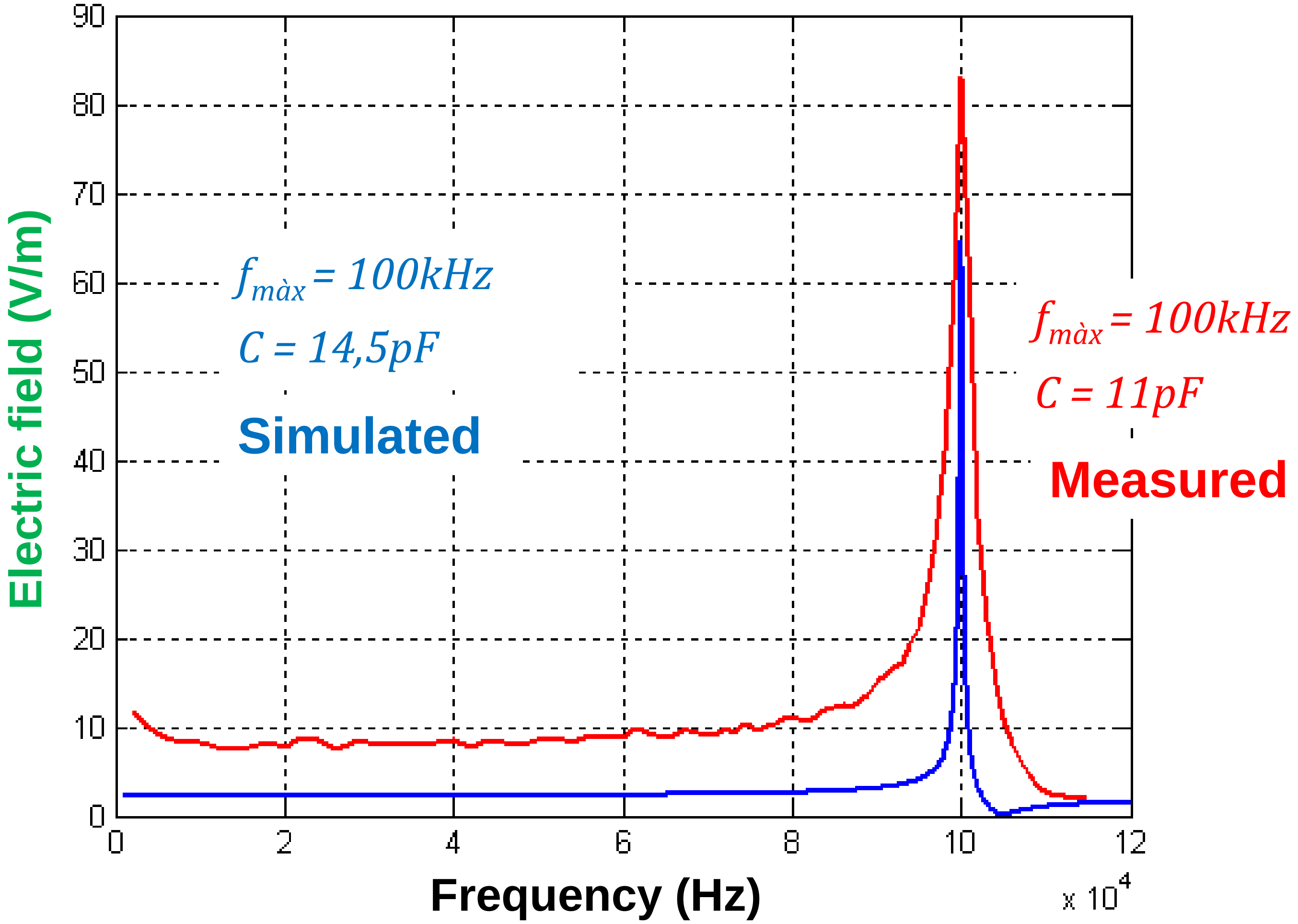
Simulated

$f_{màx} = 117kHz$

$E_{màx} = 81{,}7V/m$

Measured





$f_{màx}$ = 100kHz

C = 14,5pF

Simulated

$f_{màx}$ = 100kHz

C = 11pF

Measured

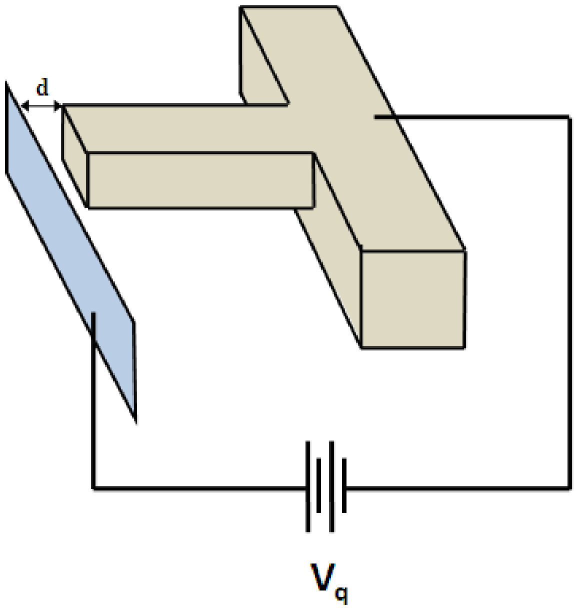
Vibration amplitud at resonance

$$F_i(t) = q \cdot E_i(t) \qquad F_i(t) = qE_i\, cos(\omega t + \phi)$$

$$u(t) = A\, cos(\omega t + \phi) \qquad A = \frac{4QqE_i l^3}{Yt^3 w}$$

Harvested mechanical power

$$P = F \cdot v \qquad v_{mitja} = \frac{4A}{T} = \frac{4\, A\, \omega}{2\pi}$$

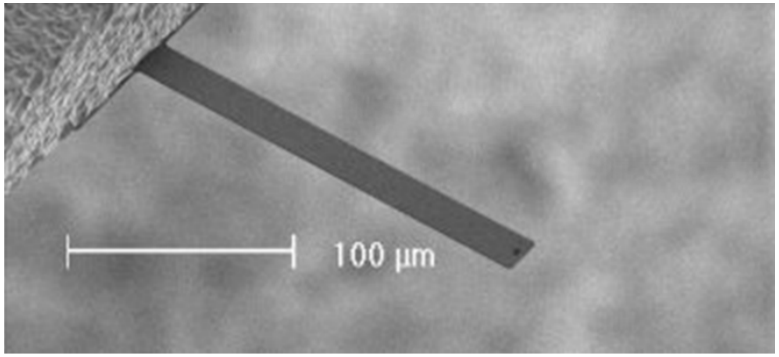


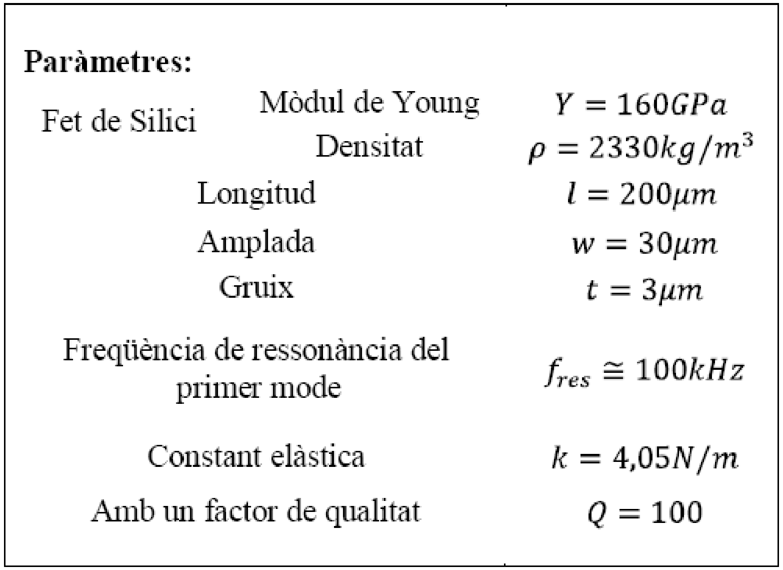
$$\boxed{q = C \cdot V_q}$$

$$C = \varepsilon_0 \varepsilon_r \frac{A_{eff}}{d}$$

d: cantilever tip – electrode distance

A_{eff}: Effective area cantilever tip - electrode





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	Amb un factor de qualitat	$Q = 100$

For this cantilever and applying V_q=20V from d=3um:

$q \approx 5.3 \cdot 10^{-15}$ C

$A \approx 1.7$ nm

P ≈ 50 fW

V = $18 \cdot 10^3$ um^3 = $18 \cdot 10^{-9}$ cm^3

P/V = 2.8 uW/cm^3

V = 0.3 cm^3

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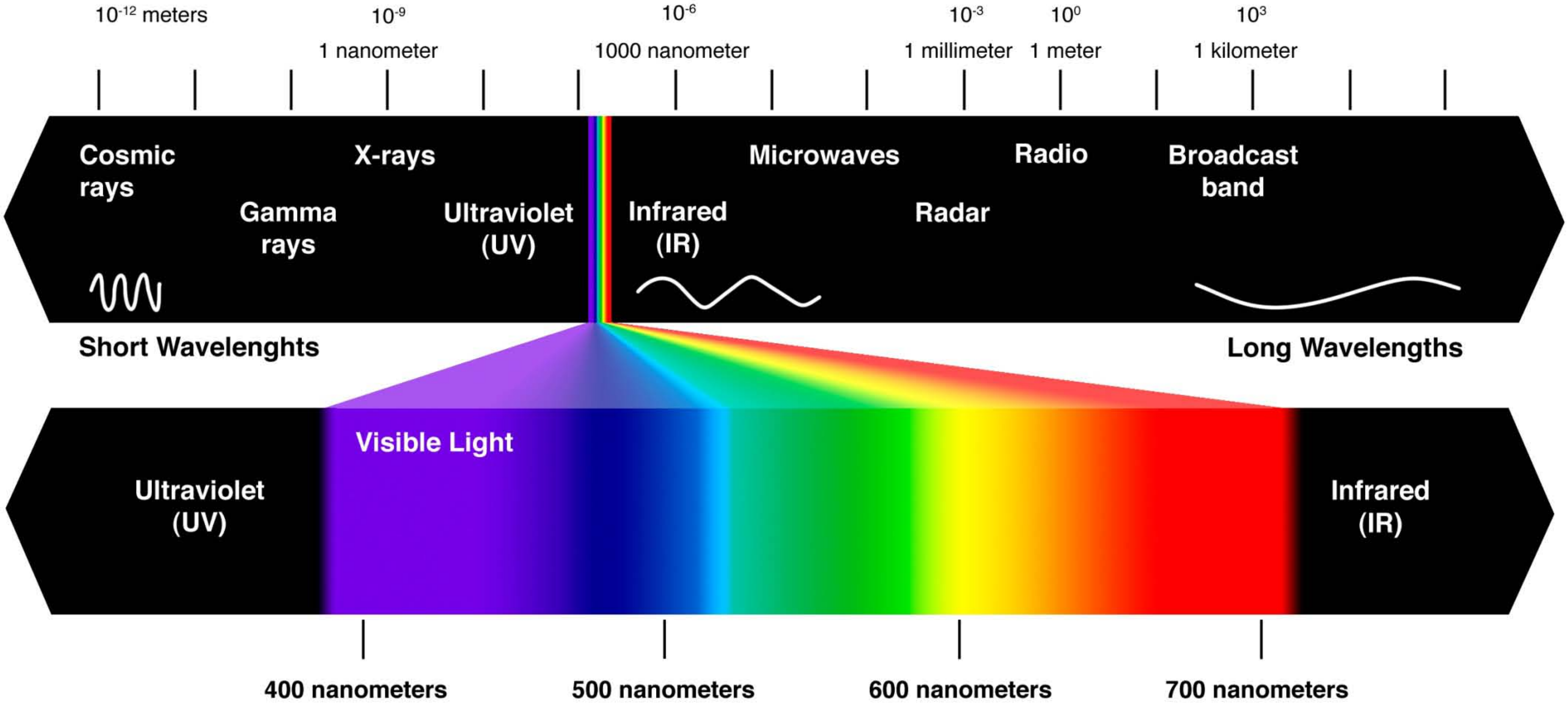


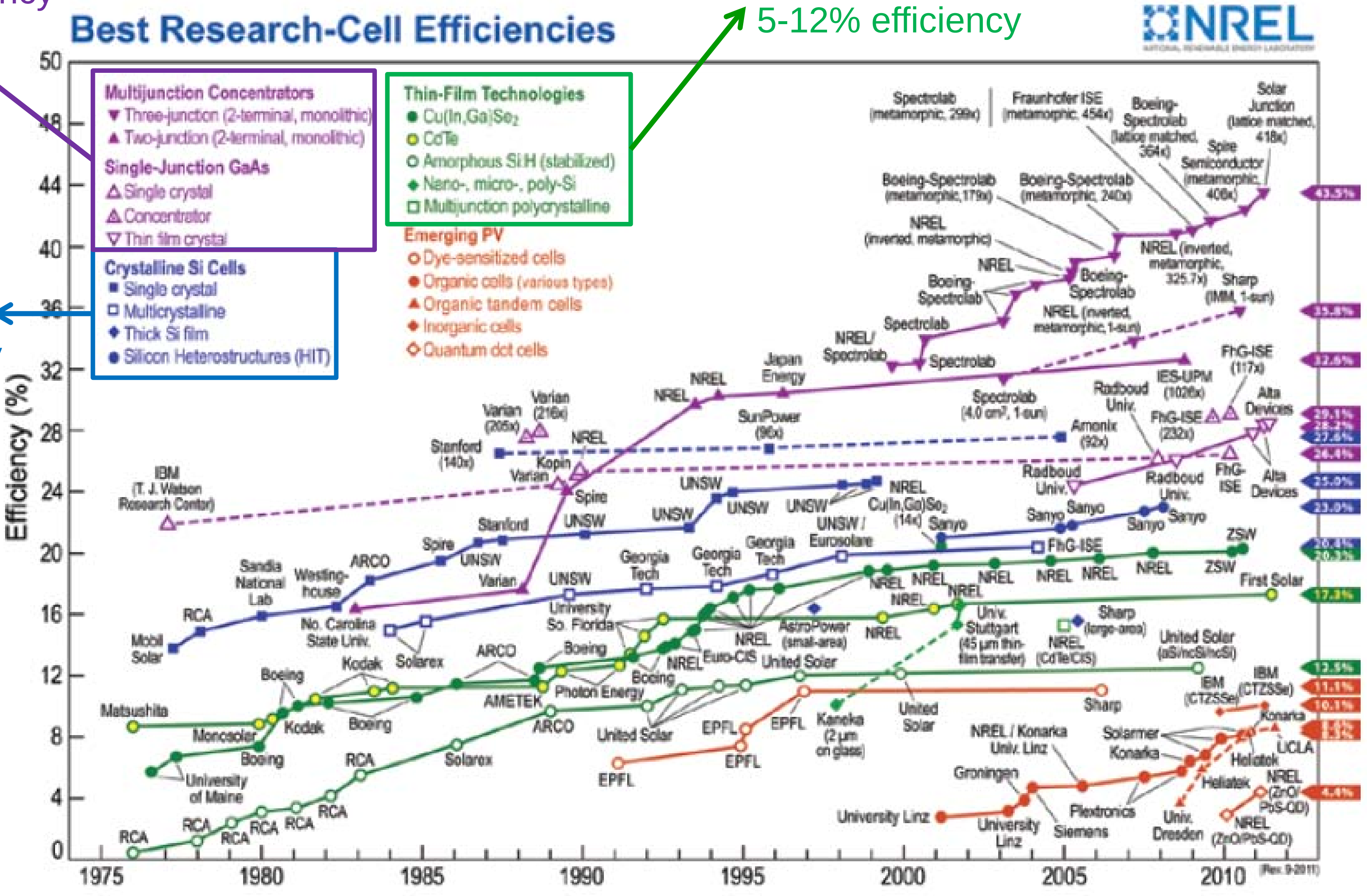
$$\boxed{c = \lambda \cdot \nu}$$

$$\boxed{E = h \cdot \nu}$$

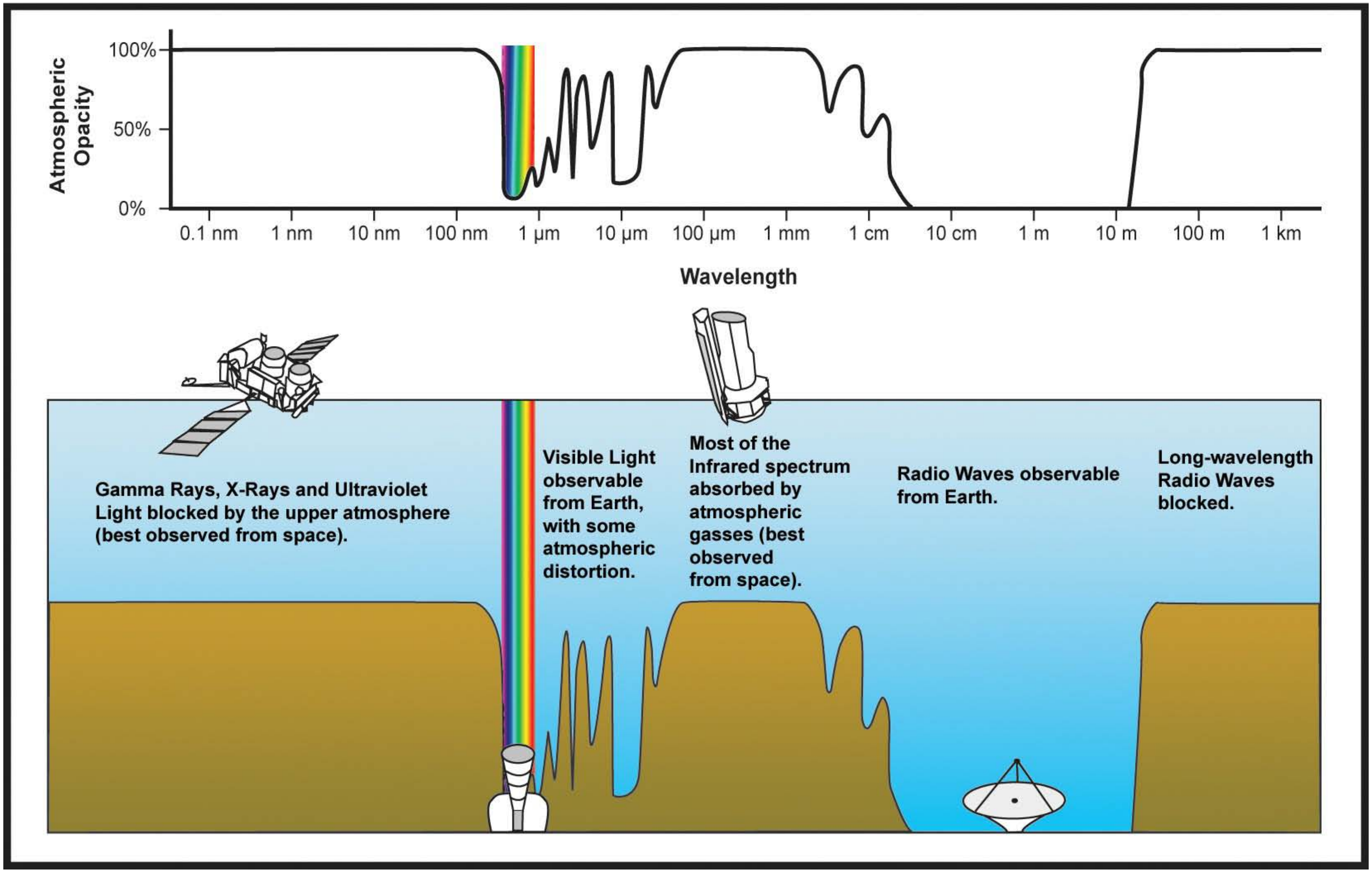
3rd generation
40-50% efficiency

2nd generation
10% market
5-12% efficiency

1st generation
90% market
15% efficiency



Best research-cell efficiencies 1975–2010



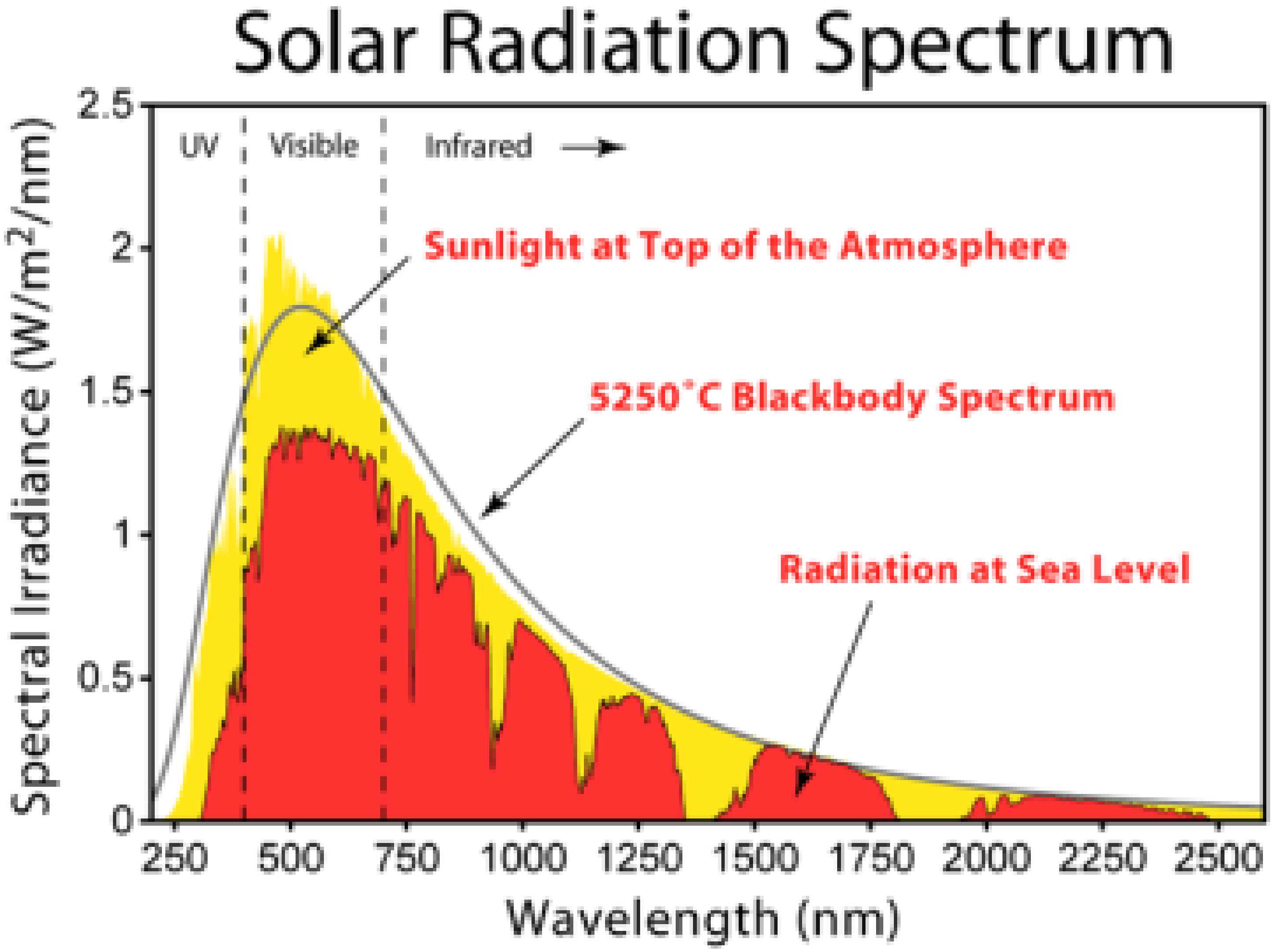
Gamma Rays, X-Rays and Ultraviolet Light blocked by the upper atmosphere (best observed from space).

Visible Light observable from Earth, with some atmospheric distortion.

Most of the Infrared spectrum absorbed by atmospheric gasses (best observed from space).

Radio Waves observable from Earth.

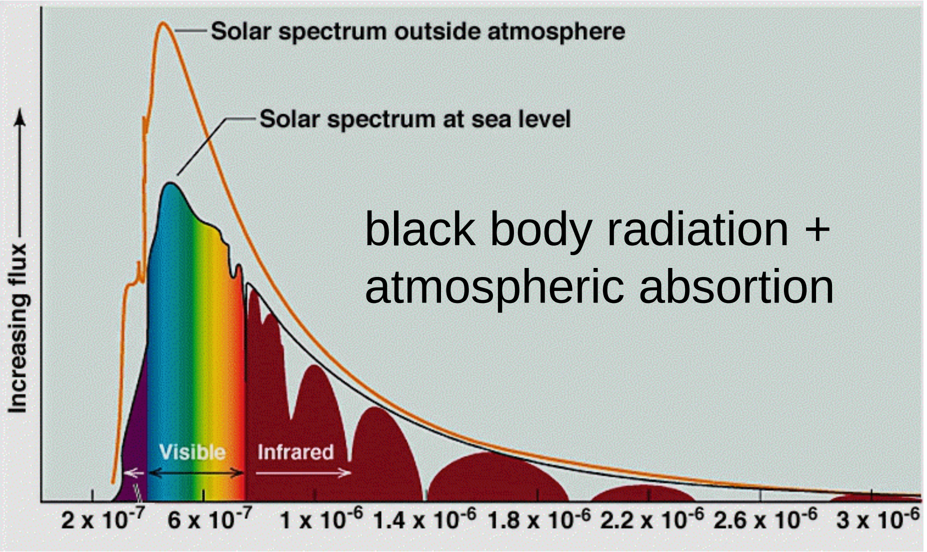
Long-wavelength Radio Waves blocked.


Solar Radiation Spectrum
Spectral Irradiance (W/m²/nm)
Wavelength (nm)
UV
Visible
Infrared →
Sunlight at Top of the Atmosphere
5250°C Blackbody Spectrum
Radiation at Sea Level
0
0.5
1
1.5
2
2.5
250
500
750
1000
1250
1500
1750
2000
2250
2500

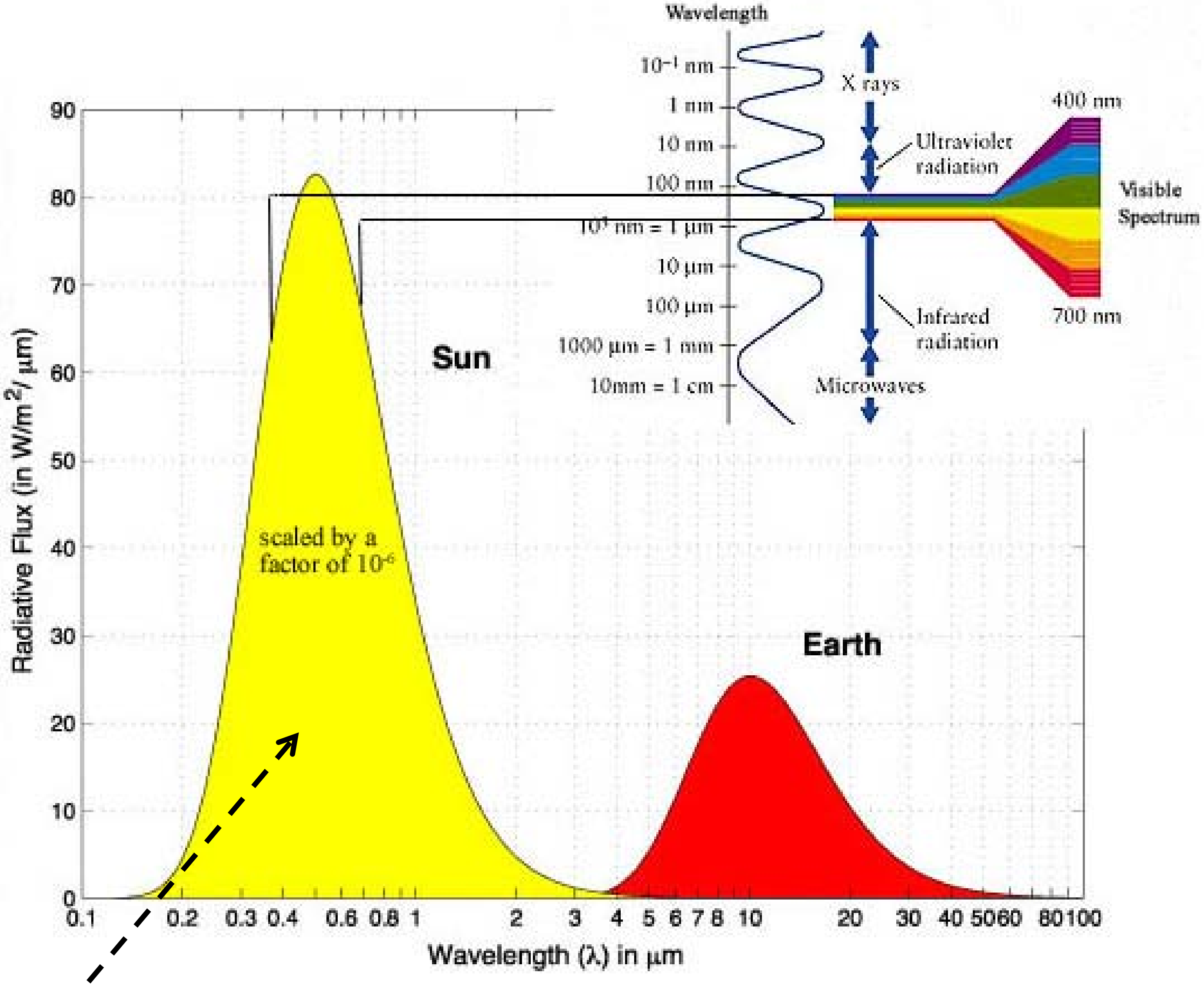
During the day the maximum energy is in the visible (λmax$\approx$ 500 nm)

During the night, the maximun energy is in the IR

(λmax $\approx$ 10-15 μm)

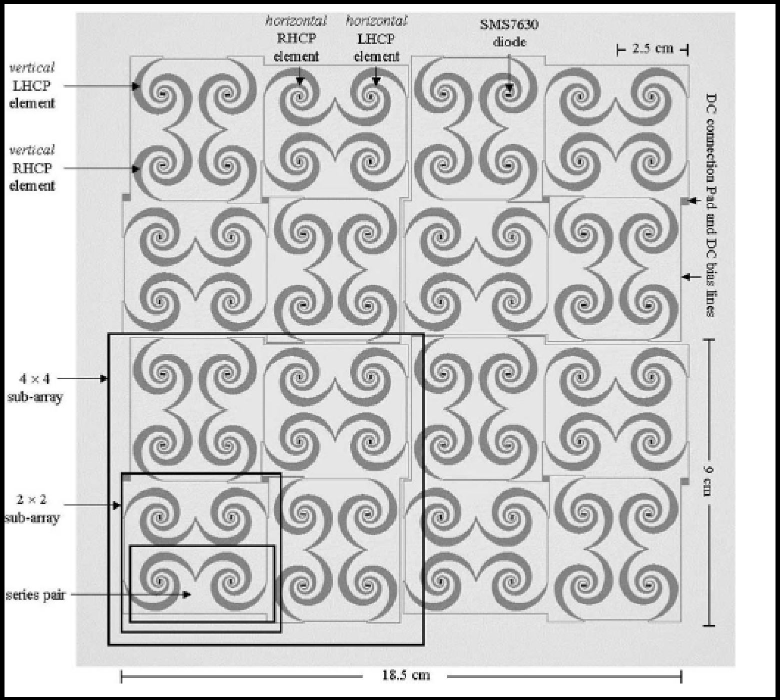


black body radiation + atmospheric absorption



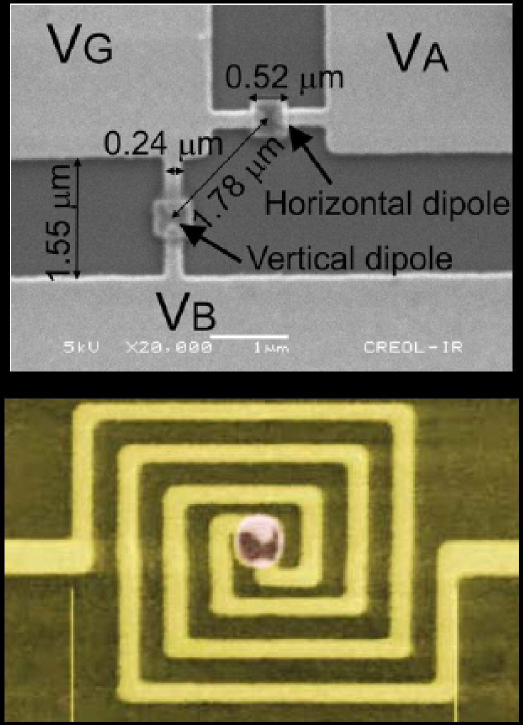
Corresponds to the Sun surface
At the Earth orbit distance, flux is reduced by a factor 50.000

GHz rectenna



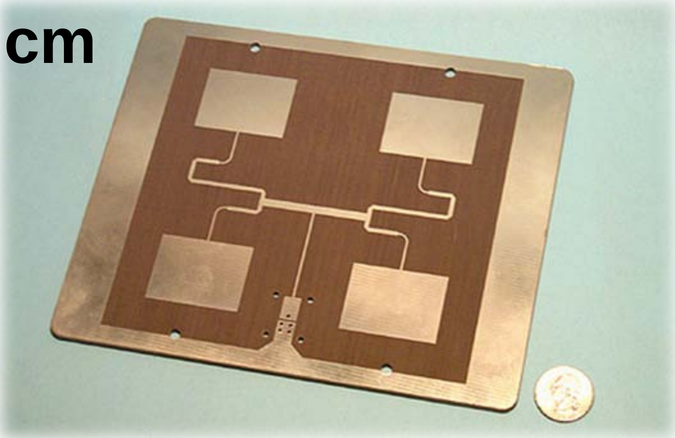
Hagerty et al., “IEEE Trans on MTT”, (2004)

THz optical rectenna

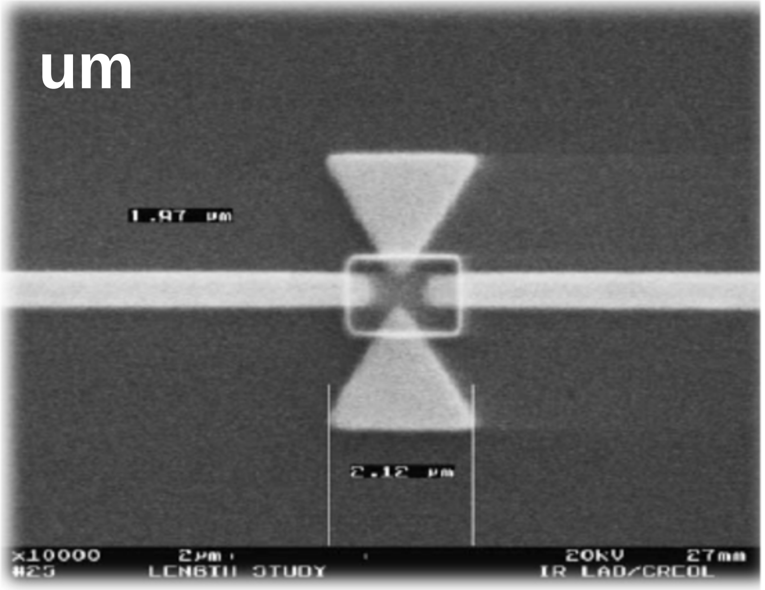


Alda et al. Opt. Lett. (2009)

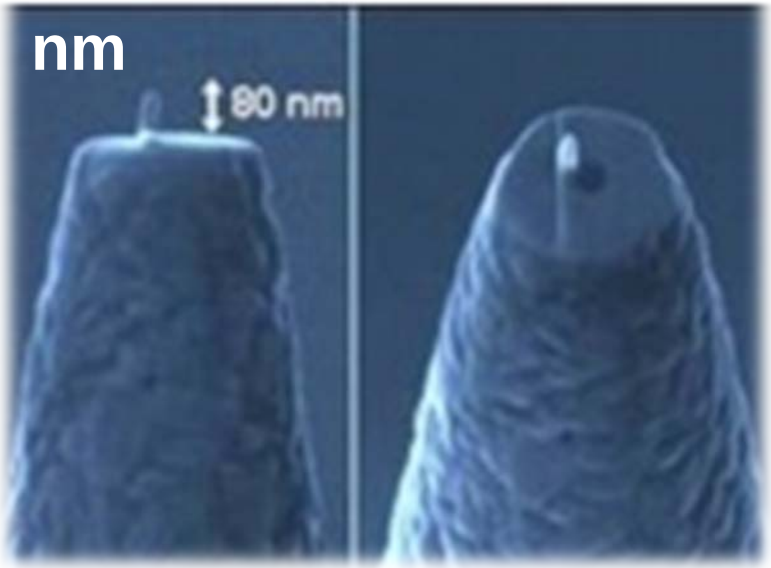
Optical nano-antenna technology



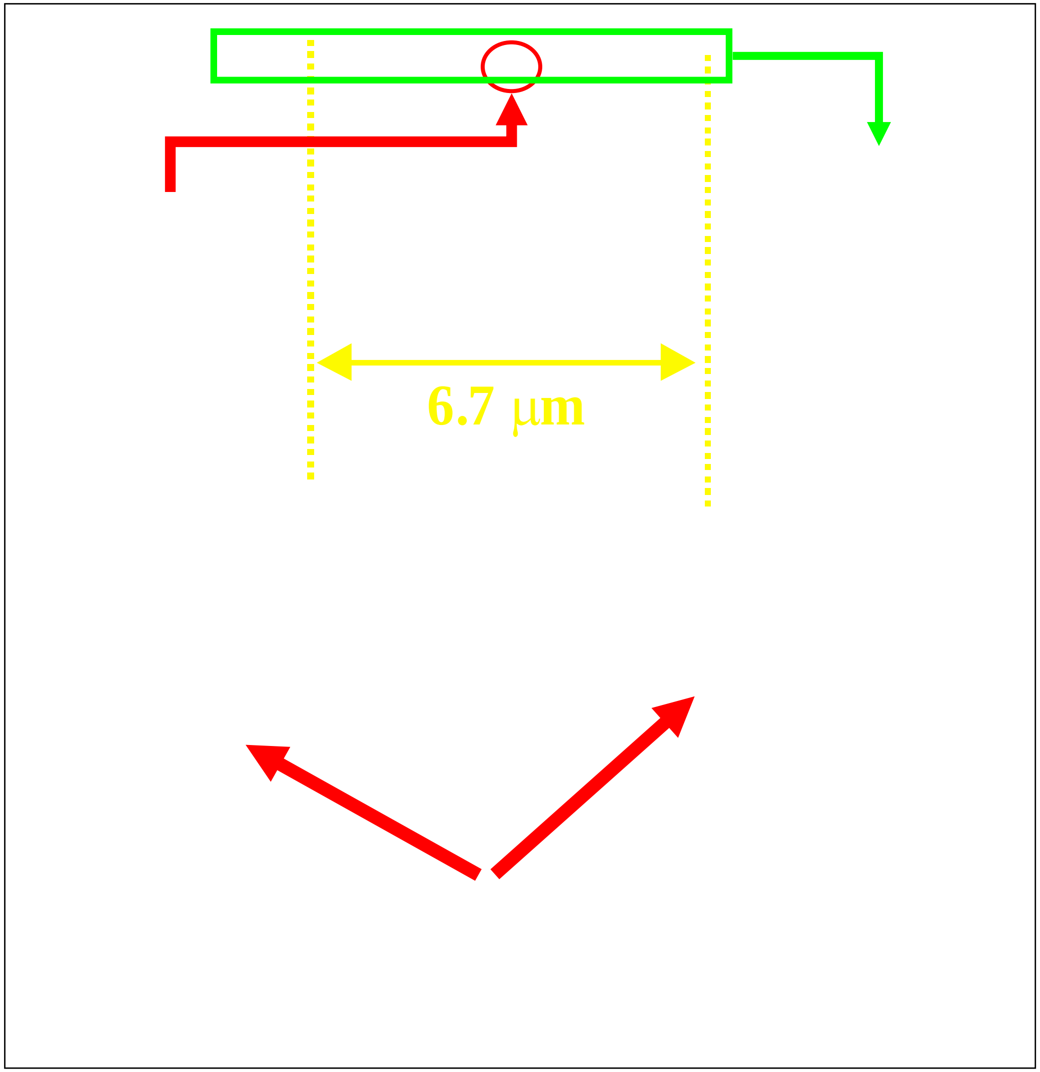
Microwave patch-antenna



Infrared bow-tie antenna



Visible dipole antenna


6.7 µm

What is an optical nano-antenna

- A light detector
- A metallic resonant structure that couples the radiation to a transducer element
- A detection element coupled with an antenna working at optical frequencies

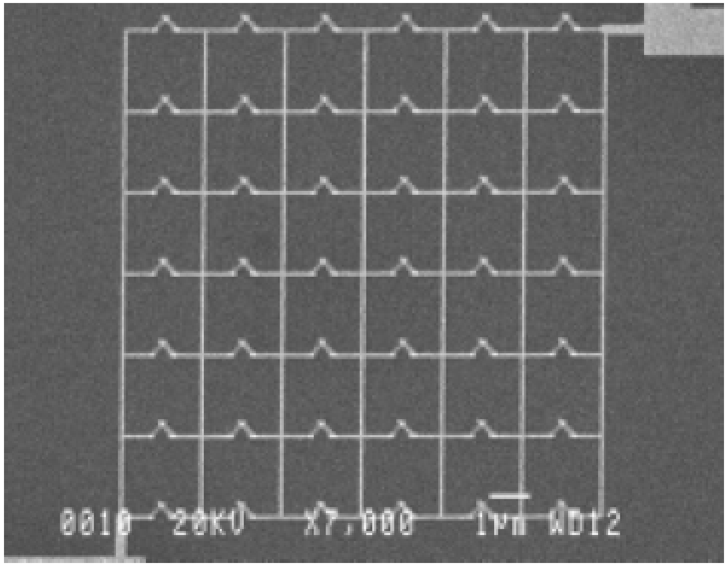
What is NOT an optical nano-antenna

- A simple downscaled version of a radioelectric or microwave antenna
- A competitor for the semiconductor light detectors
- A phase detector (important advances)
- An emitter (no yet, but coming)

Properties of an optical nano-antenna

- Point-like detector: Minimum spatial footprint
- Polarization sensitive detector
- Fast detector
- Tunable detector
- Directional selective detector
- Integrable with opto-electronics
- Work at room temperature
- Transduction mechanism:
  - *Bolometric material: dissipative*
  - *Metal-Oxide-Metal Union: non-linear rectification.*
- These mechanisms are usually placed at the feed-point of the antenna structure.

Optical rectenna



Theoretical efficiencies ≈ 96%

Shottky diodes: f < 5 THz

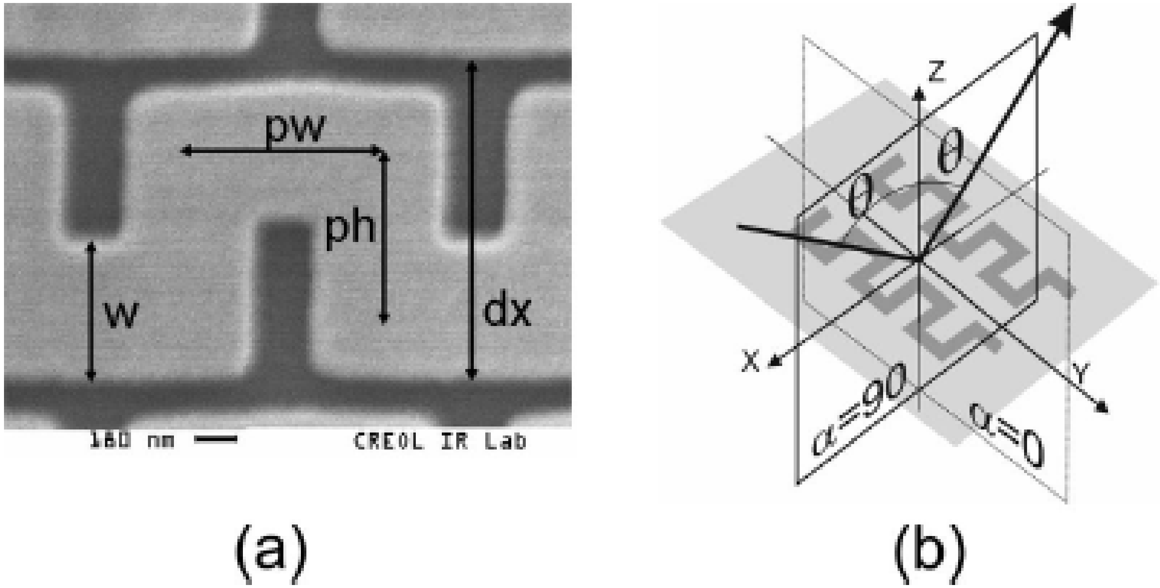
MIM diodes: f ≈ 150 THz (2um)
Two limitations:
-Integration
- Zero bias response: pour non-linearity of the i-v characteristic at V=0.

Optical resonant structures

- The metallic subwavelenght structures are not connected to read-out electronics.
- Control of the reflected, transmitted, or absorbed radiation.
  - *Polarization control: Polarizers and retarders*
  - *Spectral control: Frequency Selective Surfaces (FSS)*

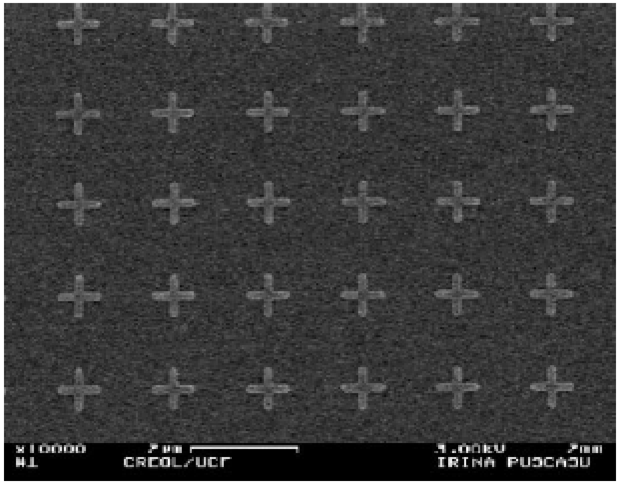
Polarization control

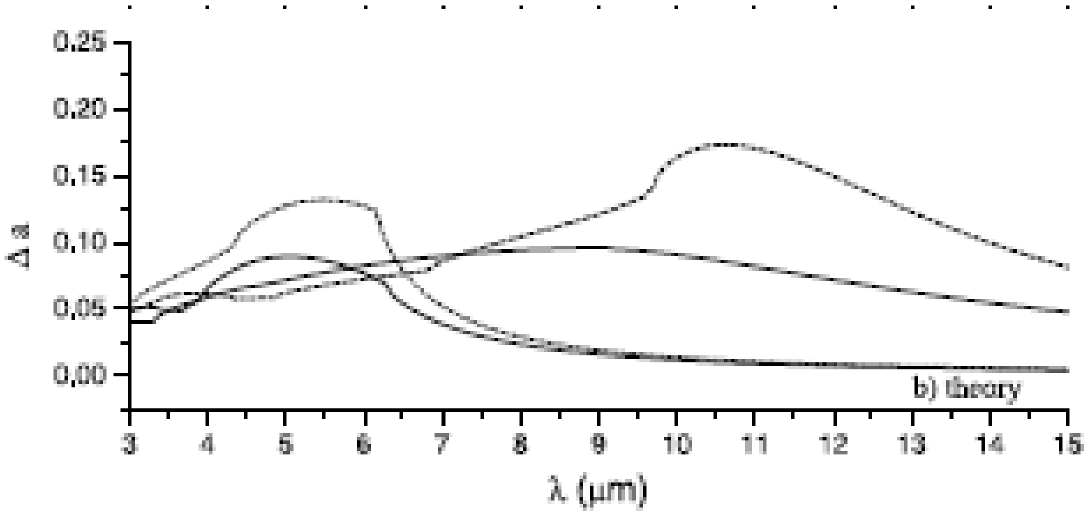
- Meander-lines and polarization elements:
  - Change in the state of polarization using metallic periodic structures

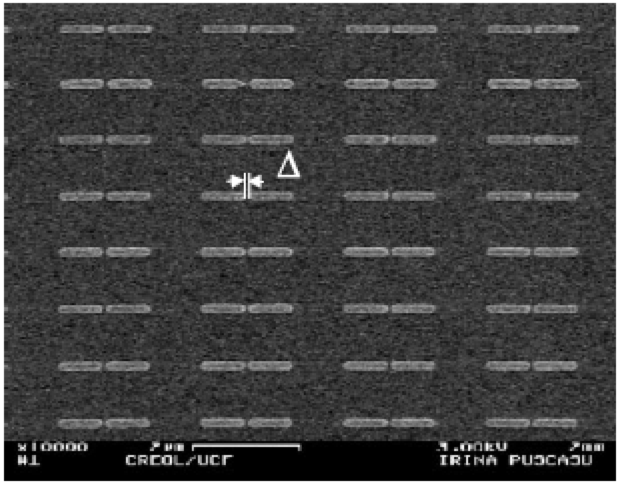


Frequency selective structures (FSS)

Modification of the spectral reflectivity, transmissivity and absortance.







NOEMS oscillators

APPLIED PHYSICS LETTERS VOLUME 79, NUMBER 5 30 JULY 2001

Autoparametric optical drive for micromechanical oscillators

M. Zalalutdinov,[a] A. Zehnder, A. Olkhovets, S. Turner, L. Sekaric, B. Ilic, D. Czaplewski,
J. M. Parpia, and H. G. Craighead
Cornell Center for Materials Research, Ithaca, New York 14853-2501

(Received 21 March 2001; accepted for publication 31 May 2001)

Self-generated vibration of a disk-shaped, single-crystal silicon micromechanical oscillator was observed when the power of a continuous wave laser, focused on the periphery of the disk exceeded a threshold of a few hundred μW. With the laser power set to just below the self-generation threshold, the quality factor for driven oscillations increases by an order of magnitude from $Q = 10\,000$ to $Q_{\mathrm{enh}} = 110\,000$. Laser heating-induced thermal stress modulates the effective spring constant via the motion of the disk within the interference pattern of incident and reflected laser beams and provides a mechanism for parametric amplification and self-excitation. Light sources of different wavelengths facilitate both amplification and damping.

[DOI: 10.1063/1.1388869]

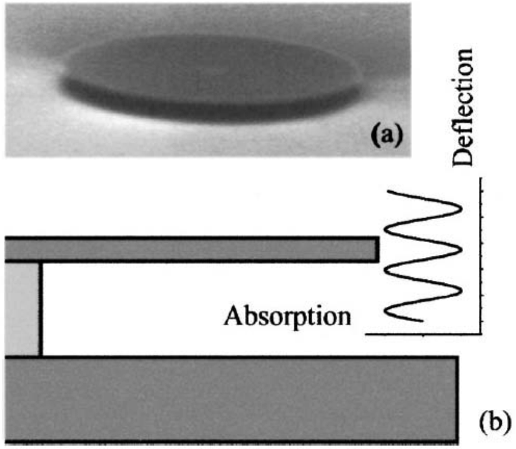


FIG. 1. (a) A scanning electron micrograph of the disk oscillator is shown. (b) A schematic vertical cross section (right half) of the disk oscillator with position-dependent absorption due to the interference effect is presented.

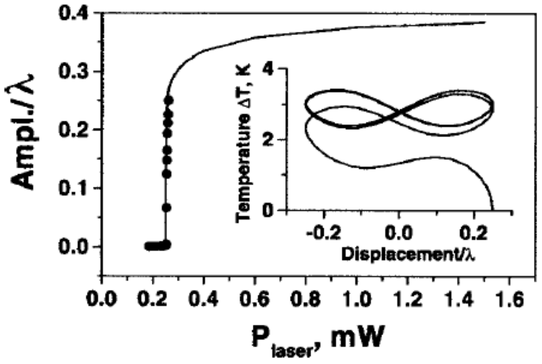
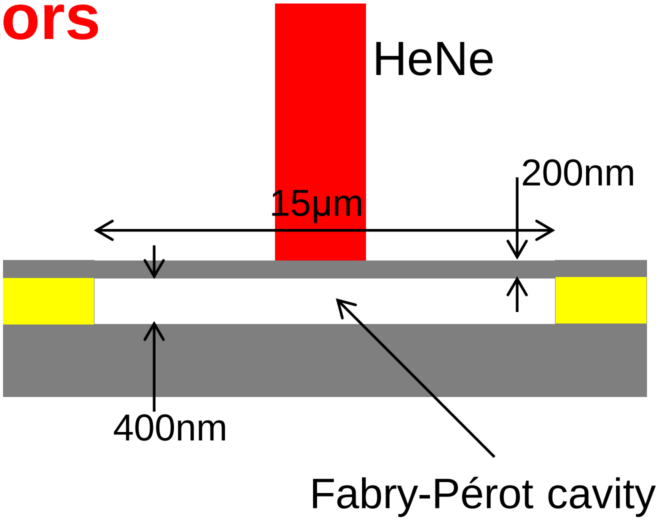


FIG. 3. Amplitude of the self-oscillating peak as a function of the CW laser power is shown. Circles represent experimental data (normalized). The result of the theoretical calculations for the amplitude of vibration due to parametric self-excitation is shown by the solid line. Inset demonstrates modulation of the local overheating (disk temperature under the laser beam) caused by the motion within the interferometric pattern. The laser intensity and the ratio of temperature diffusion time to the period of oscillation define the loop area, which is related to the energy income per cycle [$\Delta T \sim \Delta k$, Eq. (4)].

NOEMS oscillators

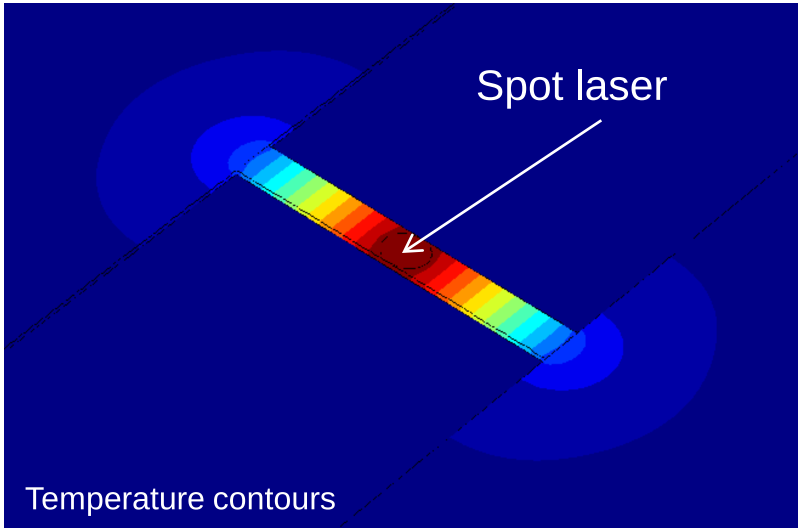


Structure example:

- Type: bridge
- Fabrication causes residual compressive stress
  - ✓ It makes the bridge to be arched 40 nm at the periphery
- Materials (from a SOI wafer)
  - ✓ Bridge: Si
  - ✓ Pillar: SiO_2
  - ✓ Substrate: Si

“Excitation” source:

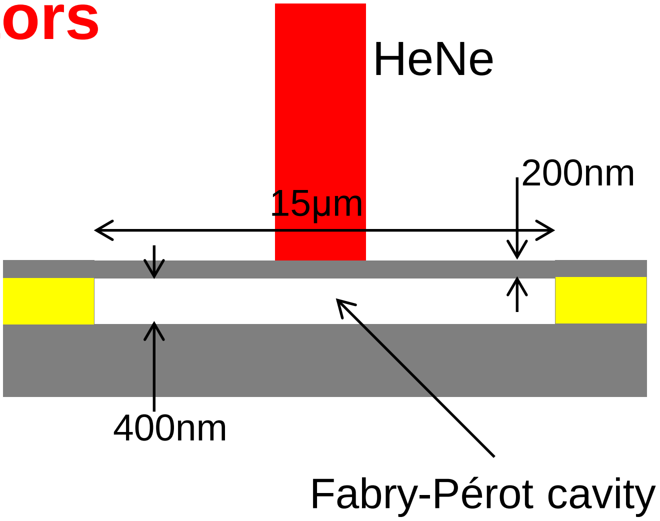
- Continuous Wave (CW) HeNe laser
  - ✓ λ = 632,8 nm
- Spot radius of about 2-5 µm
- Position at the center of the beam



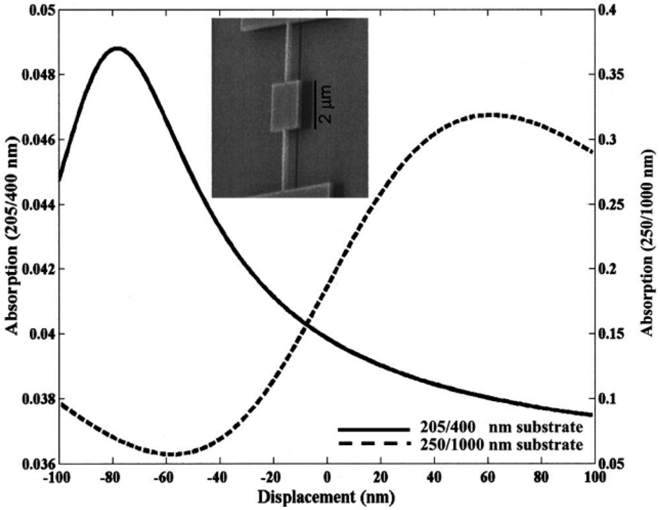
NOEMS oscillators

$$\ddot{z} + \frac{\omega_0}{Q}\dot{z} + \left(1 - \frac{T}{T_b}\right)z + \beta z^3 - DT = 0$$

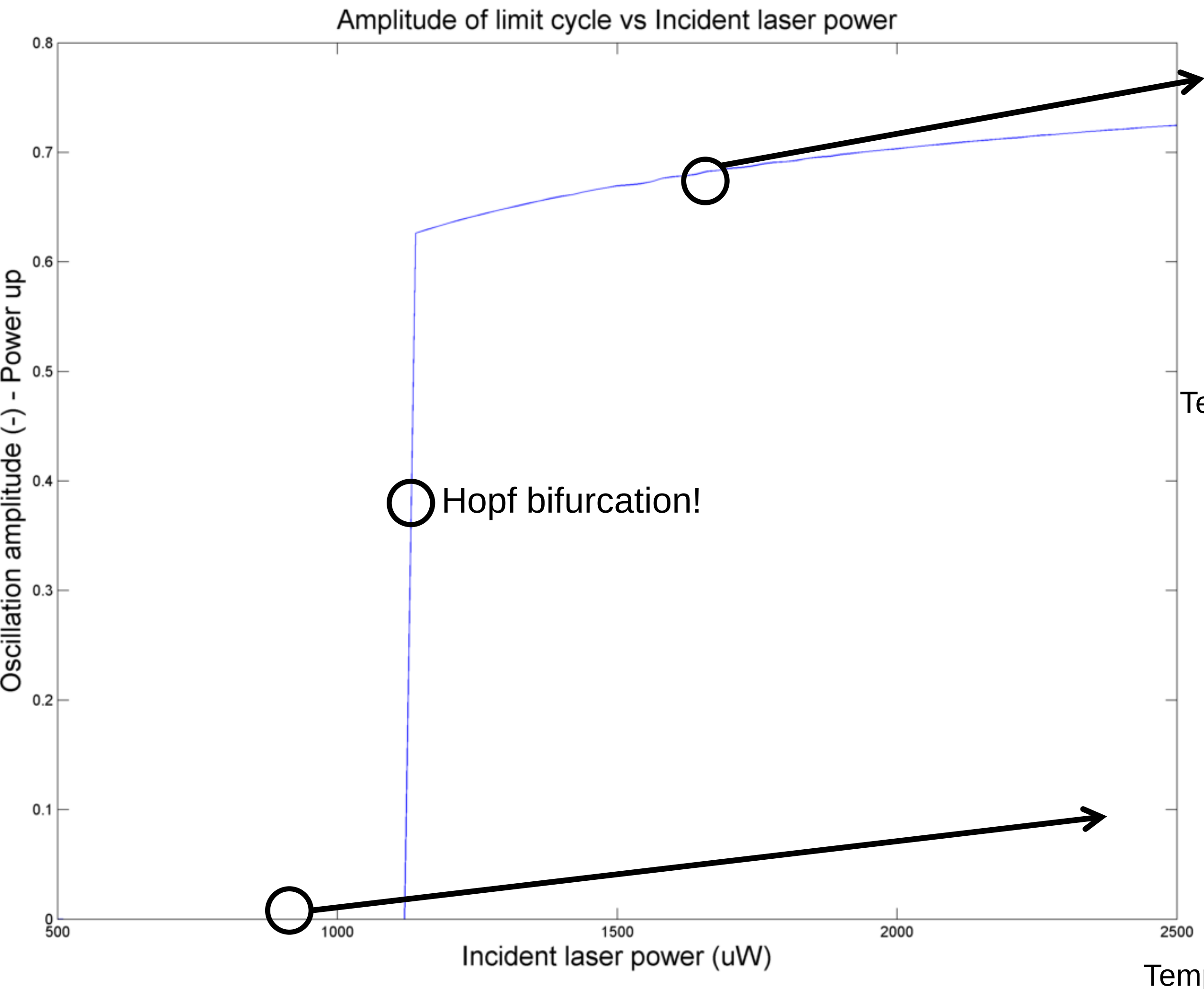
$$\dot{T} = AP_{absorbed}\left(z\right) - BT$$



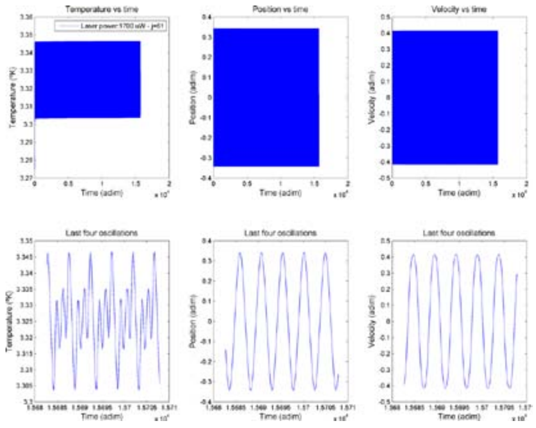
→ *Example*: $\dot{T} = AP_{laser}\left[\alpha + \gamma \sin^2\left(z - z_0\right)\right] - BT$



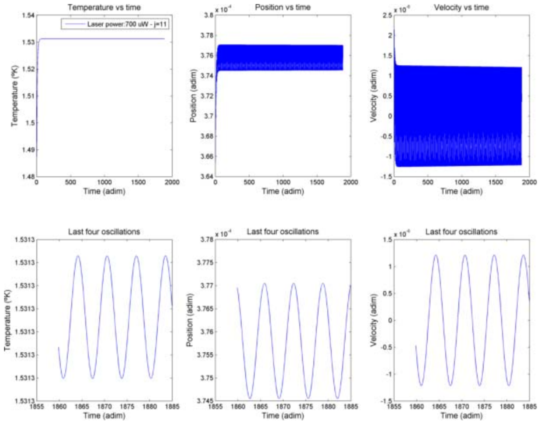
NOEMS oscillators



Hopf bifurcation!

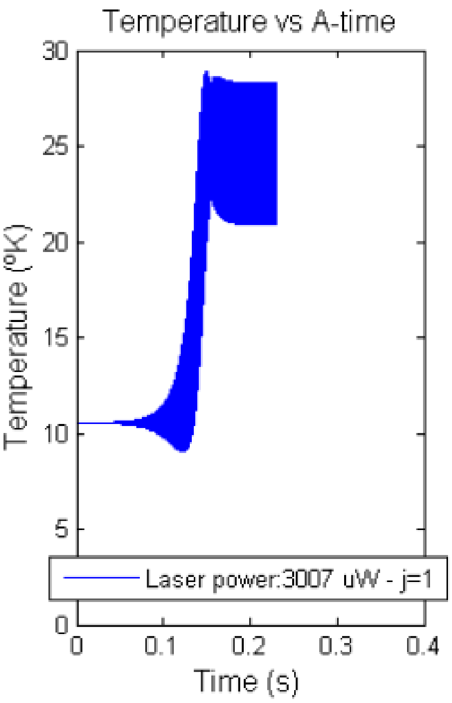


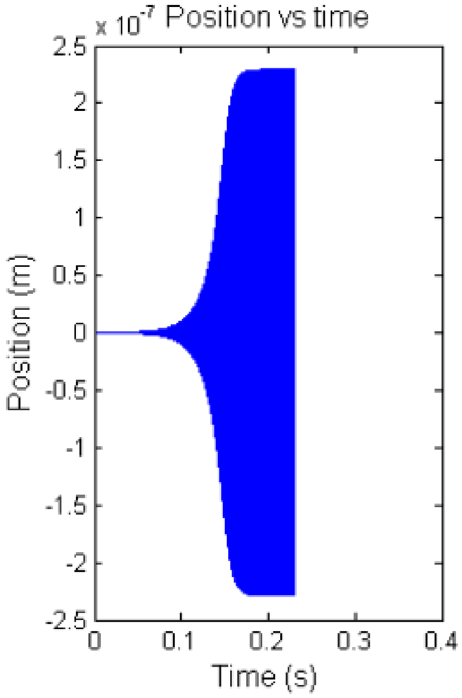
Temperature, position and velocity reach the steady state with periodic motion

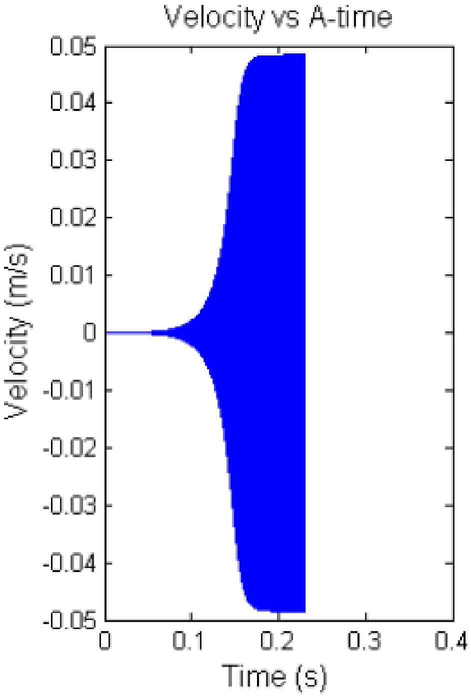


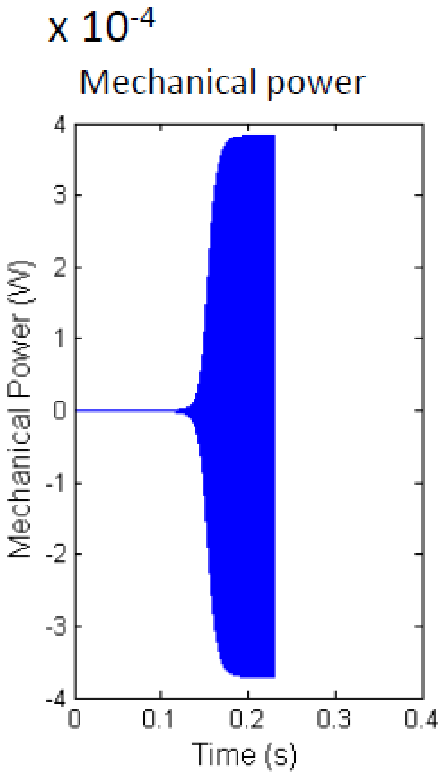
Temperature, position and velocity decreasing till there is no temporal variation at the steady state

NOEMS oscillators

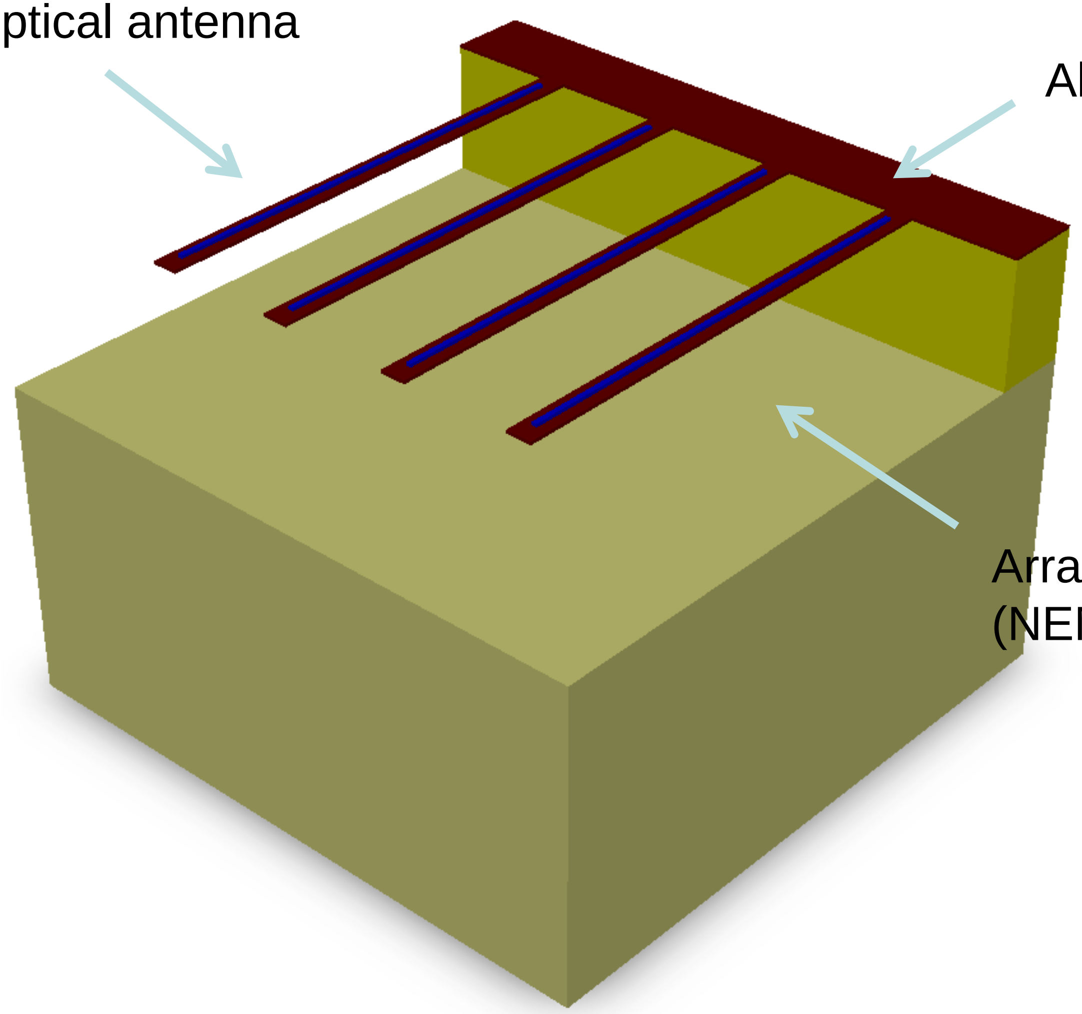








NOEMS oscillators coupled to optical resonant structures
OPACMEMS devices



Array of optical antenna
(FSS)

AlN (piezo)

Array of nanocantilevers
(NEMS)

Outline

Energy available in the EM spectrum

RF energy harvesting. The MEMSTENNA concept.

Alternatives to Photovolatics:
    Optical rectenna. From RF rectenna to optical rectenna
    Opacmems devices

Storage

Storage

IOP Publishing Journal of Micromechanics and Microengineering

J. Micromech. Microeng. **19** (2009) 094015 (5pp) doi:10.1088/0960-1317/19/9/094015

Storing elastic energy in carbon nanotubes

F A Hill[1], T F Havel[1], A J Hart[2] and C Livermore

[1] Department of Mechanical Engineering, MIT, Cambridge, MA, USA
[2] Department of Mechanical Engineering, University of Michigan, Ann

Received 13 January 2009, in final form 24 March 2009
Published 26 August 2009
Online at stacks.iop.org/JMM/19/094015

Abstract

The potential performance of carbon nanotubes (CNTs) as sprin
evaluated. Models are used to determine an upper bound on the
stored in defect-free individual CNTs and in assemblies of such
optimal energy density may be achieved in small-diameter single
tension, with a maximum theoretical energy density for CNT gr
Millimeter-scale CNT springs are constructed using 3 mm tall fo
the starting material, and tensile tests are performed to measure t
and elastic properties. The measured strain energy density of the
comparable to the energy density of steel springs.

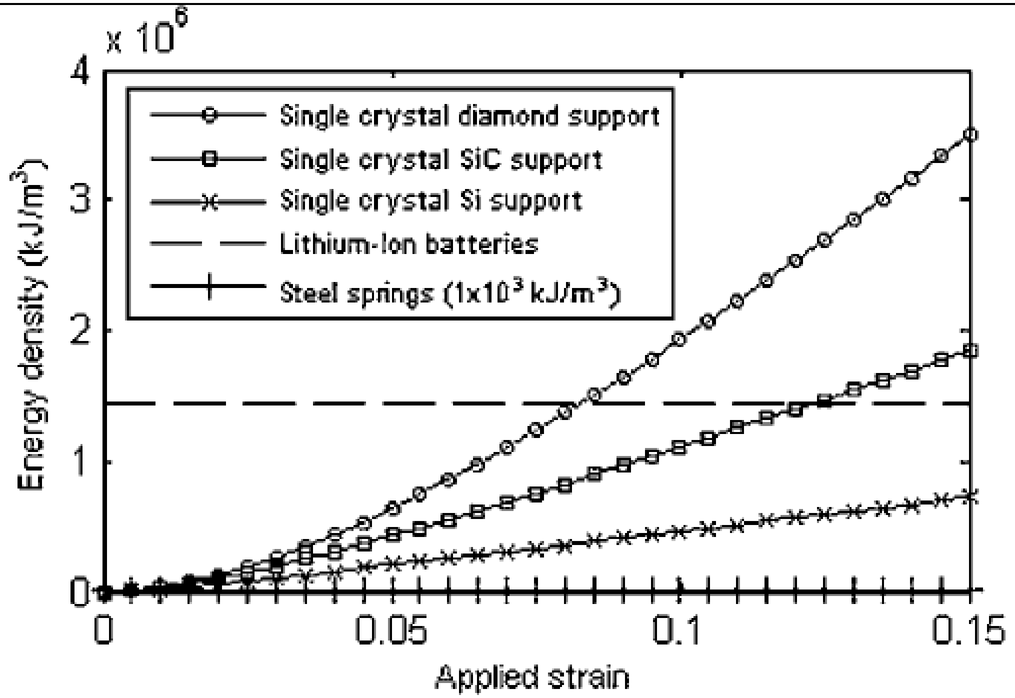
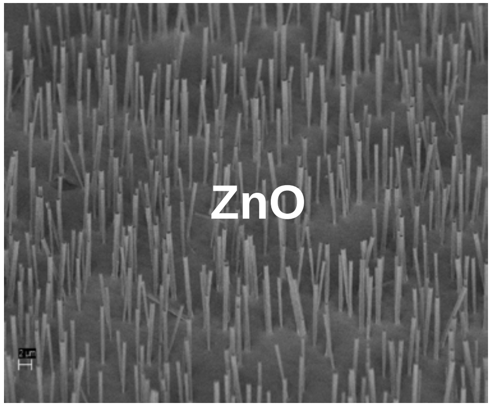
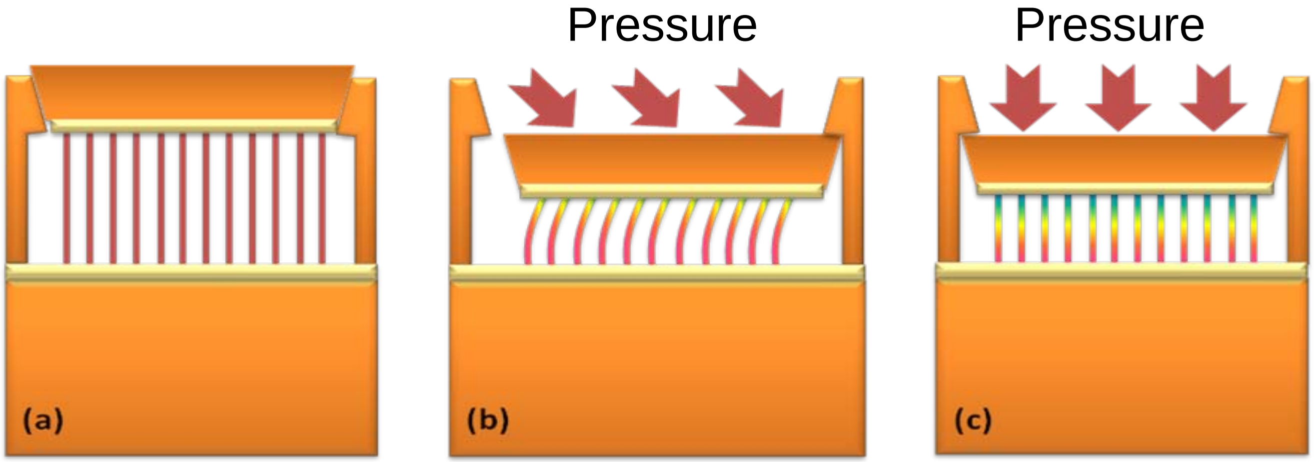


Figure 2. Energy density of SWCNT bundles under tensile loading with support structures made of single crystal diamond, silicon and silicon carbide.

Storage





Project title:
NEMSBattery: NEMS BASED MECHANICAL ENERGY STORAGE
Financed by: TEC2010-10459-E. Acción complementaria EXPLORA 2010 (micinn)
Participants: UAB, CNM
Duration from: January 2011 to: December 2012
Subvention: 24.000€
Project responsible: Francesc Torres Canals

UAB
Universitat Autònoma de Barcelona

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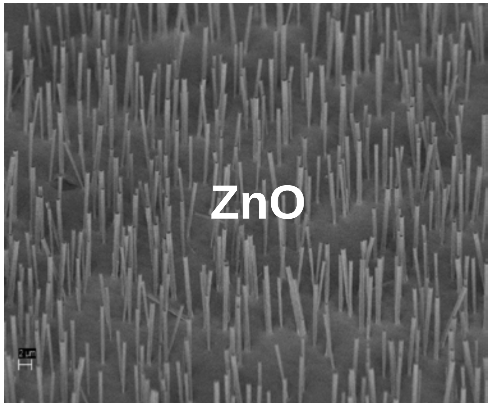
Department of Electronics Engineering
School of Engineering
University Autonoma of Barcelona (SP)

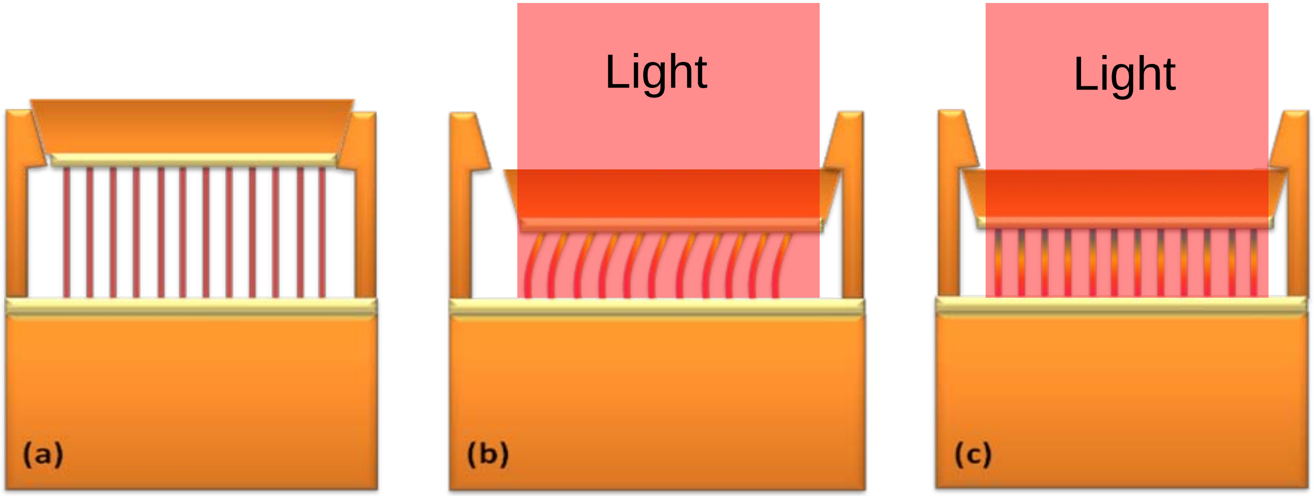
cnm

Dr. Jaume Esteve
Institute of Microelectronics of Barcelona
IMB-CNM. CSIC
Campus UAB (SP)

Aim of the project: To investigate the compression and deflection mechanisms of dense arrays of nanowires for the storage of mechanical energy.

Storage





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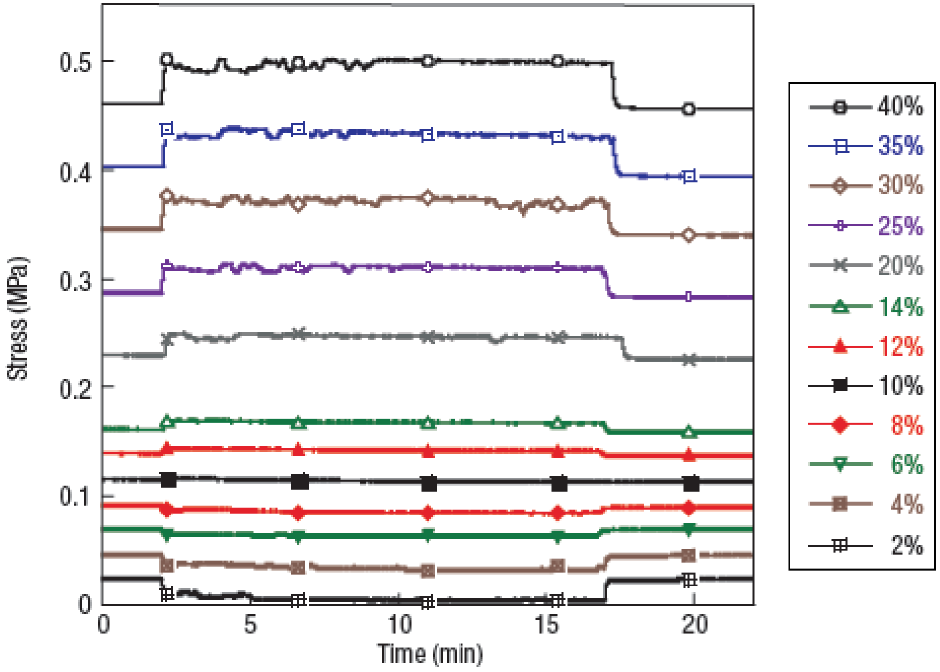
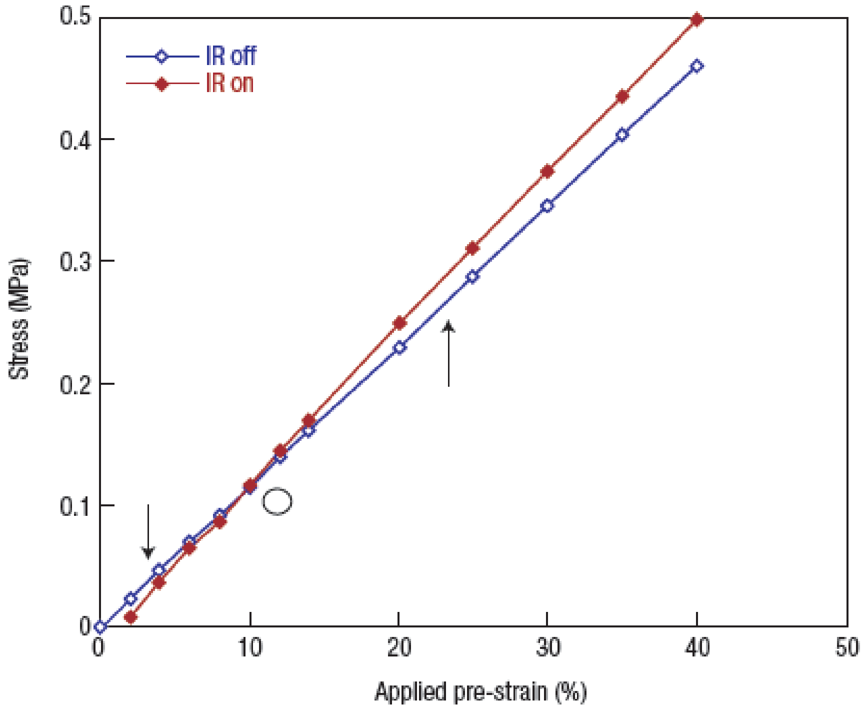
Storage

Photomechanical actuation in polymer–nanotube composites

SAMIT V. AHIR AND EUGENE M. TERENTJEV*
Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, UK
*e-mail: emt1000@cam.ac.uk

At small strains the sample tends to expand, when stimulated by photons, by an amount that is orders of magnitude greater than the pristine polymer. Conversely, at larger applied pre-strain, it will contract under identical infrared excitation.





Storage

Optically Activated ZnO/SiO$_2$/Si Cantilever Beams

J. SUSKI, D. LARGEAU and A. STEYER*
Schlumberger Industries, Centre de Recherche, SMR, B.P. 620-05, 92542 Montrouge Cédex (France)
F. C. M. VAN DE POL and F. R. BLOM
Faculty of Electrical Engineering, University of Twente, P.O. Box 217, 7500 AE Enschede (The Netherlands)

(Received January 30, 1990; in revised form August 9, 1990; accepted September 13, 1990)

The photomechanical effect induced by periodically varying sub-bandgap illumination in thin ZnO films deposited on oxidized Si has been demonstrated for the first time. The efficiency of this effect is at least one order of magnitude higher as compared to the photothermal activation of Si. Thus it can be considered as a powerful optical drive for resonant sensors. A phenomenological model of the mechanisms involved in the process is proposed. The optomechanical effect can also be used as a complementary method in determination of the surface state parameters of ZnO films.

Sensors and Actuators A, *24* (1990) 221–225

Project title:

ZEROPOWER—Co-ordinating Research Efforts Towards Zero-Power ICT

Proposal no. 270005

Financed by: FP7-ICT-2009-6. Coordination and support action. ICT-6-8.9 - Coordinating Communities, Plans and Actions **in FETProactive** Initiatives

Participants: UNIPG (UNIVERSITA DEGLI STUDI DIPERUGIA), Tyndall-UCC (UNIVERSITY COLLEGE CORK, NATIONAL UNIVERSITY OF IRELAND, CORK), UAB (UNIVERSITAT AUTONOMA DE BARCELONA), UGLA (UNIVERSITY OF GLASGOW)

Duration from: 1st January 2011 to: 31st December 2013

Subvention: 104.891€ (UAB) of 550.000€ (TOTAL)

Project responsible: Luca Gammaitoni (UNIPG project coordinator). Gabriel Abadal (responsible UAB)

Prof. Luca Gammaitoni

Prof. Douglas Paul

Dr. Georgios Fagas

Dr. Gabriel Abadal

Aim of the project: The goal of this project is to create a coordination activity among consortia involved in “Toward Zero-Power ICT” research projects (FET proactive call FP7-ICT-2009-5, Objective 8.6) and communities of scientists interested in energy harvesting and low power, energy efficient ICT.

Project title:
OPACMEMS: Optical antennae coupled to micro and nanoelectromechanical systems
Financed by: MICINN. ENE2009-14340-C02-02
Participants: UCM (subproject 01), UAB (subproject 02)
Duration from: Oct 2009 to:Oct 2012
Subvention: 180.000€ (subproy. 02)
Project responsible: Gabriel Abadal Berini

UAB
Universitat Autònoma de Barcelona

Dr. Gabriel Abadal
Department of Electronics Engineering
School of Engineering
University Autonoma of Barcelona (SP)

Universidad Complutense Madrid

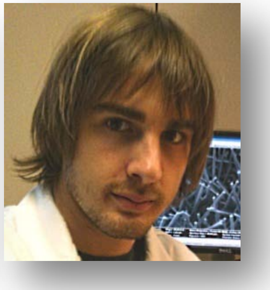
Prof. Javier Alda
Applied Optics Complutense Group
University Complutense of Madrid (SP)

Aim of the project: To investigate the IR energy conversion to the electrical domain through MEMS-NEMS devices coupled to optical resonant structures for energy harvesting applications at the **nanoscale**.


Gabriel Abadal


Jordi Agustí


Miquel López-Suárez


Gonzalo Murillo
(now at INL)


Marcel Placidi
(now at IREC)


Francesc Torres

NANERG LAB

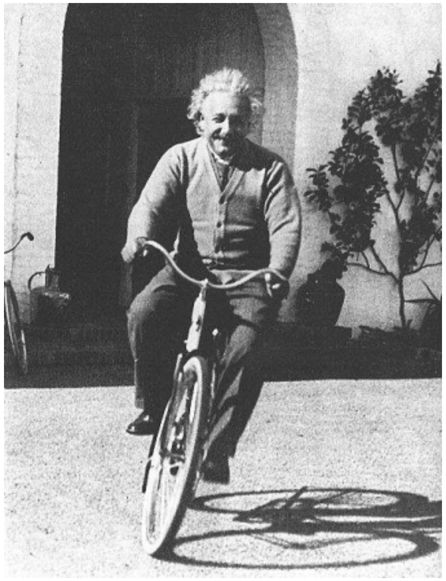
NOEMS for ENERGY LABORATORY

NANO-OPTOELECTROMECHANICAL SYSTEMS FOR ENERGY LABORATORY

http://grupsderecerca.uab.cat/nanerglab/

***“If at first, the idea is not absurd,
then there is no hope for it”***

ALBERT EINSTEIN



Abstract

Alternatives to phtotovoltaics have been explored in the last decades in order to extend the capabilities of the energy harvesting technology to other ranges of the electromagnetic radiation spectrum and, at the same time, to radically improve the conversion efficiency. Most of these alternatives are based on classical electromagnetic antennas as the core element that converts electromagnetic radiation energy into the electrical domain.

In this lecture we will review the schemes already proposed and proved in the literature and we will analyze their actual bottleneck that need to be improved. Novel state of the art technologies that include solutions to the storage of the harvested energy will be also presented and proposed in order to be discussed as possible new alternatives. Special emphasis will be given to those conversion strategies which are based on the combination of micro and nanoelectromechanical systems (M/NEMS) and optical components. The fabrication and characterization particularities of those special M/NOEMS devices will be presented in detail.

Harvesting method	**Power Density**	**Limitations**
Silicon solar cells	100mW/cm^2 100uW/cm^2	Direct bright Sun light needed, only 2D Office light needed, only 2D
Thermoelectric	60µW/cm^2	temperature gradient needed, also 2D
Vibrational microgenerator	800µW/cm^3	Machinery needed to provide vibration