Perspective on Integration and Nanomanufacturing

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and

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Design and Manufacture of Integrated Nanosystems
Arlington, VA, March 2, 2011

COINS Application Drivers

Personal, Community, and Mobile Monitoring

Exhaust from power plant smokestack

Pesticide Spraying, California Central Valley

San Bruno Gas Explosion

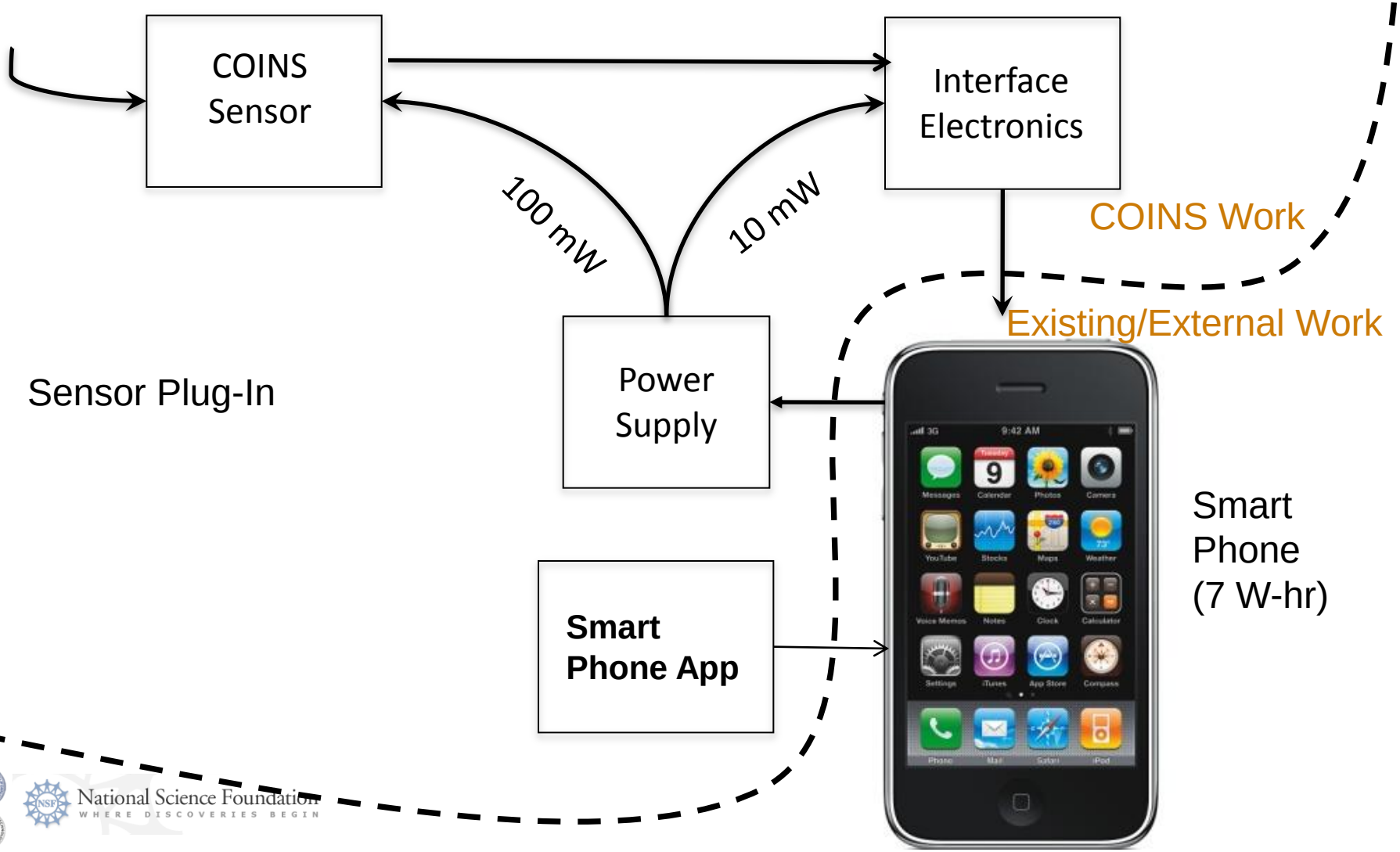
Rescuers search for survivors after earthquake in Haiti, 2010

40 lb Personal Air Monitoring System

Rapidly Deployable Chemical Detection System

Pesticides, explosives, toxicants

Personal Monitoring



Pesticides, explosives, toxicants

Community Monitoring

Existing/External Work

WiFi Sensor Node
e.g. Red Pine Signals
WiFi 802.11 b/g/n

Mobile Monitoring - DASH

Toxic gas, CO_2

COINS Sensor

Interface Electronics

100 mW

10's mW

Battery

Power Supply

300 mW

Energy Harvesting

900 mW

Motors/actuators

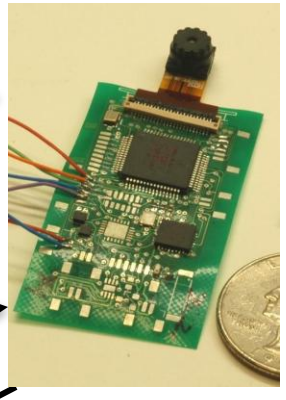
Legs

Gecko Adhesives

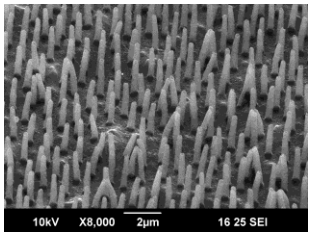
3 N/cm², adhesion coef: 10

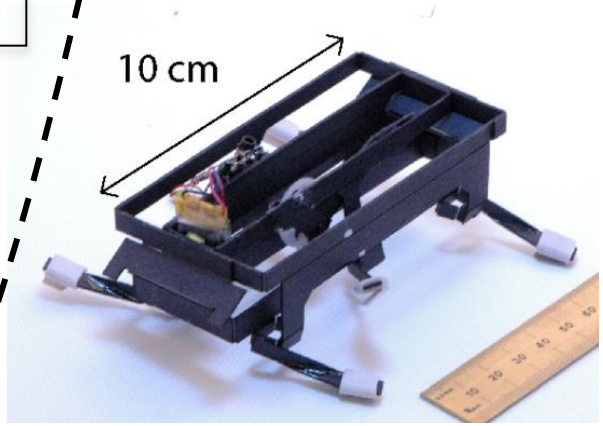
COINS Work

Existing/External Work



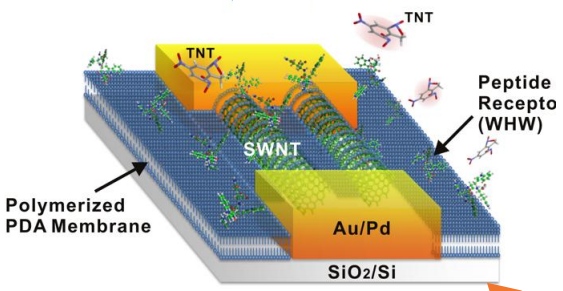
Camera, 802.15.4 radio
40 MIPS CPU, gyros, accelerometers

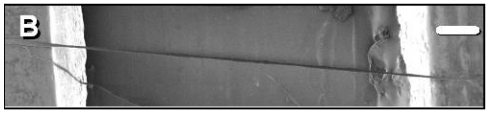


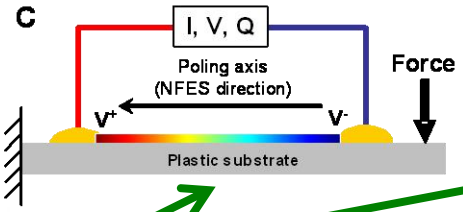


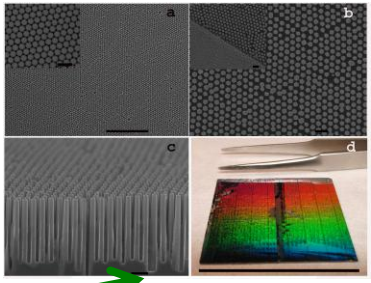
National Science Foundation

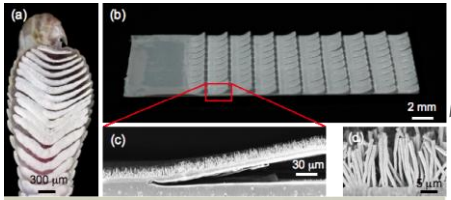
Systems Integration Challenges

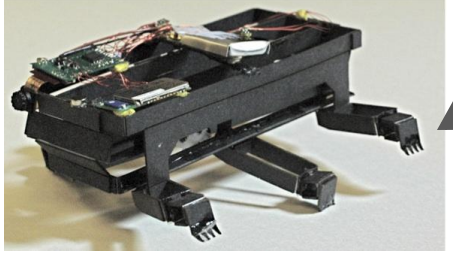


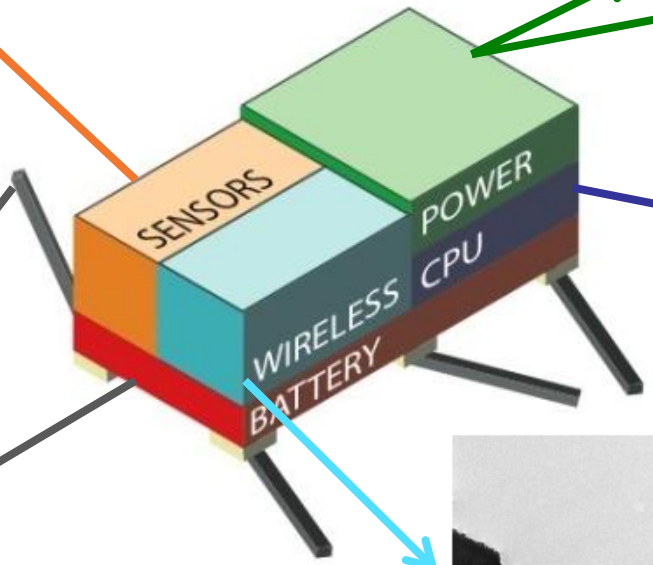


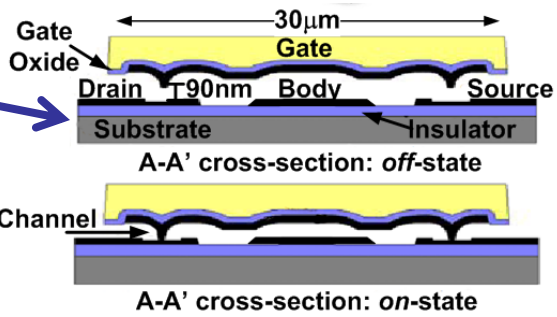


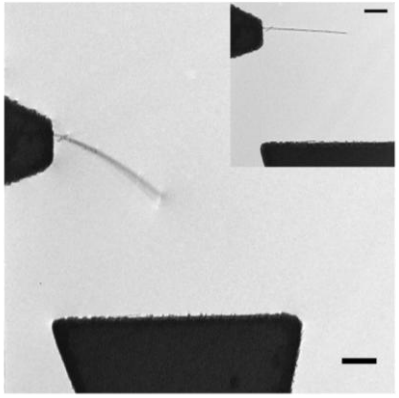




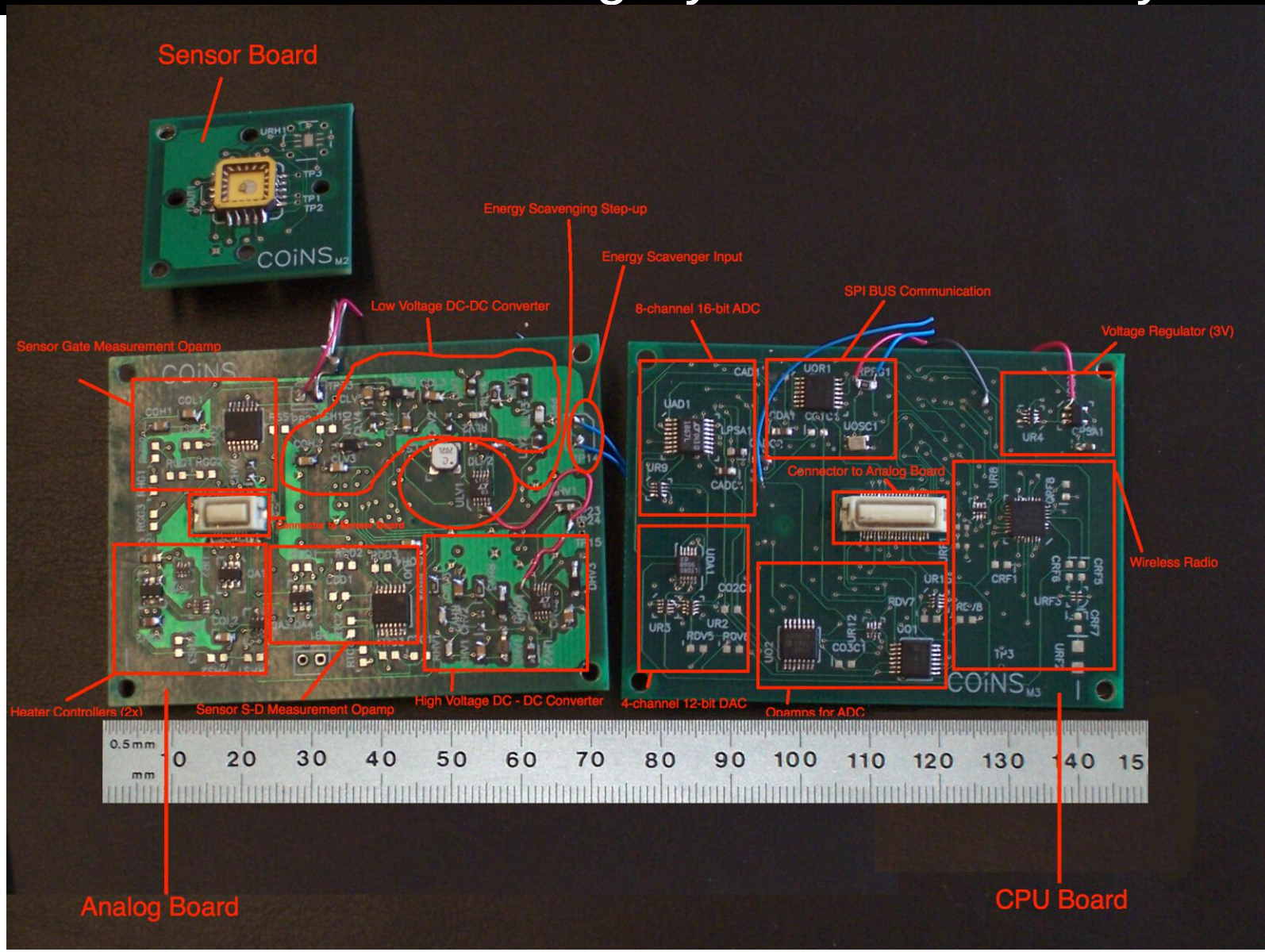






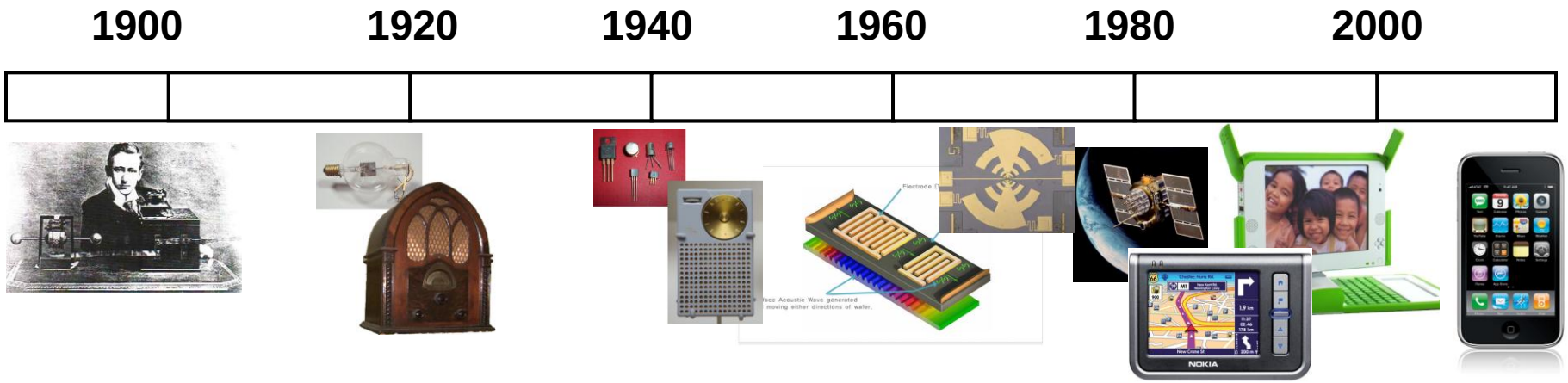


COINS Sensing System - Board Layout (Top)



COINS Fab: 2/2011

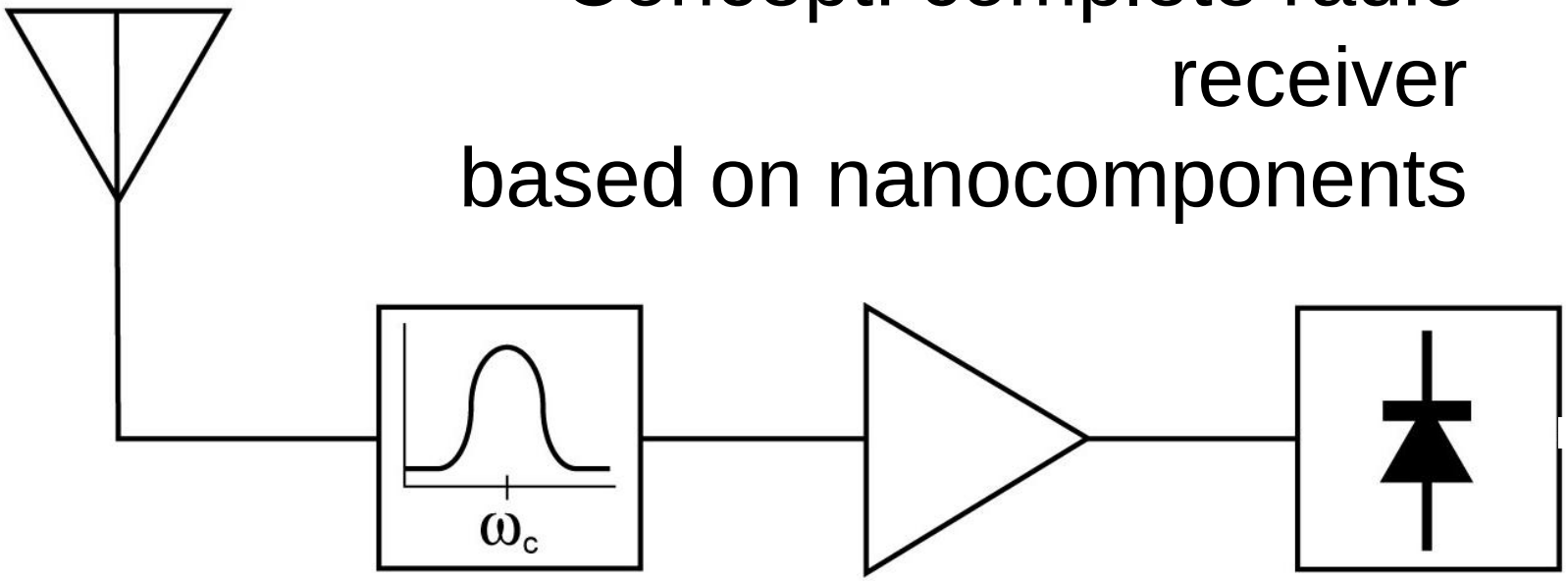
History of radio technology



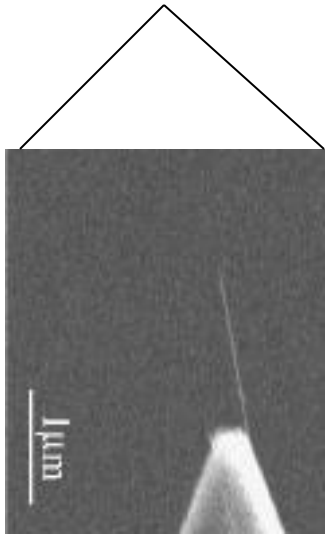
Key developments:

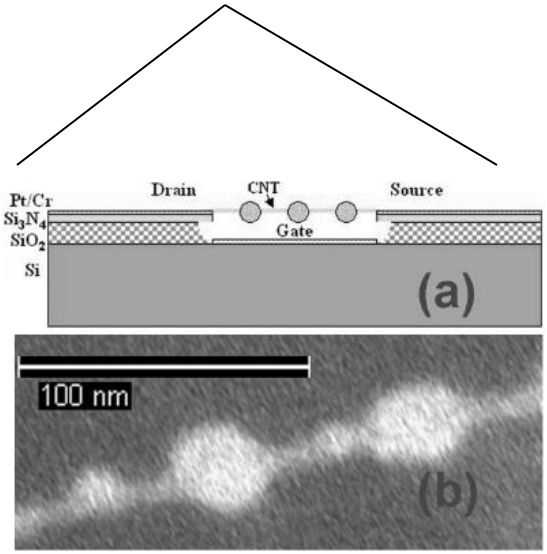
- Theory (EM, quantum mechanics)
- Materials (semiconductors)
- Integration (on-chip architecture)

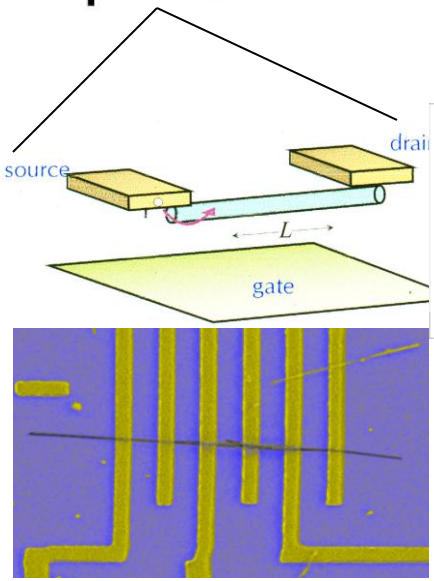
Concept: complete radio receiver based on nanocomponents

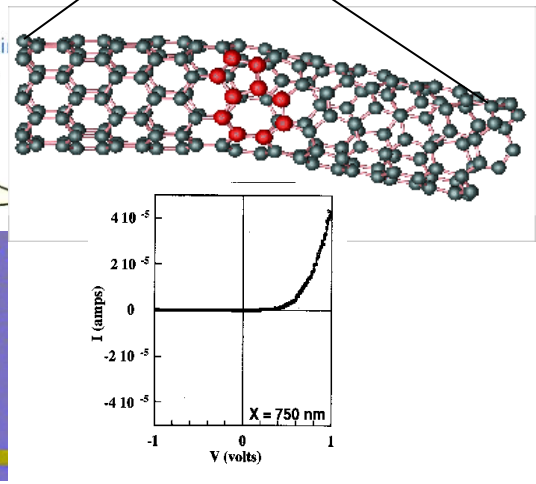


Antenna Tuner Amplifier Demodulator

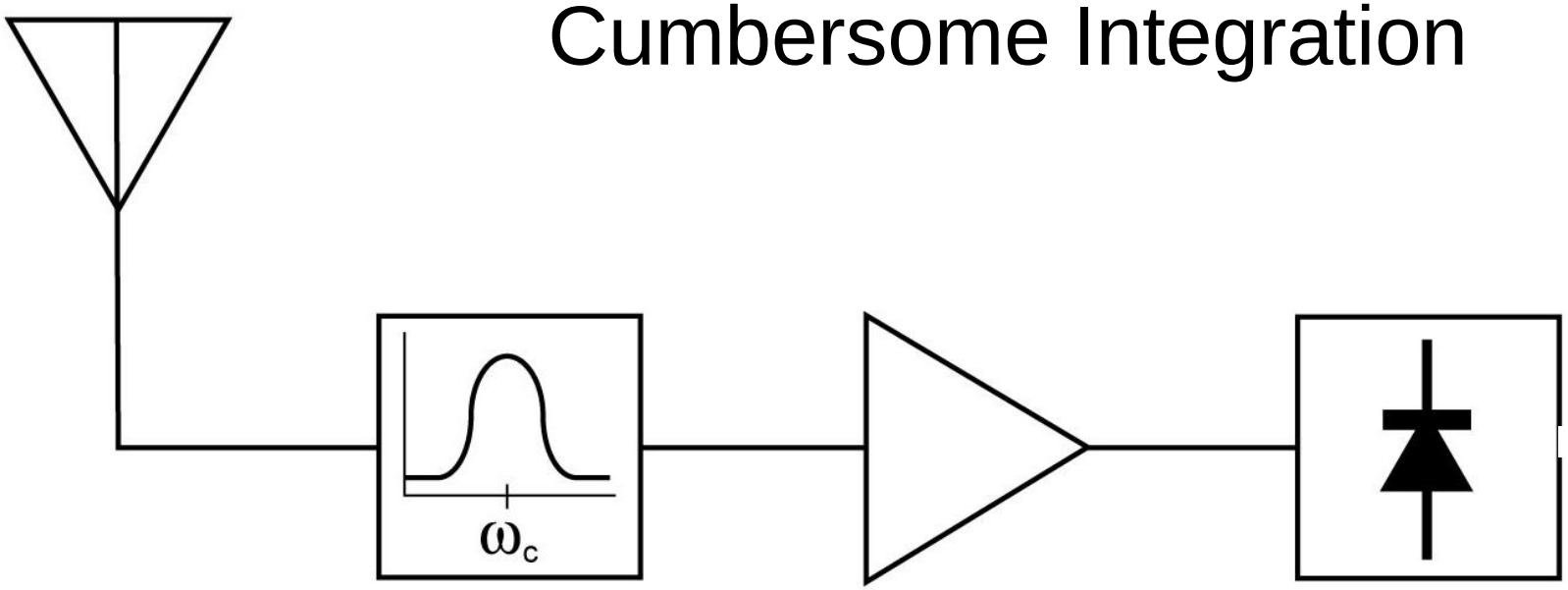




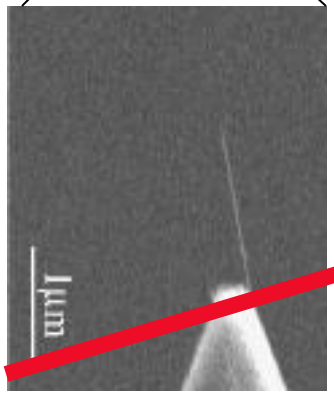


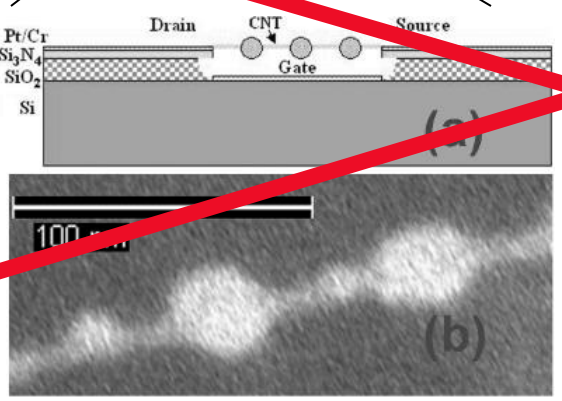


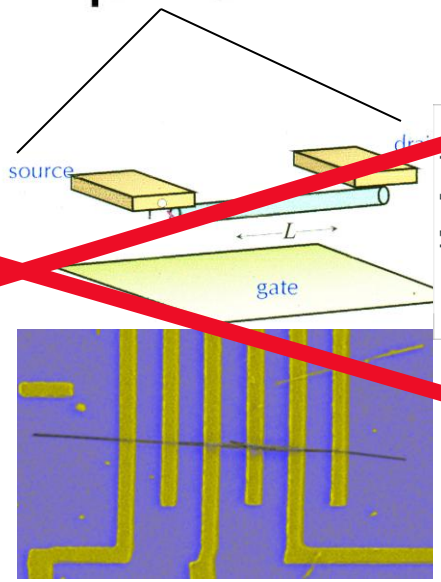
Cumbersome Integration

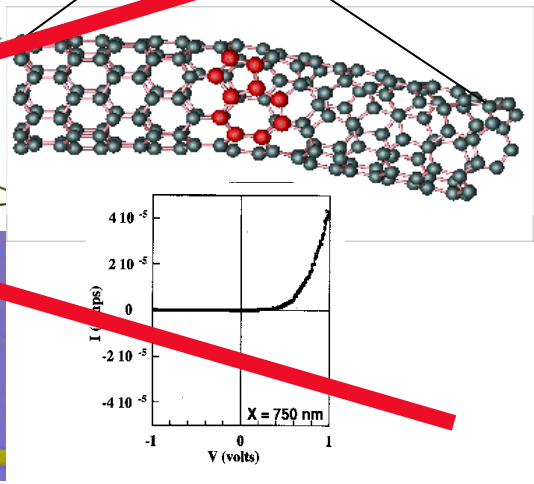


Antenna Tuner Amplifier Demodulator



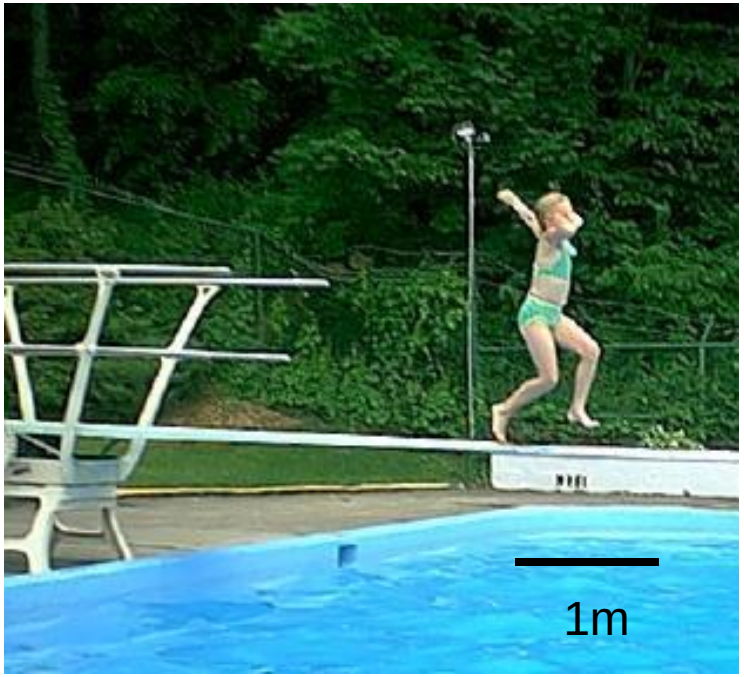






Mechanical Oscillators: Size vs Frequency

Diving board $\omega_0 \propto \frac{r}{L^2}$



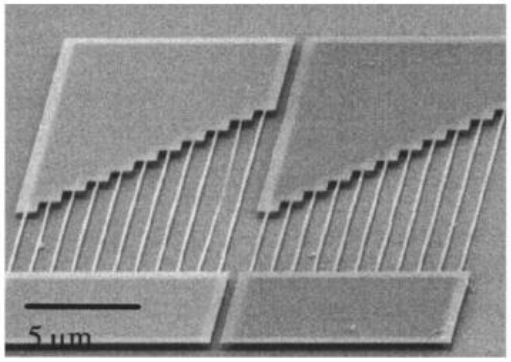
ω~1Hz

Xylophone

10 cm

ω~1,000Hz

Nanocantilevers



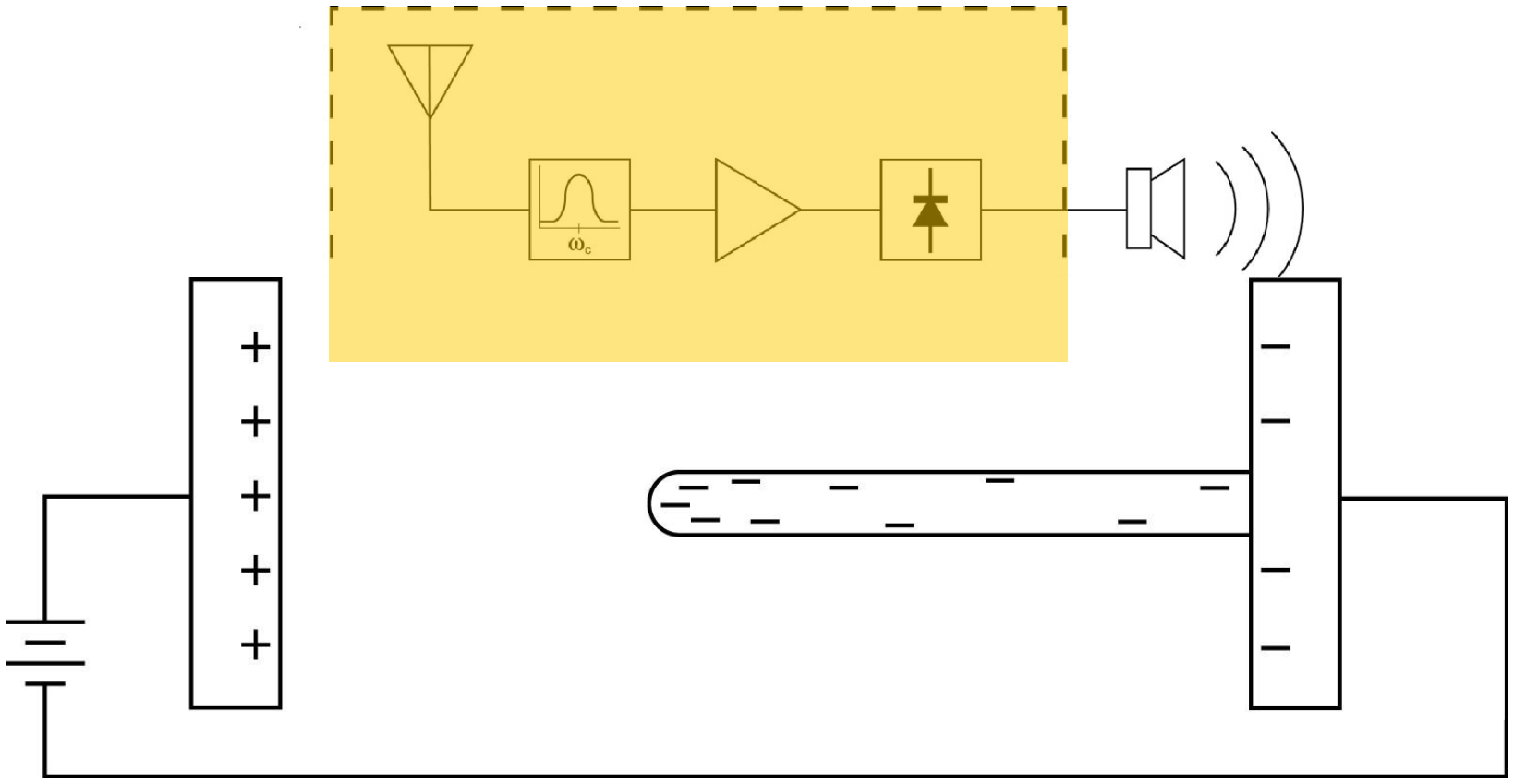
~1-10μm

ω~1,000,000Hz

Nanotube Cantilever

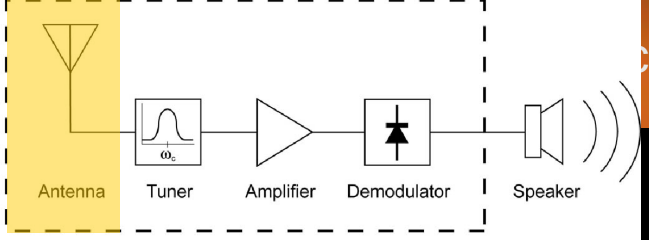
$\omega \sim 1$ MHz – 1 GHz

Ultimate Integration



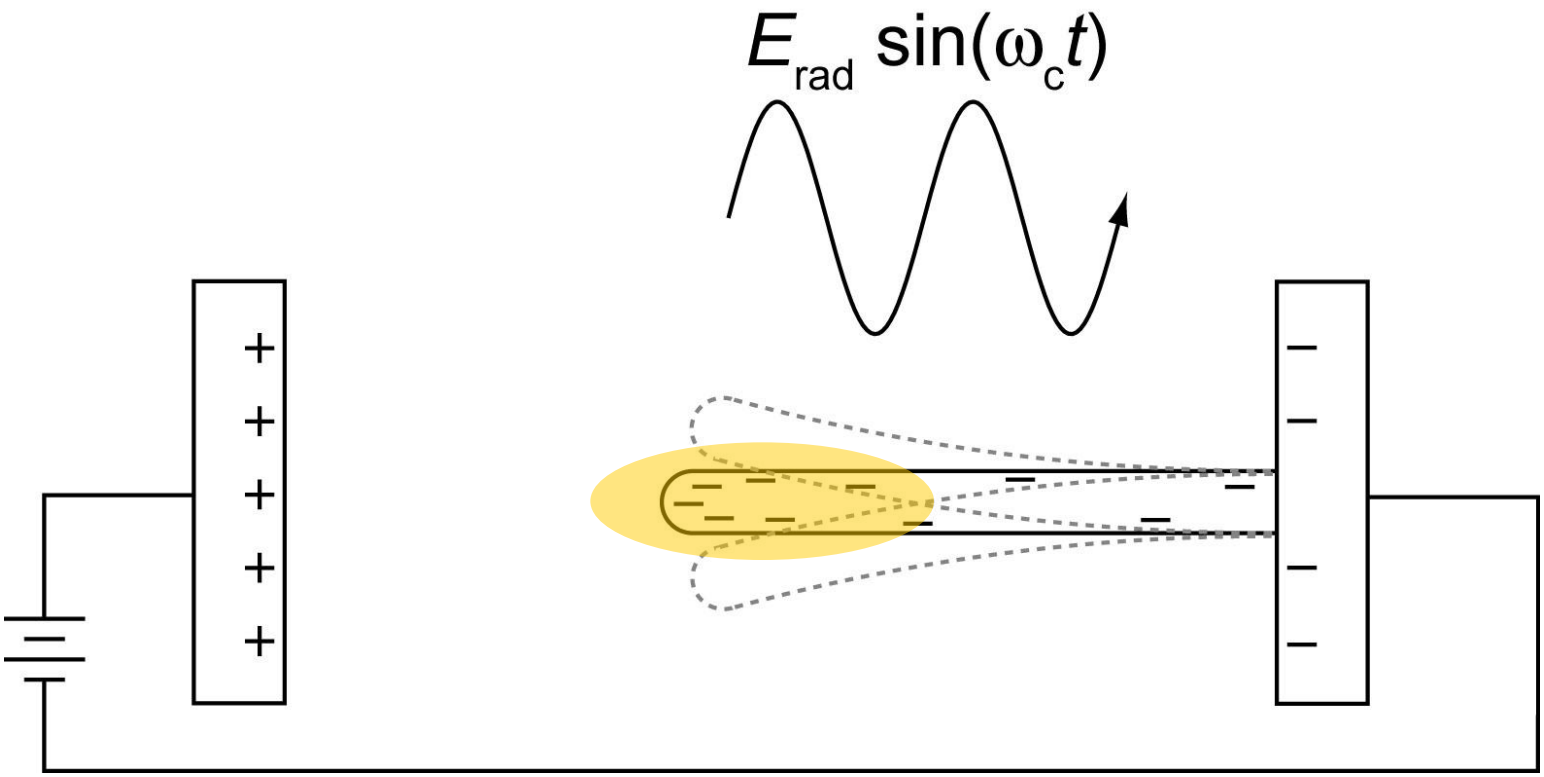
Entire radio implemented with one nanotube and counterelectrode

Antenna

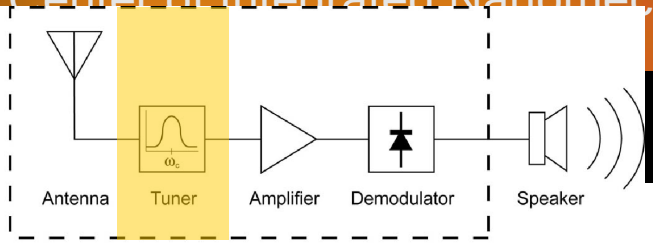


All-in-one nanotube radio

Charged tip of nanotube is sensitive to external *E* fields.

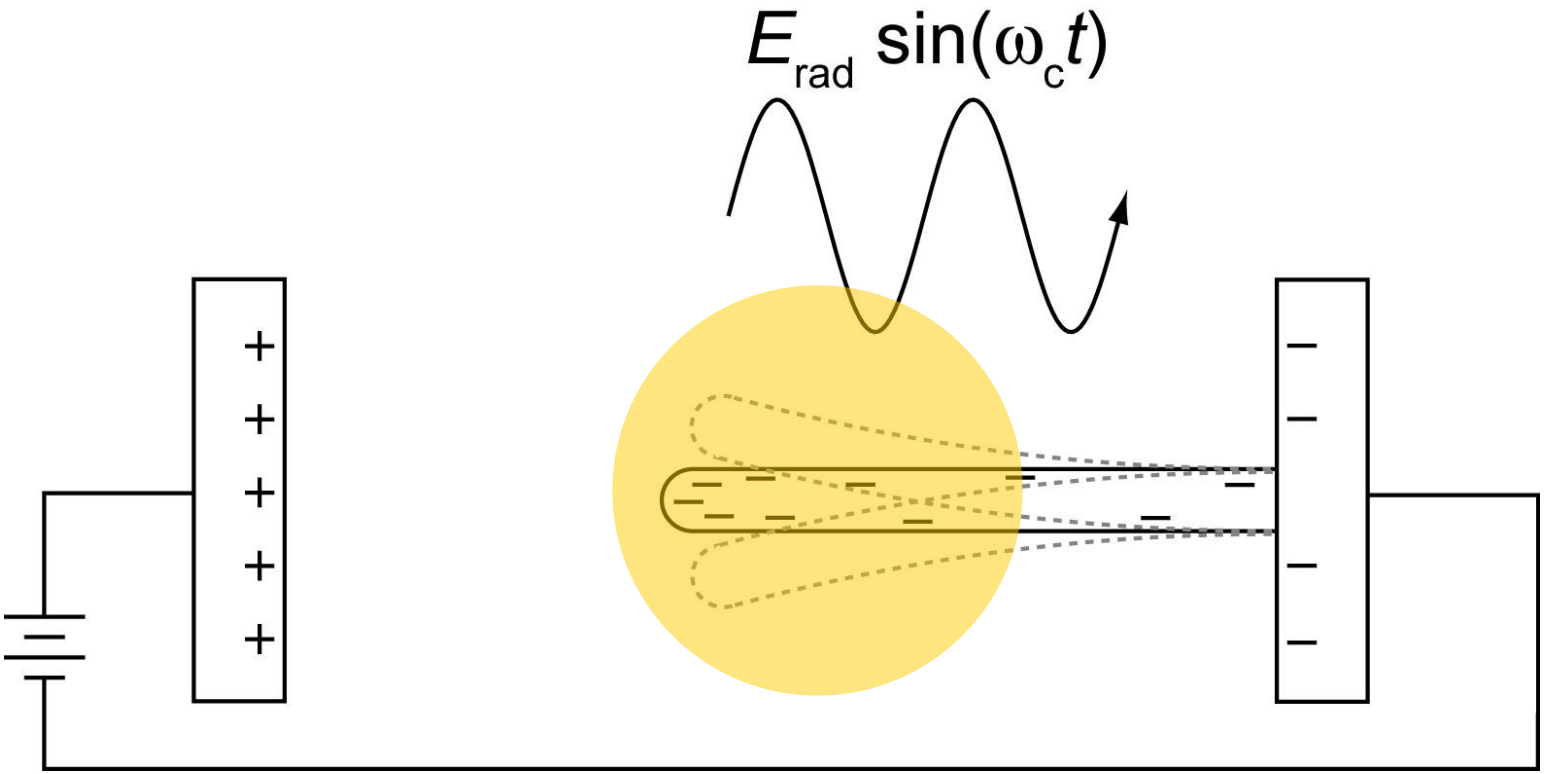


Tuner

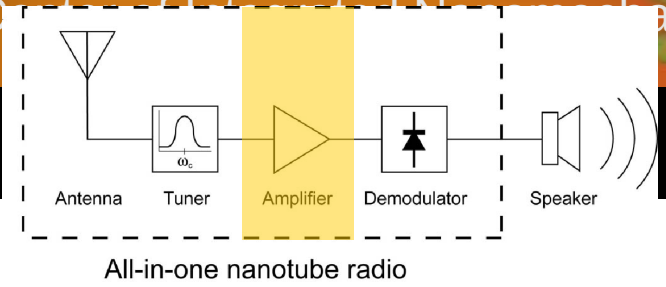


All-in-one nanotube radio

Vibrates when radio signal matches resonance frequency.

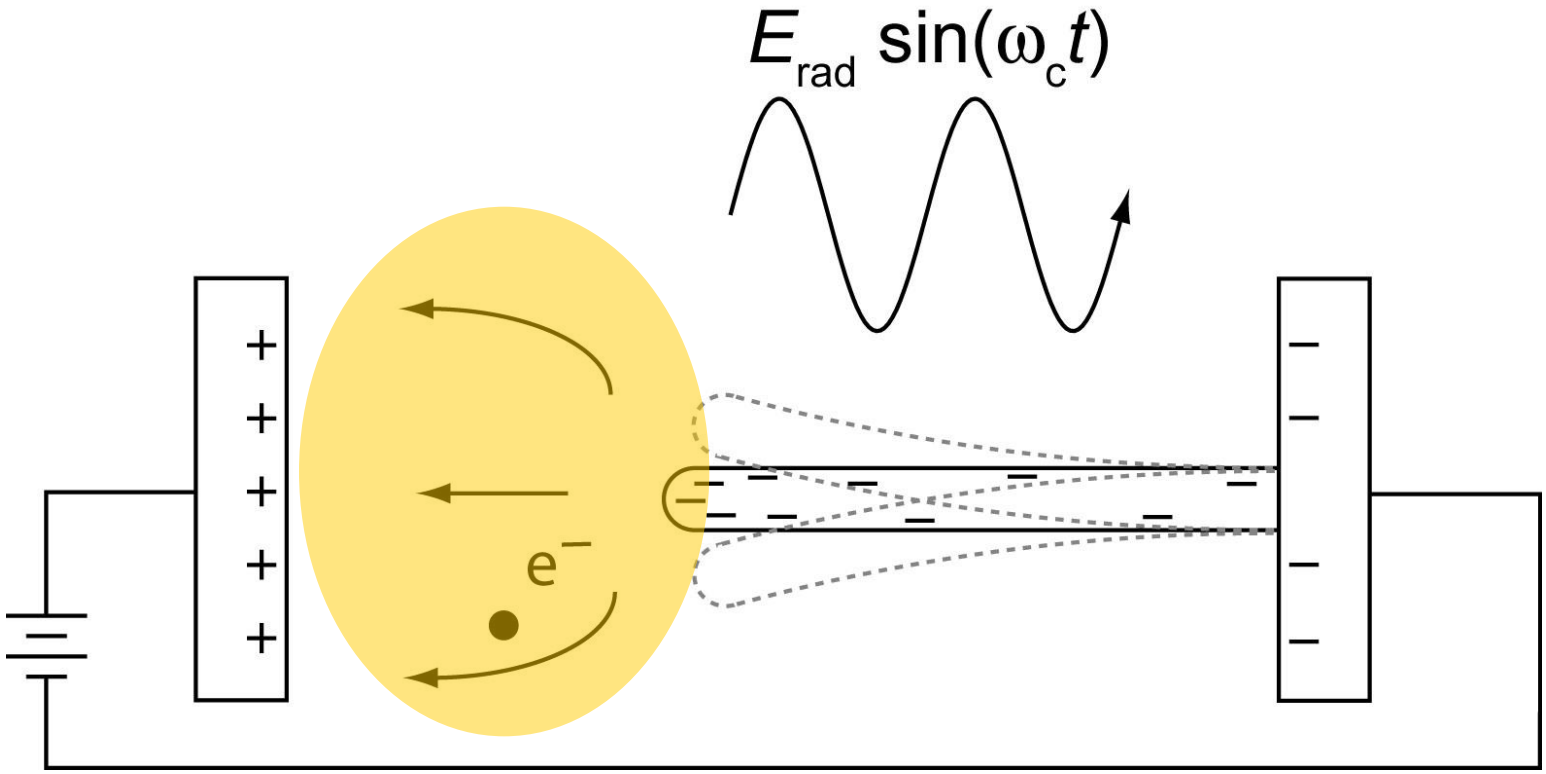


Transducer/Amplifier

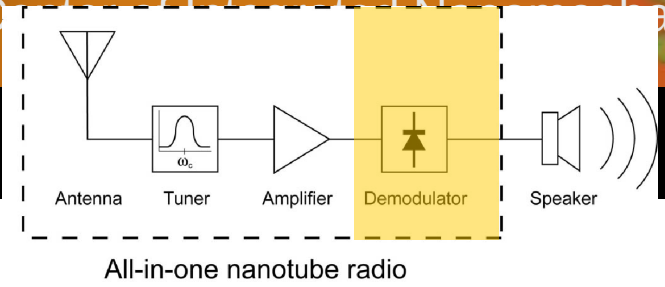


All-in-one nanotube radio

Vibrating tube modulates quantum mechanical field emission current.

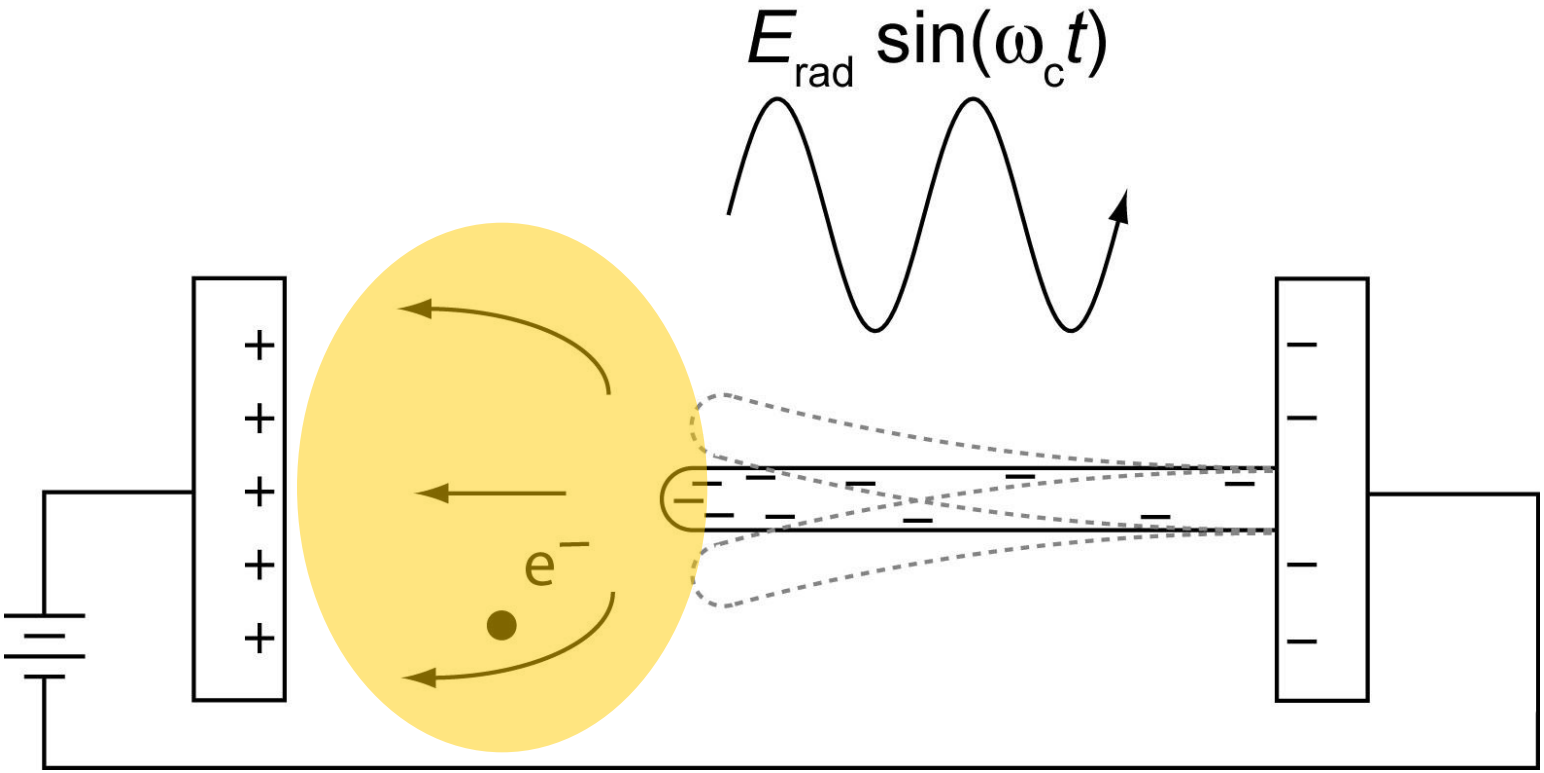


Demodulator

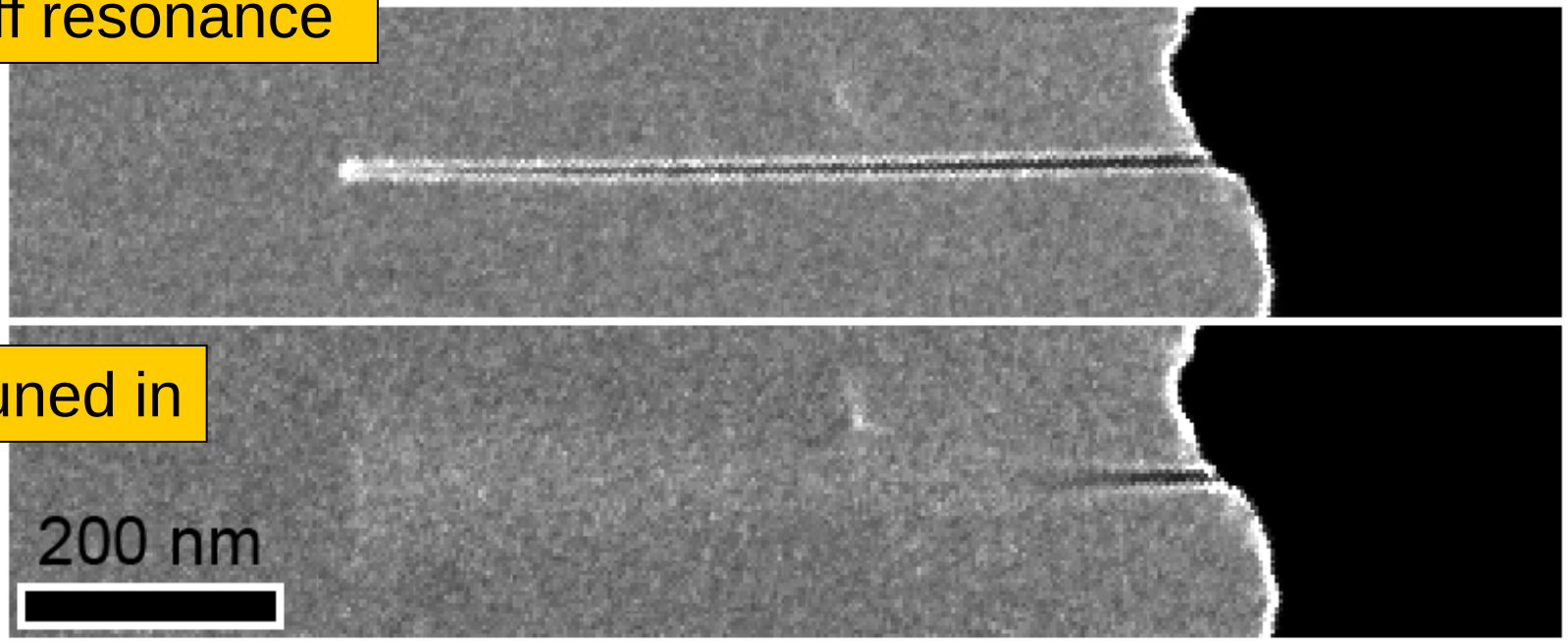


All-in-one nanotube radio

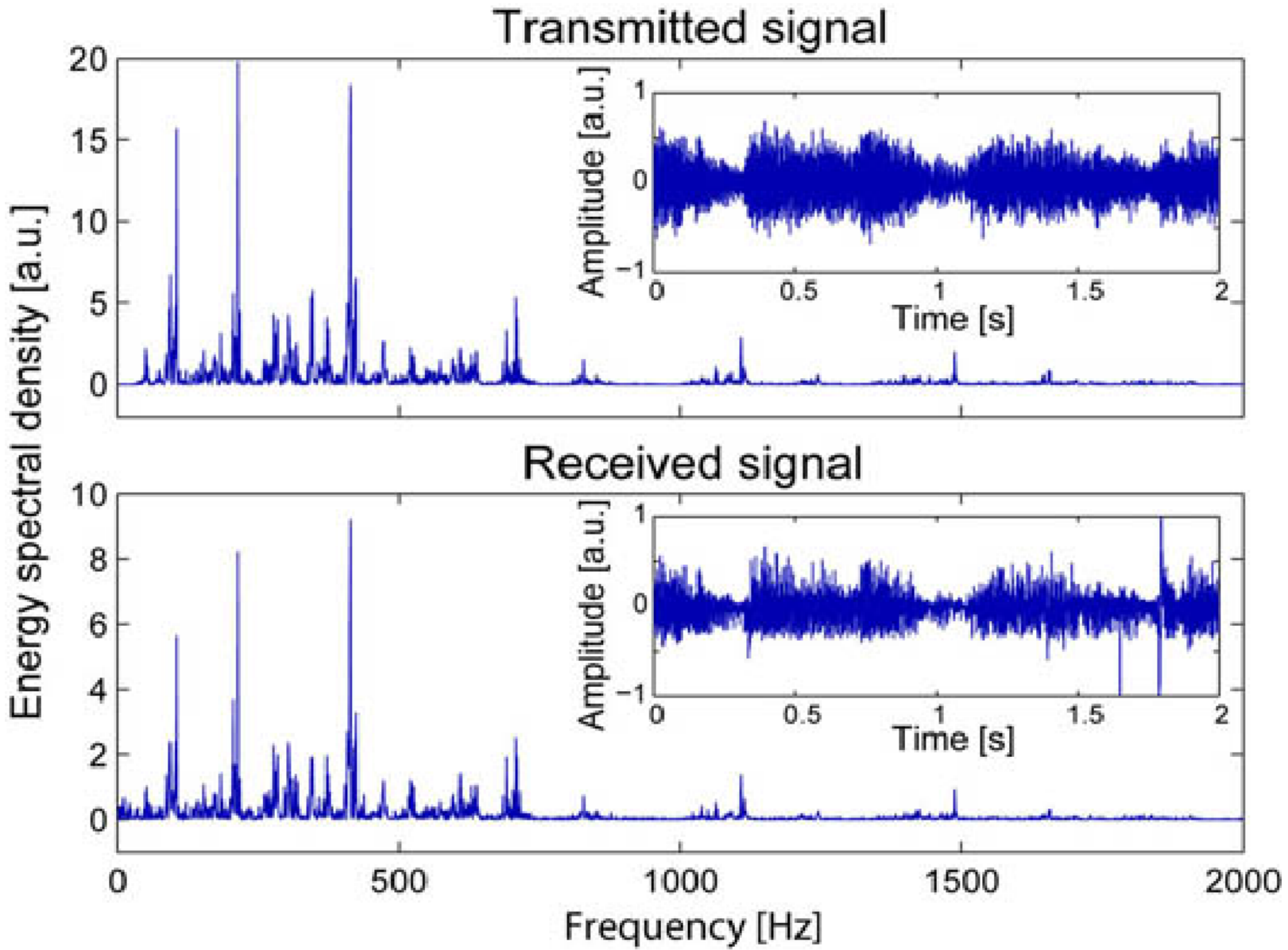
Field emission nonlinearities demodulate radio signal.



Radio in Operation



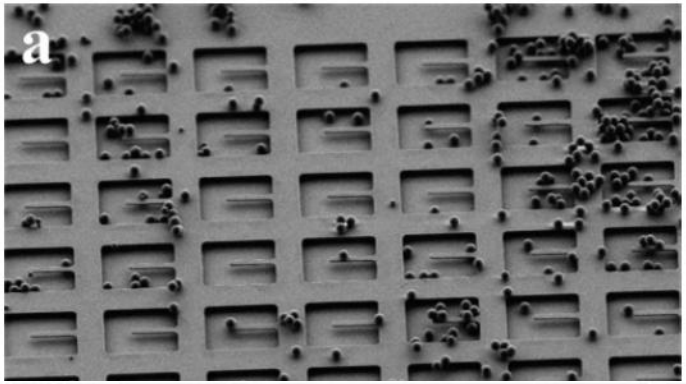
Fidelity of Received Signal

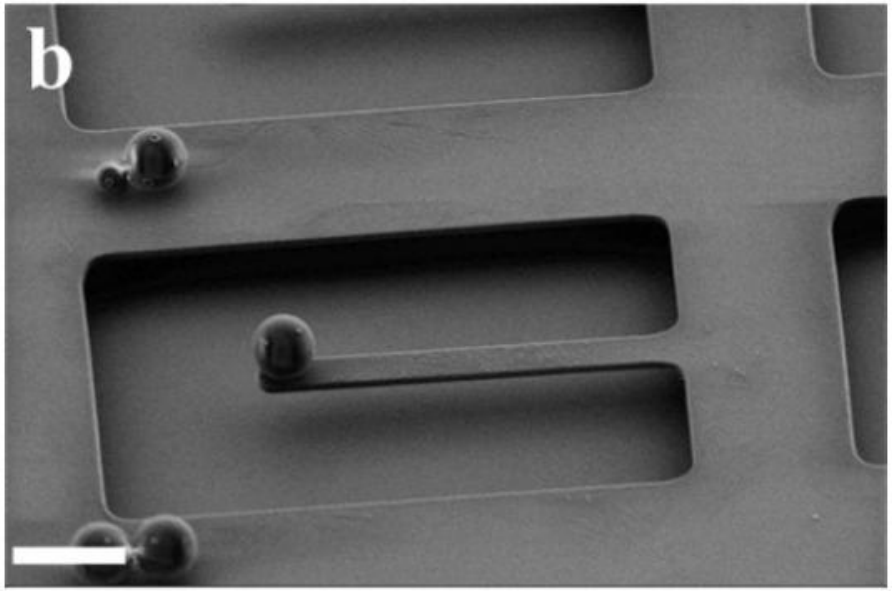


Nanomechanical Sensing

$$M_{\min} \propto \sqrt{\frac{M_{\text{eff}}}{{\omega_0}^3 {x_c}^2 Q}} \propto \sqrt{\frac{L^5}{rQ}}$$

High mass sensitivity

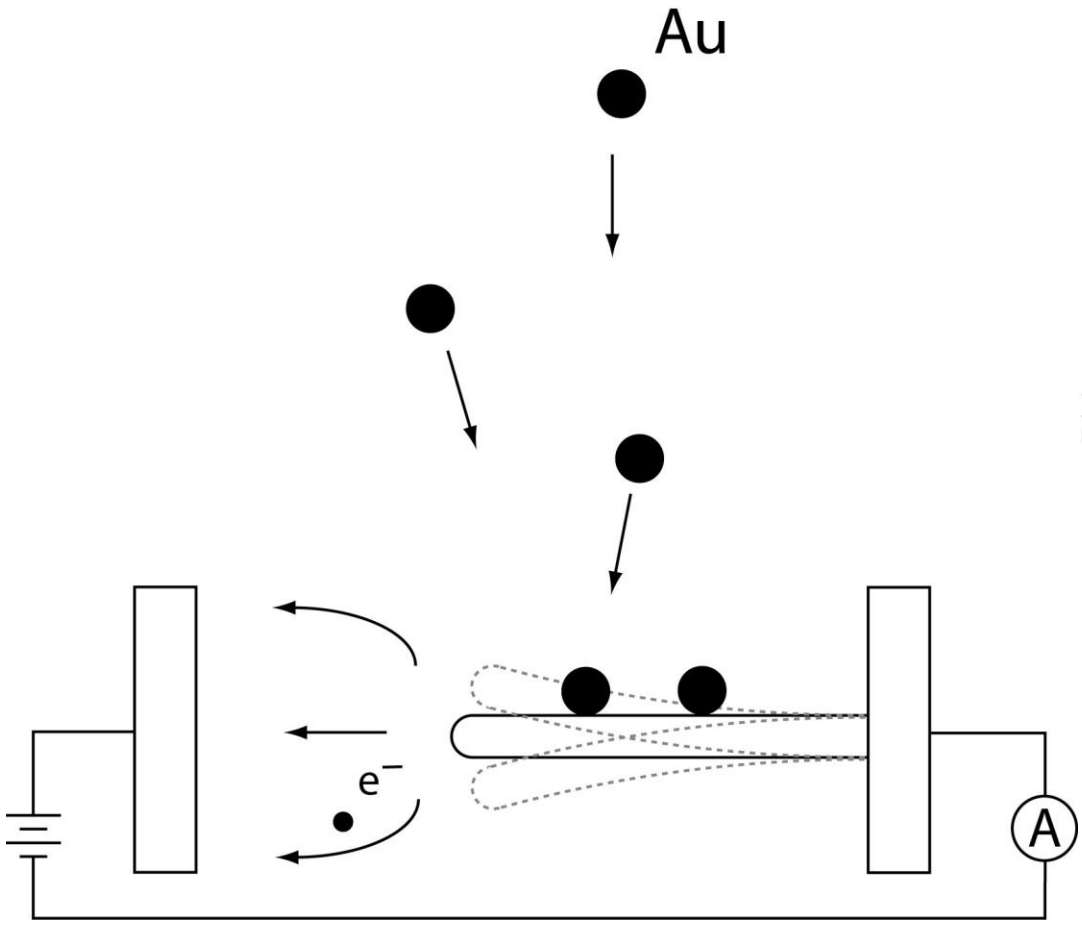


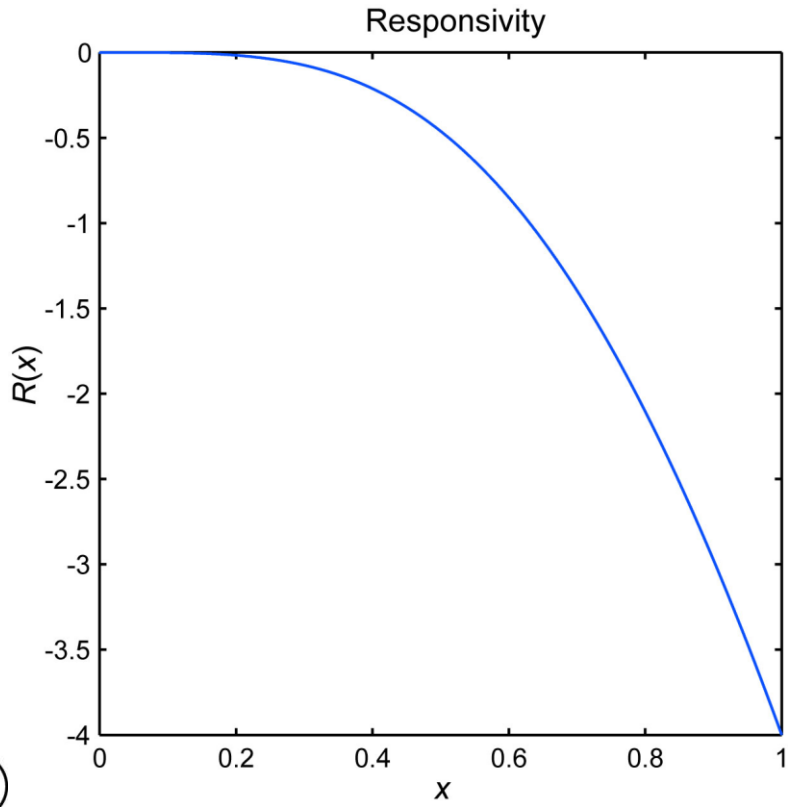


Mechanical -> no ionization necessary

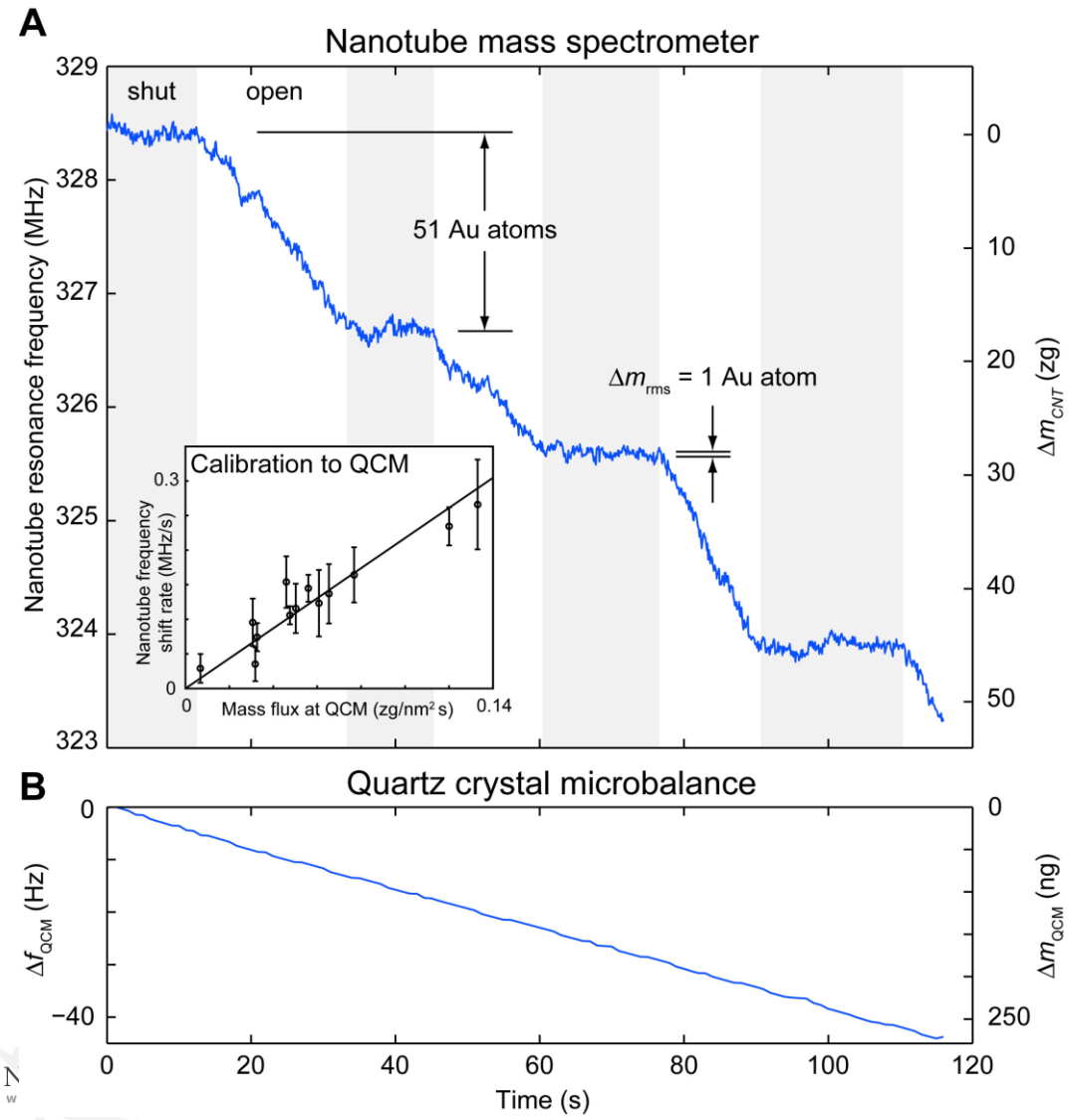
[B. Ilic *et al.*, *Nano Lett.* **7**, 2171 (2007)]

Nanotube Mass Sensor





Single Nanotube Mass Sensor



(zg = 10^{-21}g)

mass resolution:

0.13 zg/√Hz

=0.4 Au atoms/ √ Hz
(room temperature)

Challenge– Tyranny of Numbers

Single transistor → Fully integrated, manufacturable system

1948 1959 (concept); 1970's (implementation); 2000 Nobel Prize

Single nanodevice → Fully integrated, manufacturable system

1997

Demodulation/Amplification

Fowler-Nordheim:

$$I = c_1 A(\gamma E_{ext})^2 \exp\left(-\frac{c_2}{\gamma E_{ext}}\right)$$

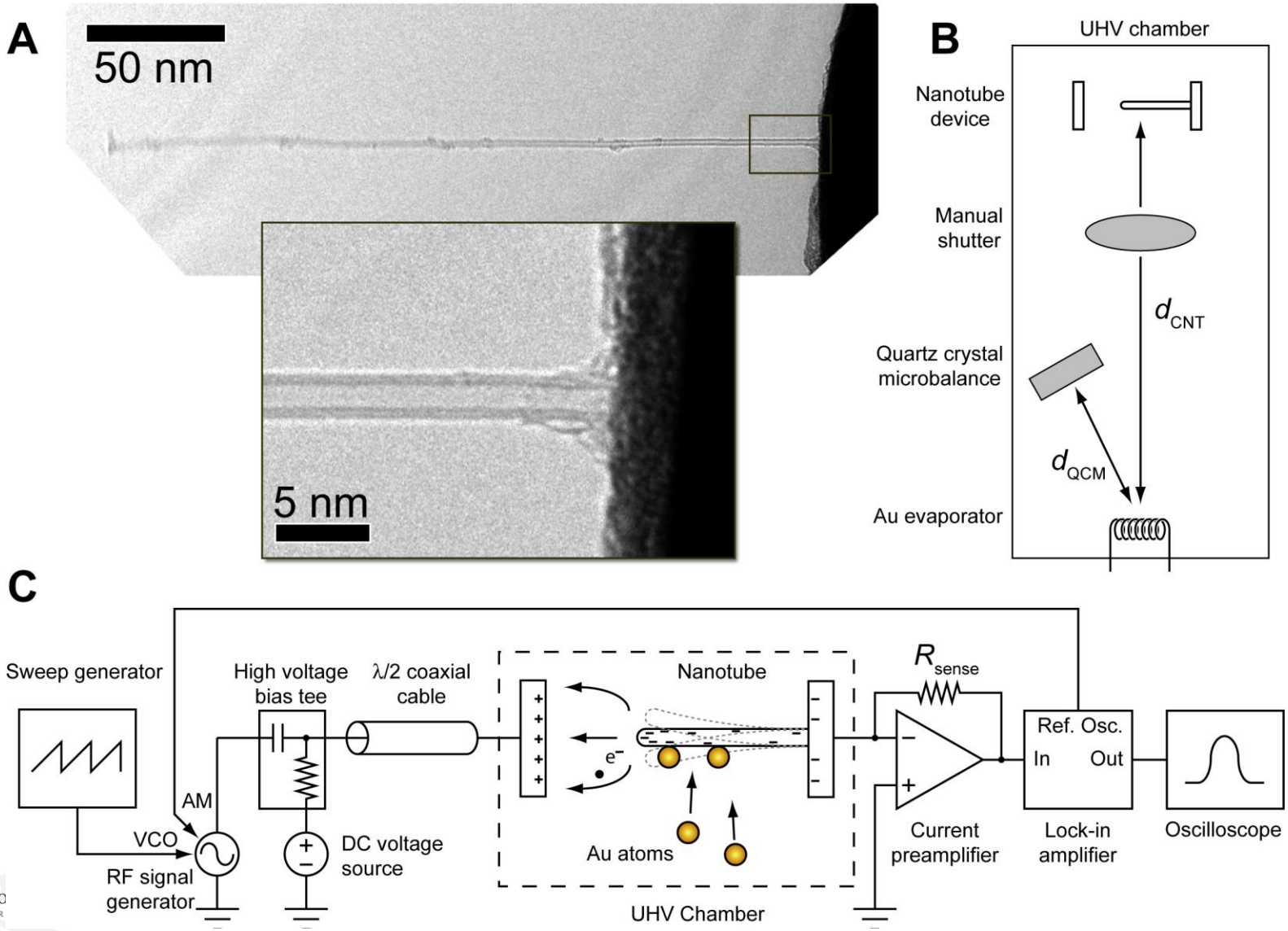
Field enhancement perturbation:

$$\gamma(t) = \gamma_0 + \Delta\gamma(t)$$

Demodulation:

$$\Delta I(t) = I_0(1 + \alpha + \alpha^2/2)\cdot(\Delta\gamma(t)/\gamma_0)^2; \qquad \alpha = \frac{c_2}{\gamma_0 E_{ext}}$$

Nanotube Mass Sensor



mAu