A Personal View of Electromagnetic Phenomena

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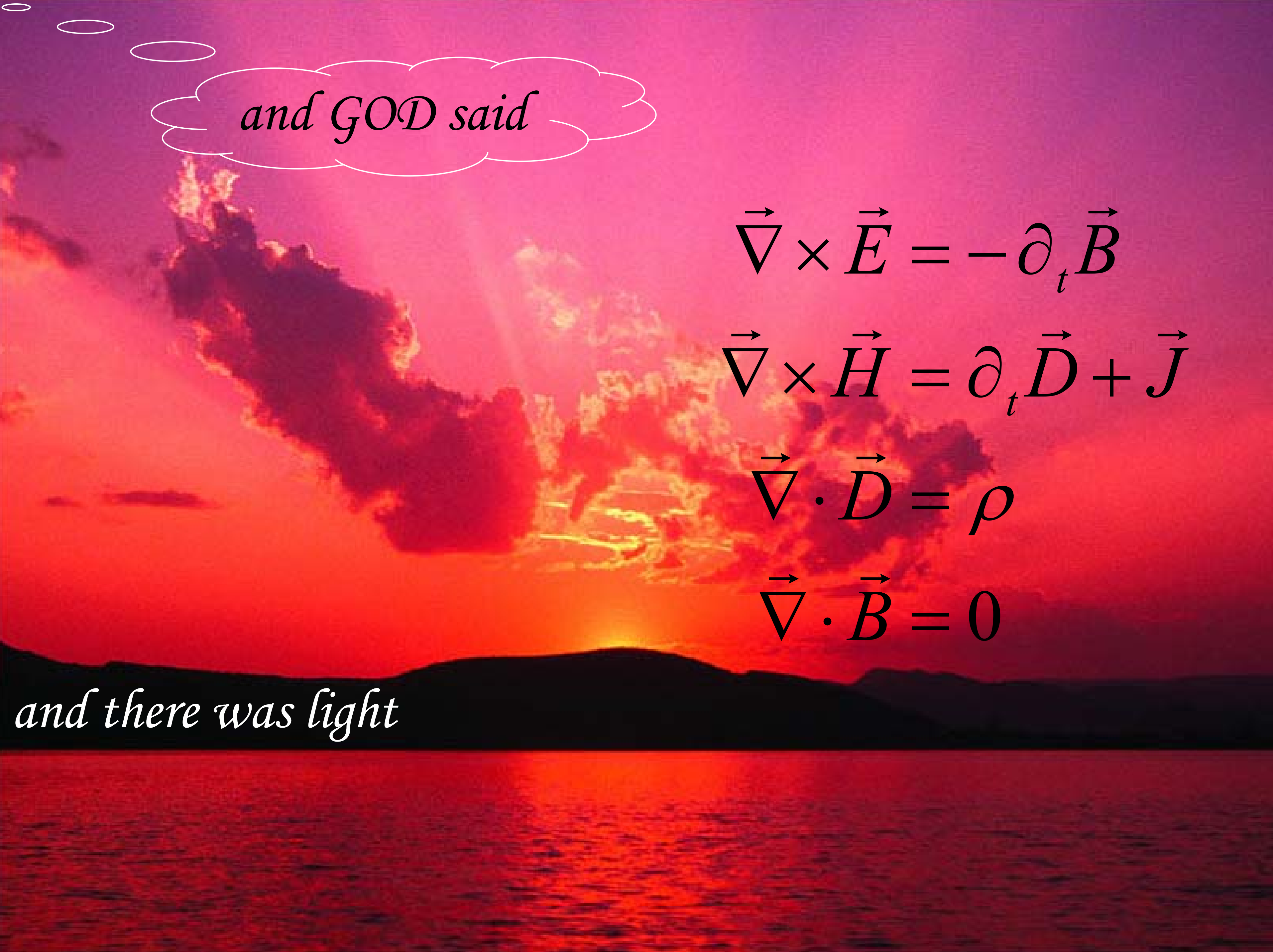

and GOD said
$$\vec{\nabla} \times \vec{E} = -\partial_t \vec{B}$$
$$\vec{\nabla} \times \vec{H} = \partial_t \vec{D} + \vec{J}$$
$$\vec{\nabla} \cdot \vec{D} = \rho$$
$$\vec{\nabla} \cdot \vec{B} = 0$$
and there was light

Outline

- Statics and Quasi-Statics:

    Microscopy at nanometer scale

    Electron sources

    Interface with bio-systems

    Coupling Phenomena

    Micro-Electro-Mechanical -System

- Dynamics:

    Photonic Band Gap Structures

    Interaction with bio-systems

    Frank-Hertz (PASER) & accelerators

    X-ray sources: tools for nano-science

Statics & QS: Microscopy @ Nanometer Scale

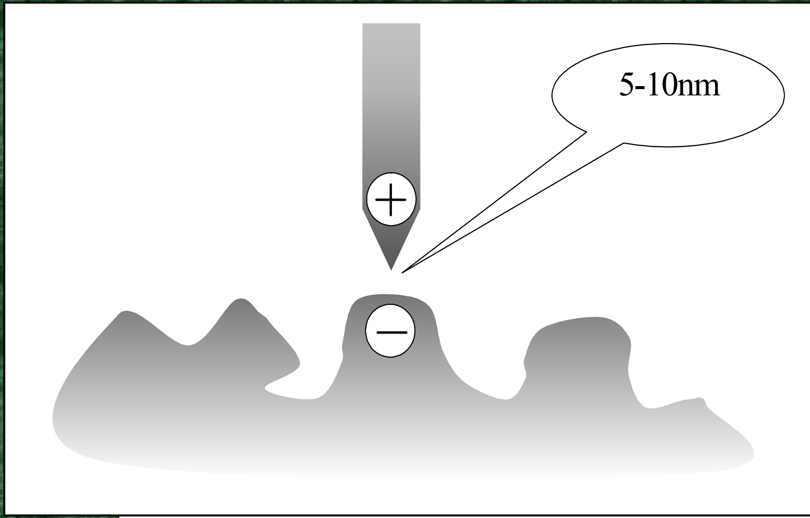
- Our ability to measure length is limited by the "ruler" used
- From the perspective of the human eye, the limit is of the order of typical wavelength – 0.5μm
- There are several concepts that may be used for bypassing this inherent limitation -- most of them do not use light

Statics & QS: Microscopy @ Nanometer Scale

- Force at the atomic level

  - Capacitance change related to the distance and the radius of curvature of the tip

  - Change in capacitance (assuming constant voltage) $\rightarrow$ current



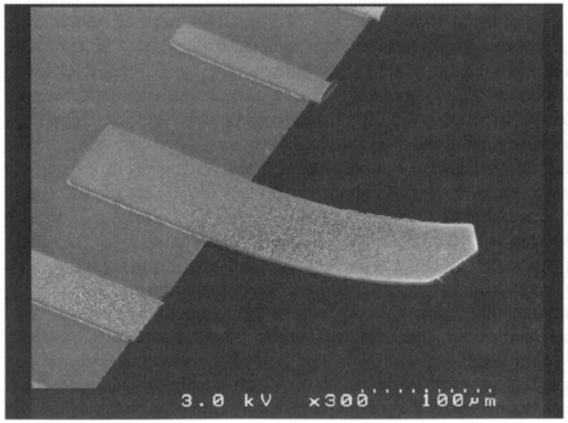
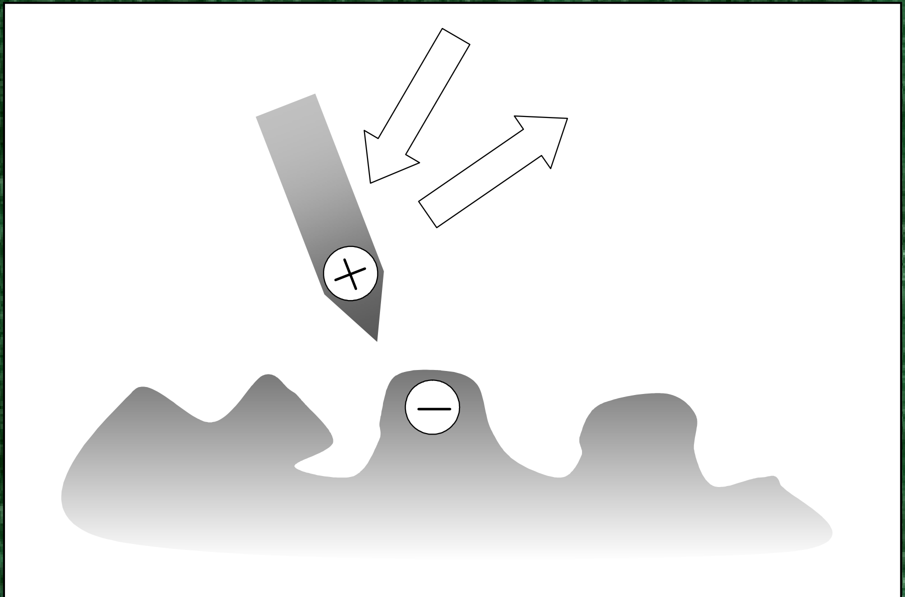


Figure 5.85 SEM image of micromachined a-Si waveguide-cantilever.

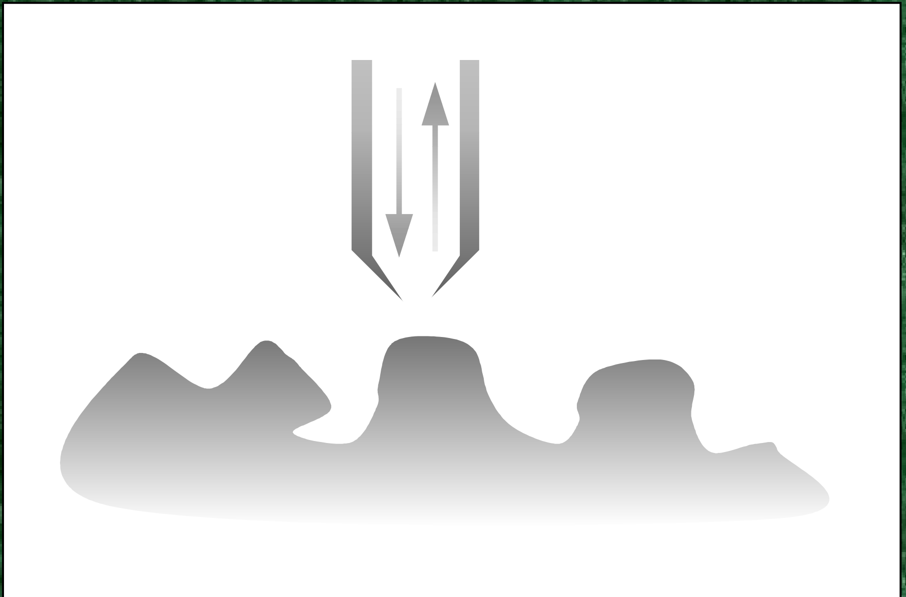
Statics: Microscopy @ Nanometer Scale

- Force at the atomic level
  - The applied electric field can deflect the tip according to the geometric details of the structure.
  - Attached to the tip there is a "mirror ". It reflects an incoming laser beam
  - The information about the motion of the tip is in the reflected wave



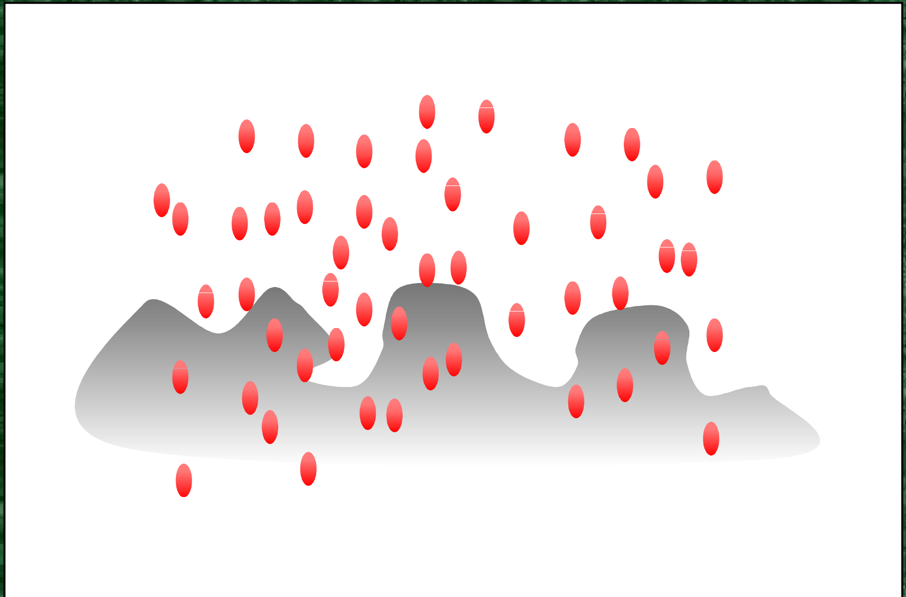
Statics: Microscopy @ Nanometer Scale

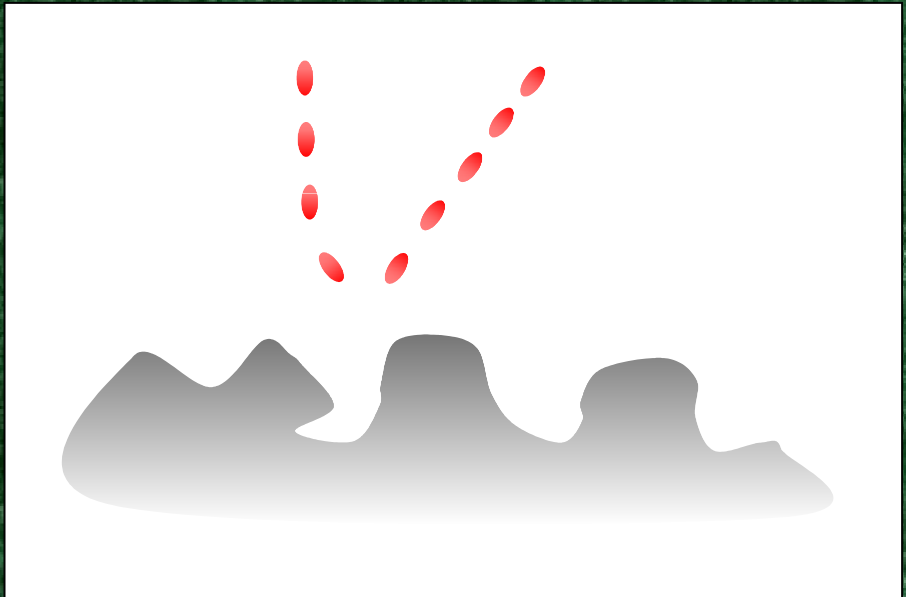
- Scattering of waves at the atomic level
  - Near -field microscopy relies on evanescent waves
  - Waves that propagate in one direction but decay in another
  - Resolution determined by the size of the aperture and its height from the surface.



Statics: Microscopy @ Nanometer Scale

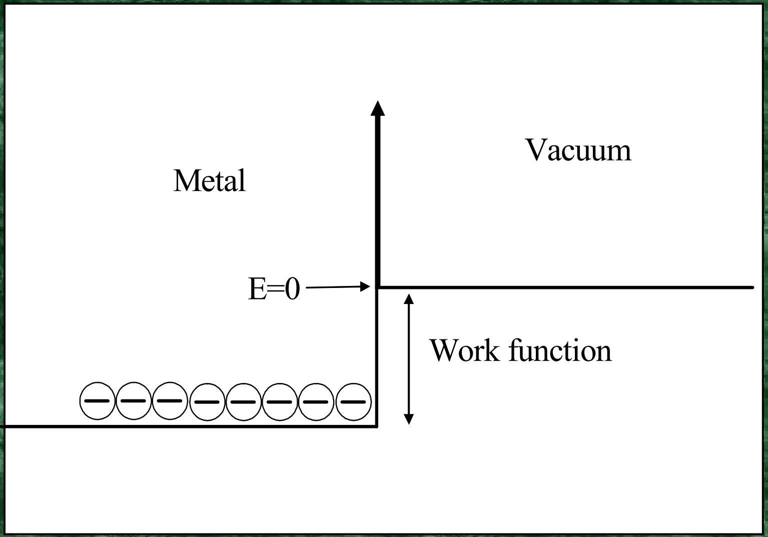
- *Scattering or Transmission of electrons at the atomic level*
  - Features of the surface or bulk determined by energetic electrons (0.3 - 0.4 MeV).
  - Low energy electrons may better help reproducing characteristics of the surface.





Statics & Quasi-Statics: Electron Sources

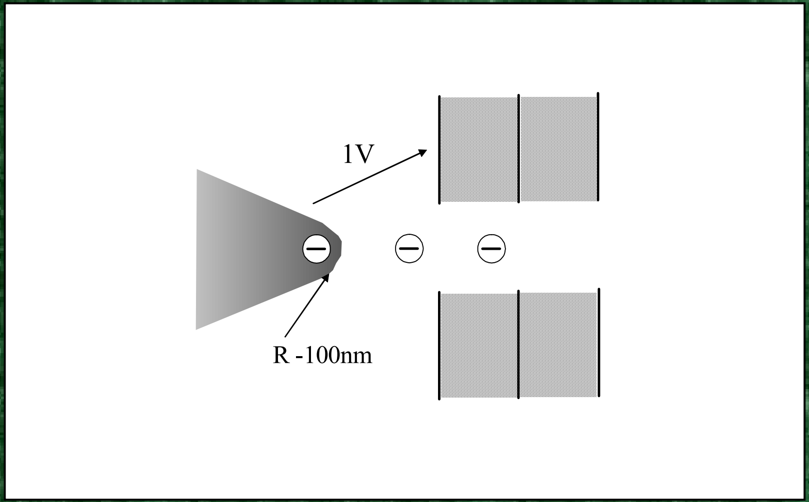
- *Thermionic emission:* heat up metal , kinetic energy of some electrons facilitate to overcome the work function therefore free electrons become available.
  Problem: heat
- *Photo-emission:* Photons from a laser beam provide sufficient energy to electrons for overcoming the work function of a metal.
  Problem: quantum efficiency
- *Field emission:* External electric field may extract electrons
  Problem: intense electric field



Fowler-Nordheim

$$\boxed{J \propto E^2 \exp\left(-\frac{E_{cr}}{E}\right)}$$

Statics & Quasi-Statics: Electron Sources



- *Intense electric field is not a big problem. What is an intense field? Typical for dc*

$$E_{cr} \sim 1[\mathrm{MV/m}] \sim 10[\mathrm{kV/cm}]$$

- *Applying a few volts on the scale of 1μm generates a sufficient electric field*

$$E\colon\ 1\mathrm{V}/1\mu\mathrm{m} = 1[\mathrm{MV/m}]$$

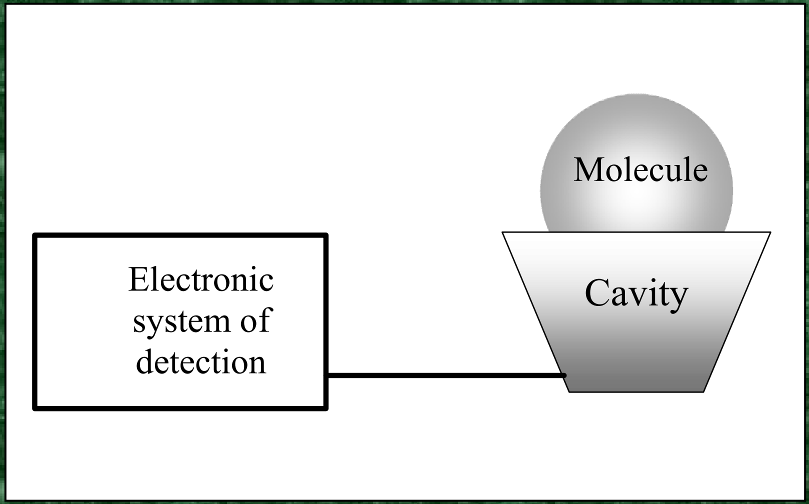
- *Field emitter array !!*

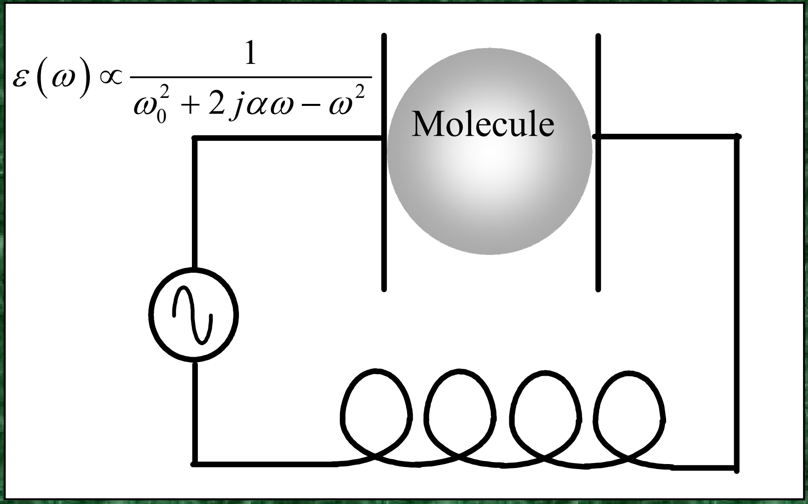
  Flat displays

  Modulated electron beam

Statics & QS: Interface with bio-systems

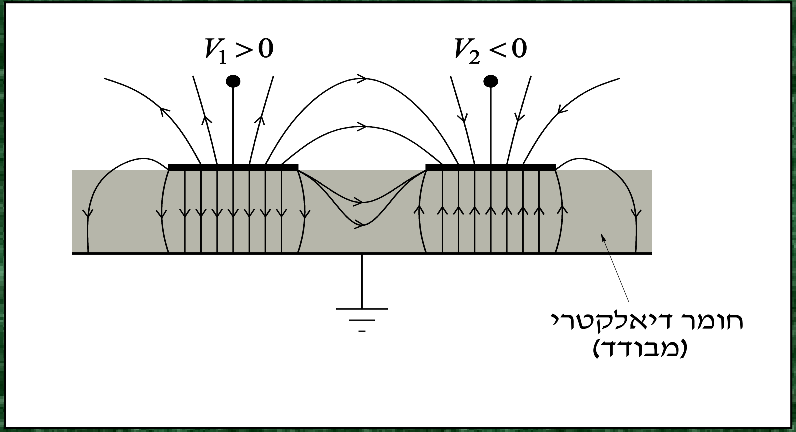
- Interface between electronic system and nerves or organs
- Bio-detectors
- Gas detectors

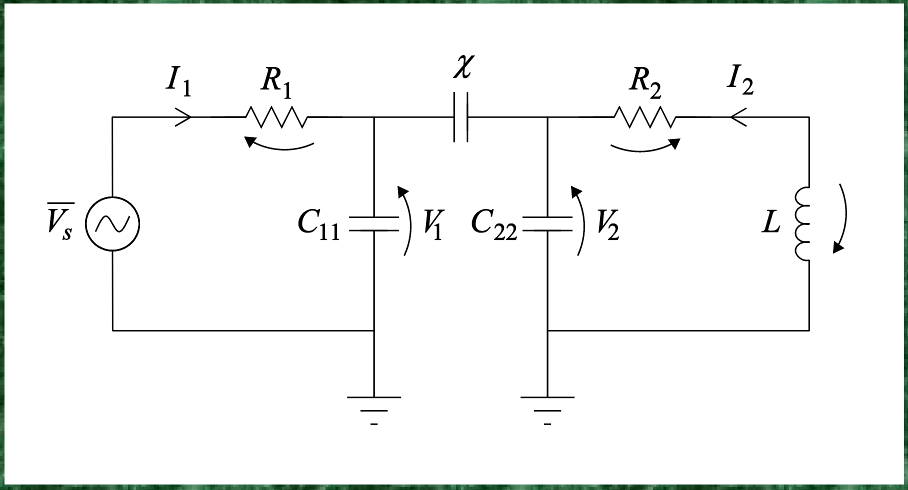




Statics & Quasi-Statics: Coupling

- *Systems operate at higher and higher frequencies*
- *Kirchoff voltage and current laws need to be extended to take into account:*
  - *# propagation time*
  - *# reflections*
  - *# dispersion*
- *High frequency effects of elements or wires (coupling)*
- *In other words, transmission line theory.*





Statics & QS: MEMS
Micro-Electro-Mechanical Systems

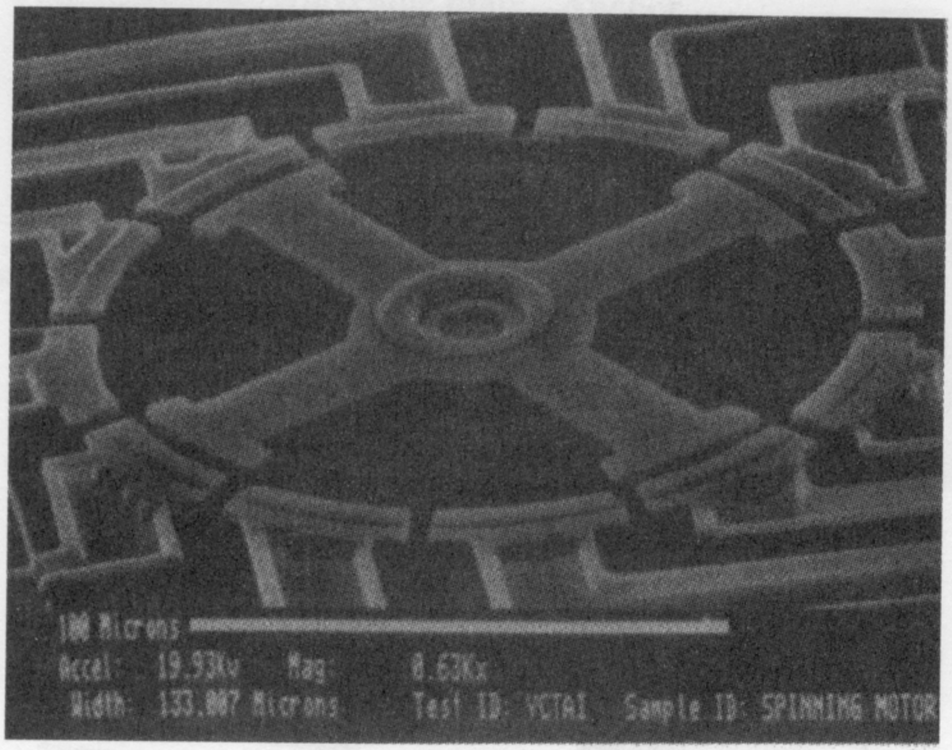


Figure 1.29 Electrostatic micromotor fabricated at Berkeley.[74]

Statics & QS: MEMS
Micro-Electro-Mechanical Systems

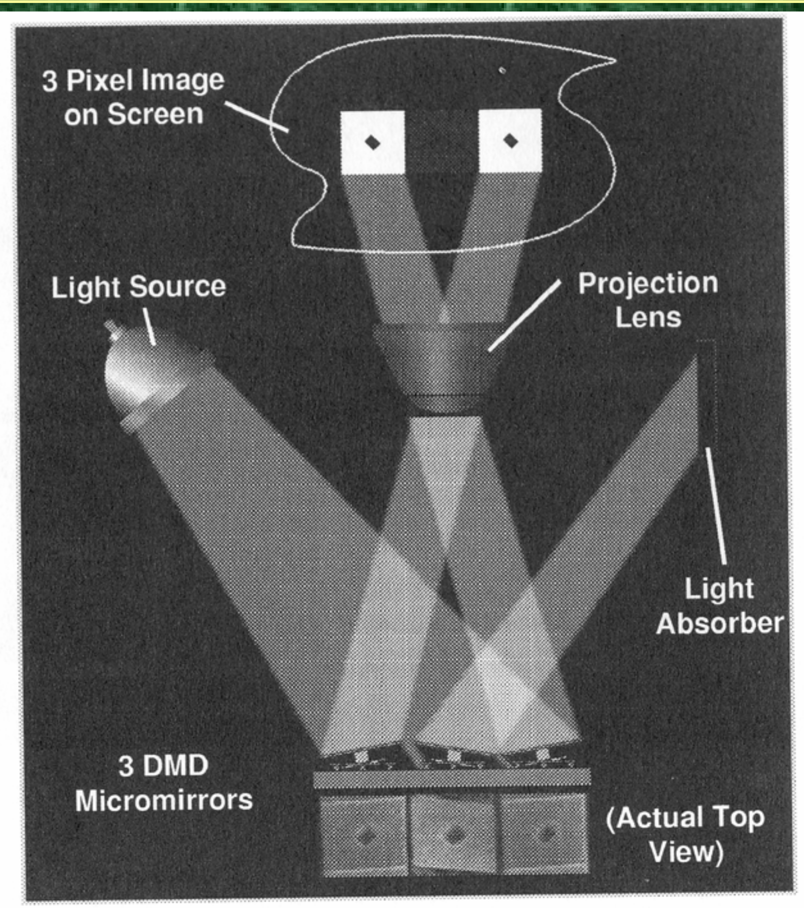


Figure 7.71 Optical schematic of projection operation.

Statics & QS: MEMS
Micro-Electro-Mechanical Systems

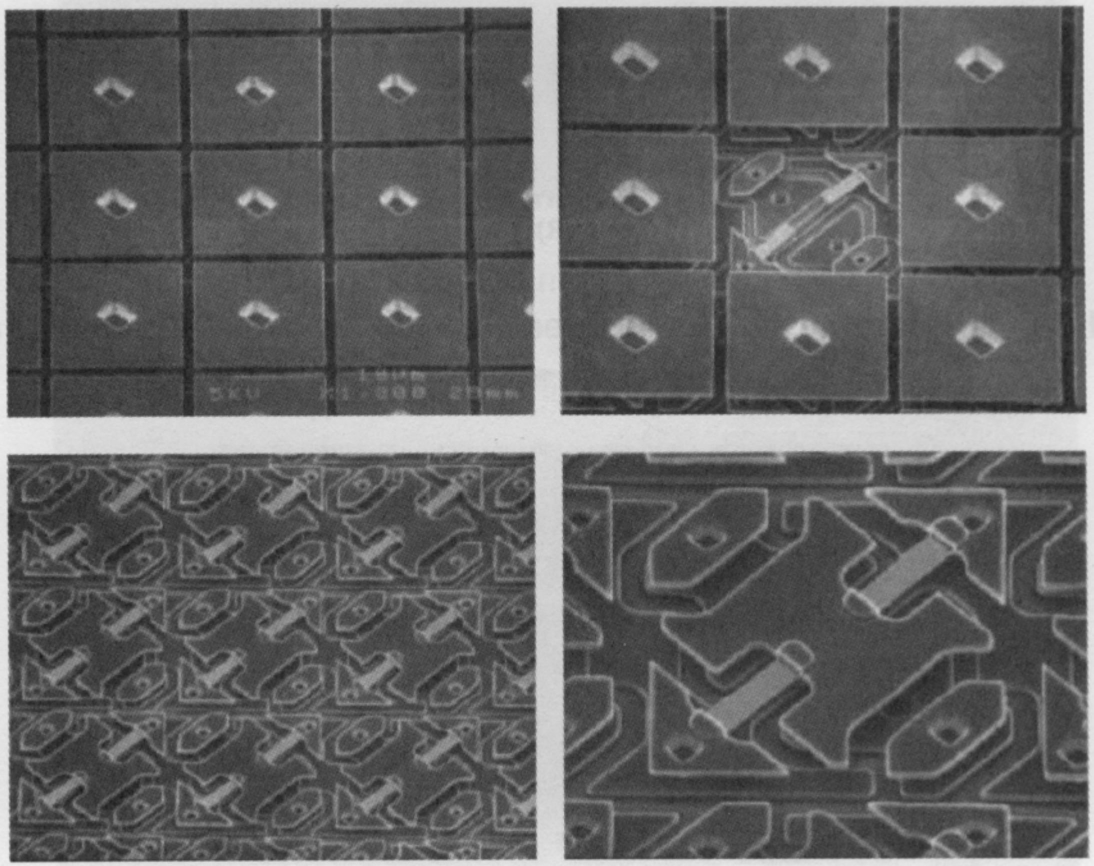


Figure 1.37 SEM photograph of a digital mirror array.

Statics & QS: MOEMS
Micro-Opto-Electro-Mechanical Systems

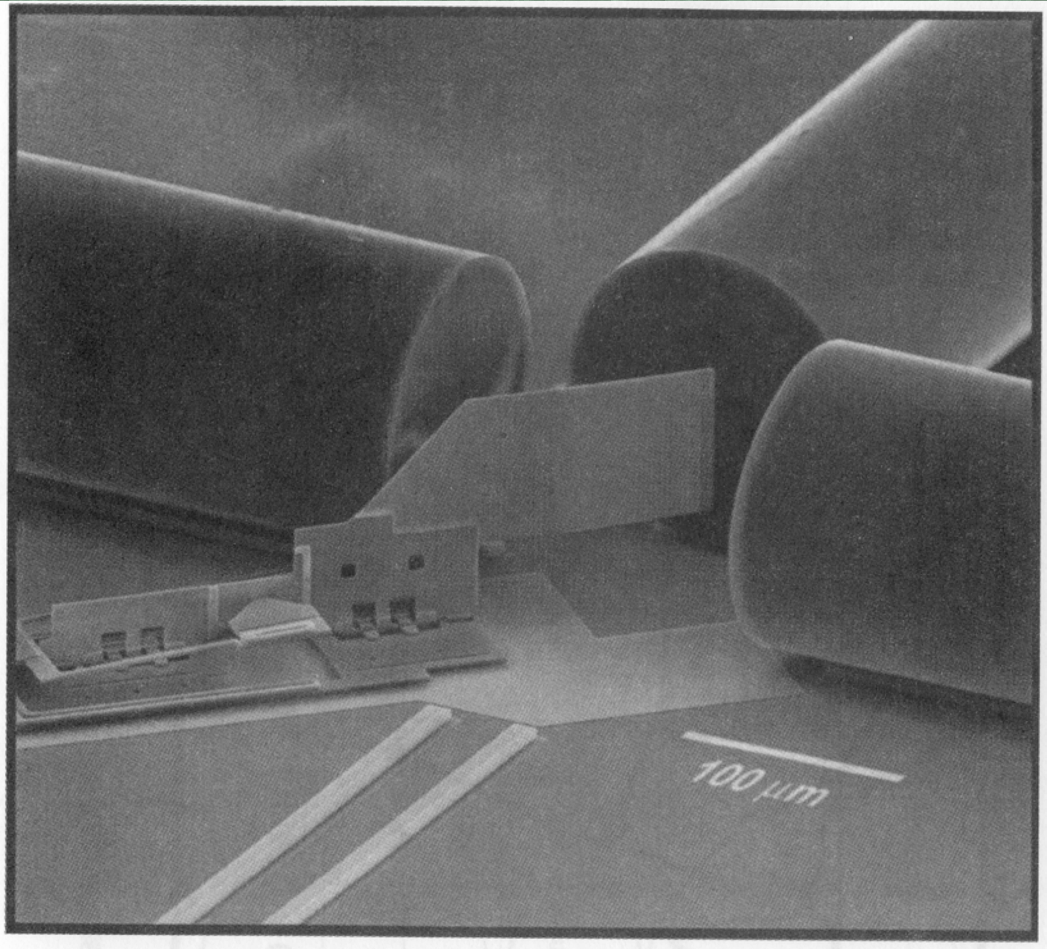


Figure 6.13 MEMS 1 × 2 optical switch.

Outline

- *Statics and Quasi-Statics:*

✓ *Microscopy at nanometer scale*

✓ *Electron sources*

✓ *Interface with bio-systems*

✓ *Coupling Phenomena*

✓ *Micro-Electro-Mechanical -Systems*

- *Dynamics:*

Photonic Band Gap Structures

Interaction with bio-systems

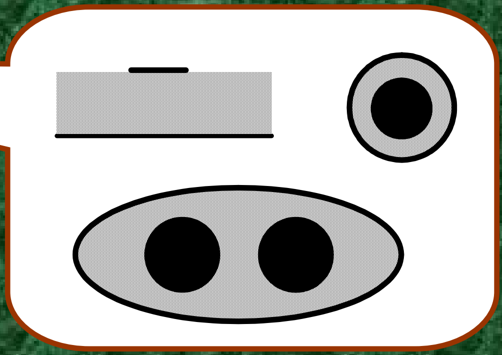
Frank-Hertz (PASER) – accelerators

X-ray sources: tools for nano-science

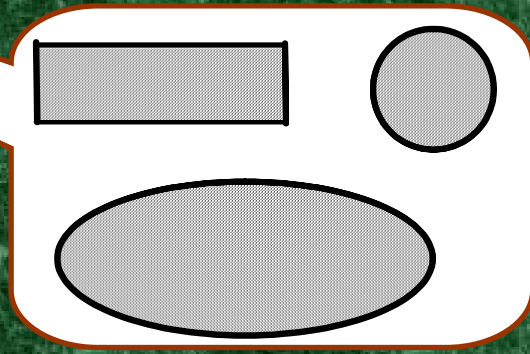
Dynamics: Photonic Band Gap (PBG)

- Guiding Electromagnetic Energy

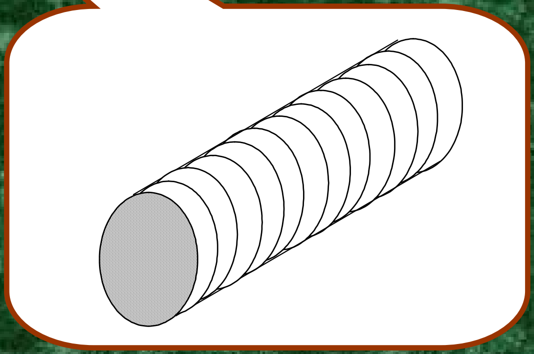
Transmission line



Waveguide



Optical fiber

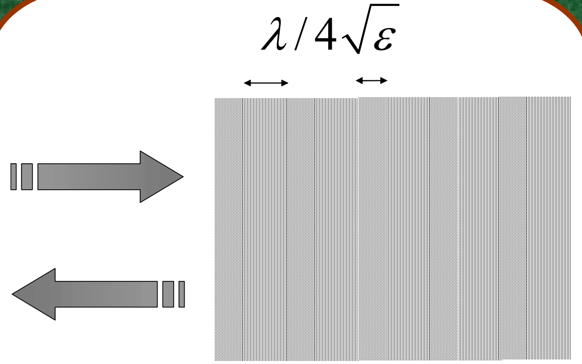


Electromagnetic energy confined by metallic walls or in regions of high dielectric coefficient

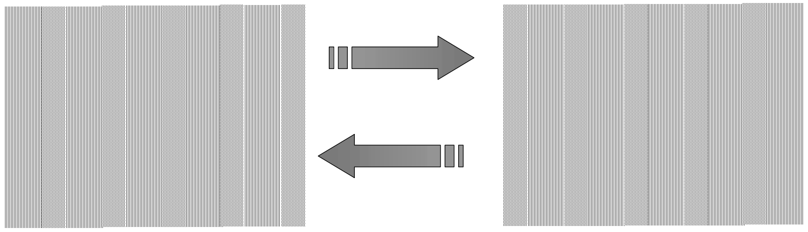
Dynamics: Photonic Band Gap (PBG)

It is possible to use destructive interference for ensuring confining electromagnetic radiation.

Bragg mirror

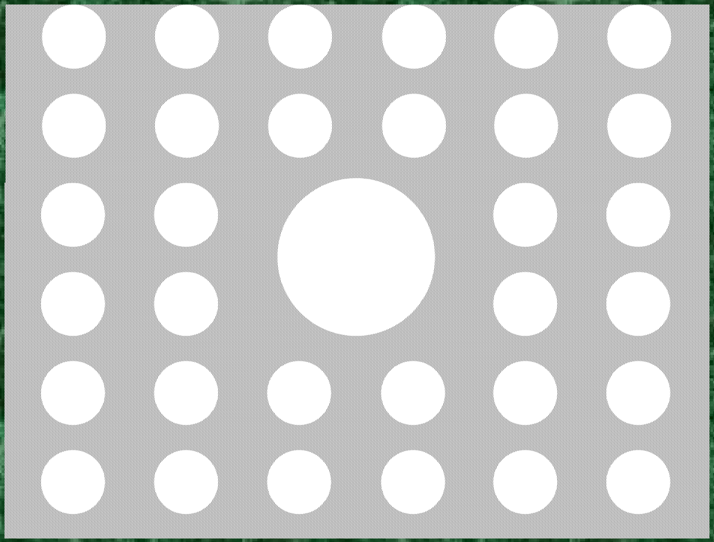


Bragg fiber



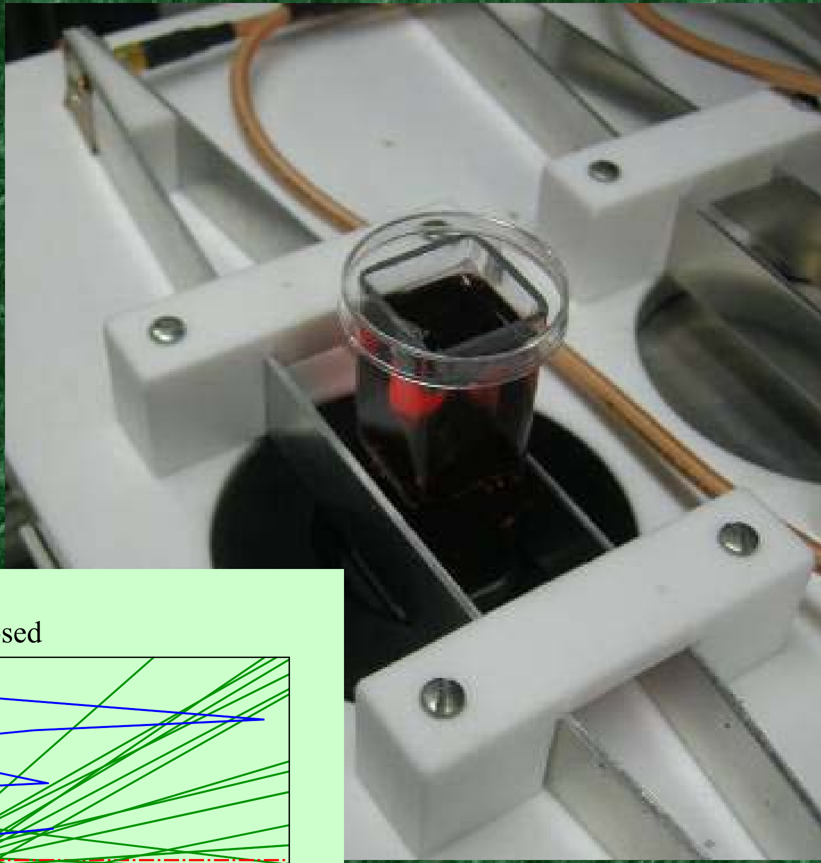
Dynamics: Photonic Band Gap (PBG)

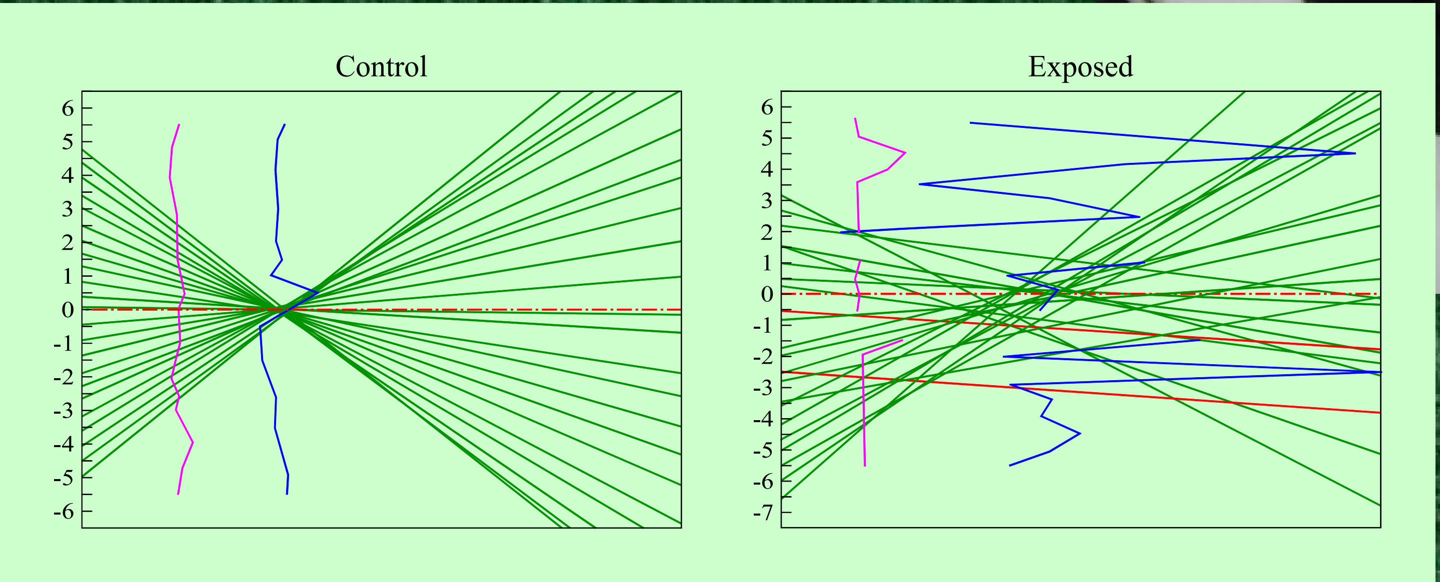
- It is possible to use destructive interference for ensuring confining electromagnetic radiation using more complex structures.
- Advantage: propagation of a significant fraction of the wave in vacuum.



Dynamics: Interaction with bio-systems

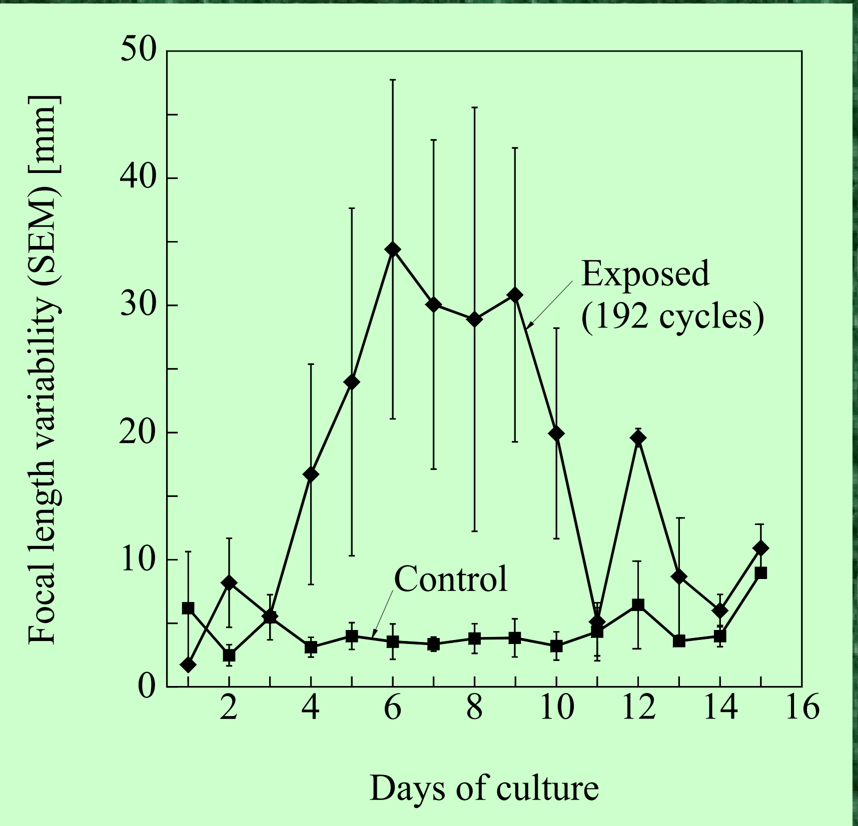
- *Interaction microwaves and the human body*
- *Eye – our electromagnetic detector*
- *Brain – our "CPU"*

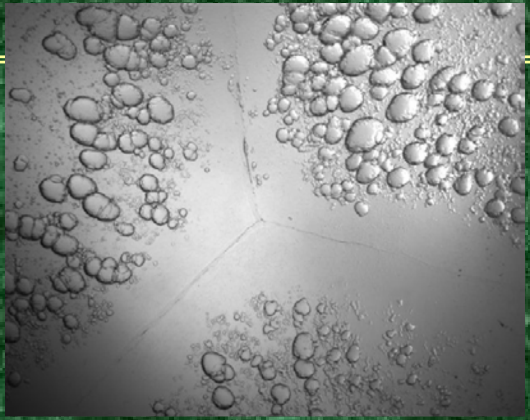


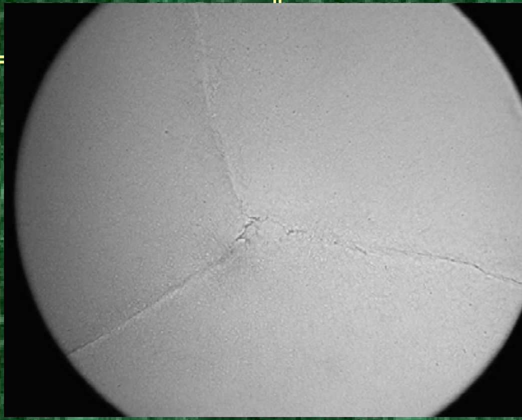


Dynamics: Interaction with bio-systems

- *Controlled temperature exposure*



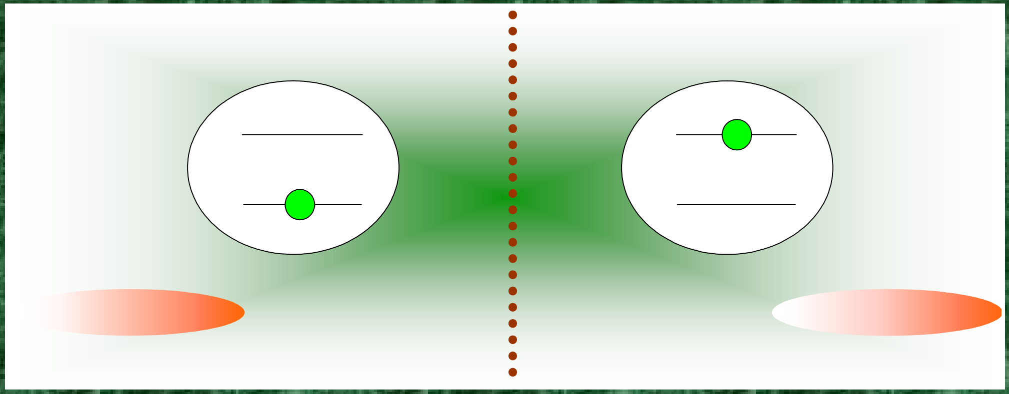




Dynamics: Frank-Hertz Effect

Electron moving in the vicinity of an atom may excite it by "kicking" the internal electron from a low energy level to a higher one.

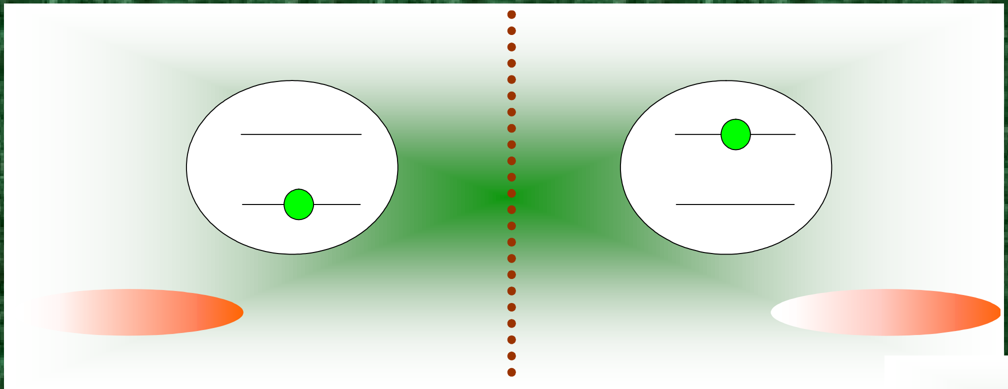
Its loss of energy equal to the difference between the energy levels

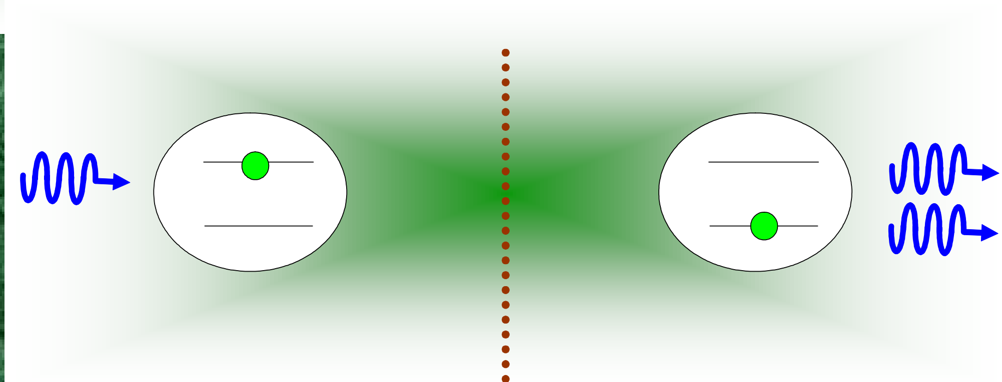


Dynamics: Frank-Hertz Effect

This is the basis to the well known

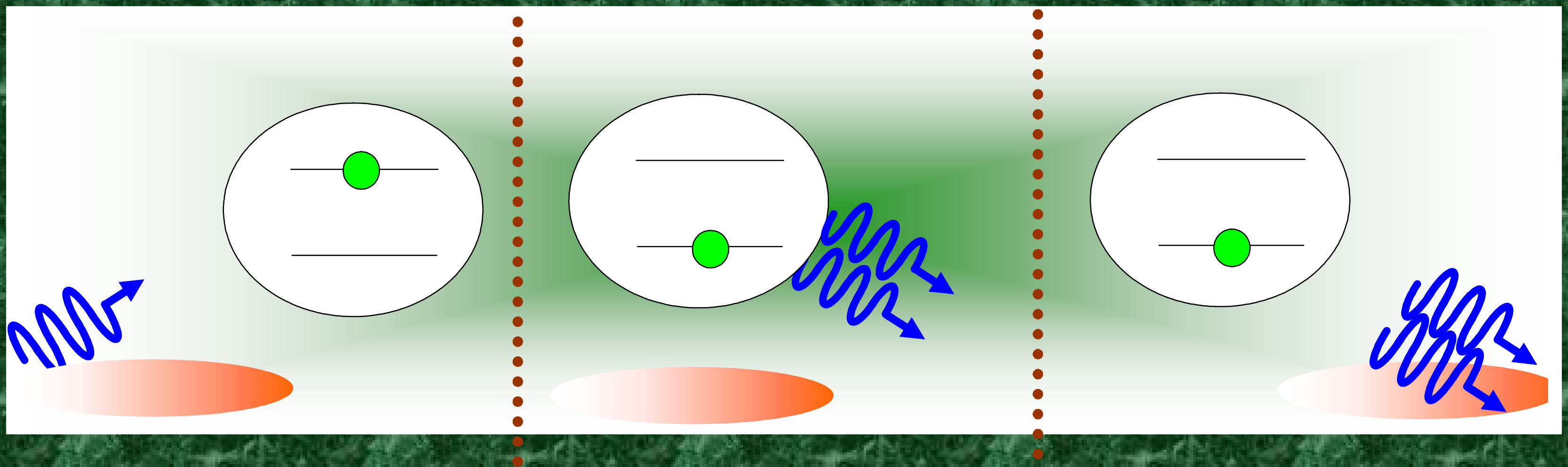
LASER: Light Amplification by Stimulated Emission of Radiation





Dynamics: Inverse Frank-Hertz Effect

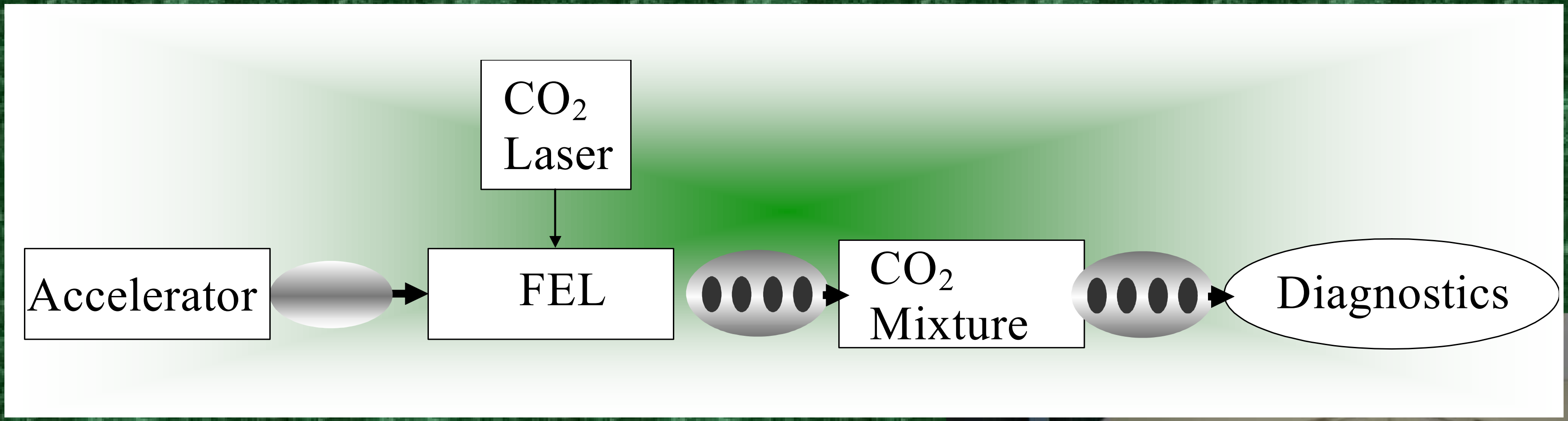
The opposite is also possible: Electron moving in the vicinity of an excited atom may be accelerated



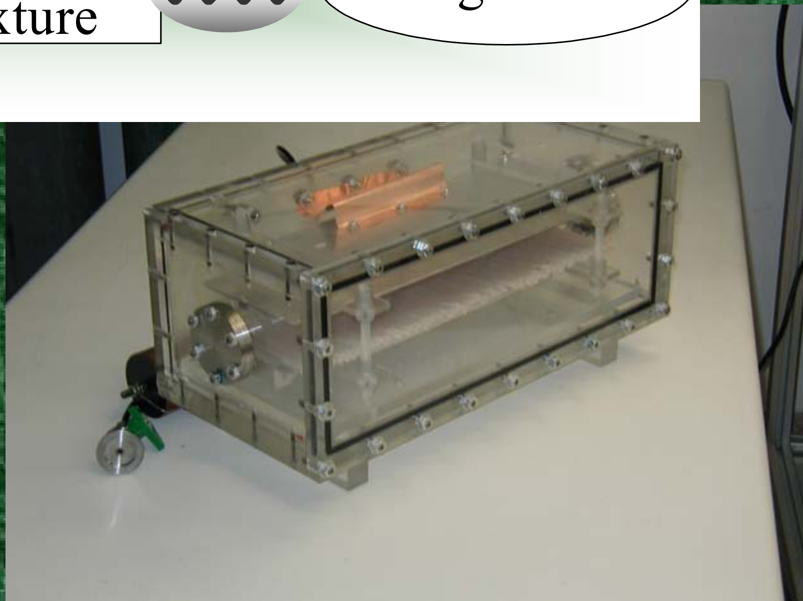
PASER: Particle Acceleration by Stimulated Emission of Radiation

Dynamics: Inverse Frank-Hertz Effect

PASER: Particle Acceleration by Stimulated Emission of Radiation

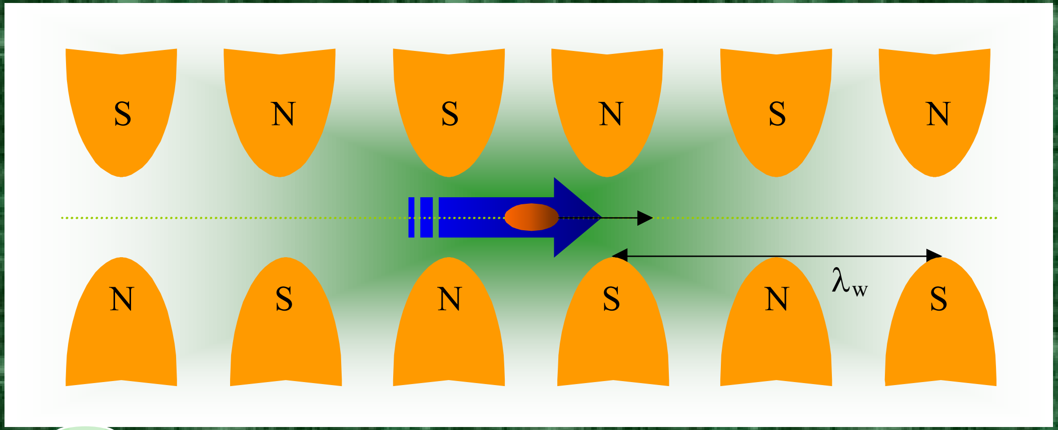


Experiment to be performed at the Brookhaven National Laboratory



Dynamics: X-ray Sources & Nano-Science

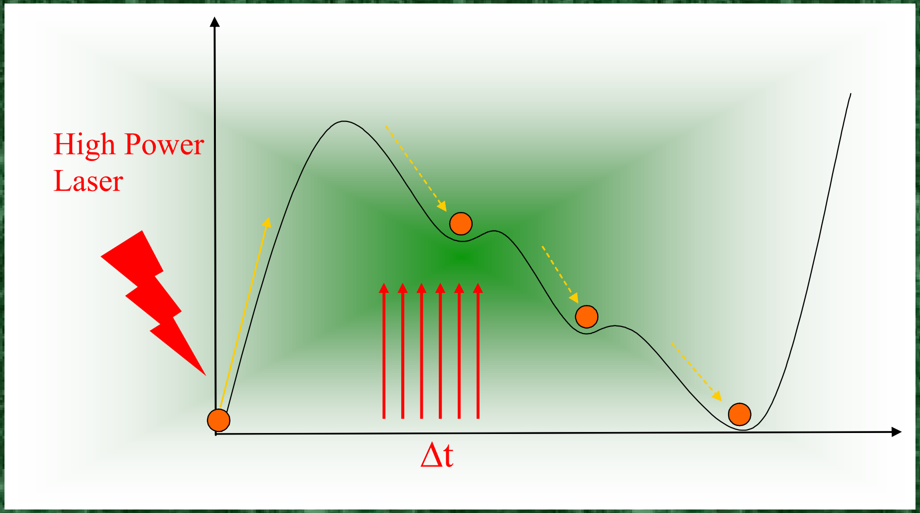
- Double Doppler shift
- Why accelerator
- "Quality" of the radiation is set by the quality of the electrons - coherence



$$\lambda \simeq \frac{\lambda_w}{2\gamma^2} \Rightarrow \lambda_w \sim 10[\mathrm{cm}] \;\&\; \gamma \sim 7\times 10^3 \Rightarrow \lambda \sim 1[\mathrm{nm}]$$

Dynamics: X-ray Sources & Nano-Science

- Advantages:
  - High intensity (good signal to noise ratio)
  - Atto-second pulses
  - Tunable
- Drawbacks:
  - Large national facility
  - Poor repetitivity
- Potential:
  - Resolve the dynamics of chemical bond
  - Resolve crystalline structures of single atoms
  - Learn about non-crystalline matter at atomic
- Alternative: high harmonic generation of laser pulses



Summary

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