A Personal View
of
Electromagnetic Phenomena

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and **GOD said**

\[ \nabla \times \vec{E} = -\partial_t \vec{B} \]

\[ \nabla \times \vec{H} = \partial_t \vec{D} + \vec{J} \]

\[ \nabla \cdot \vec{D} = \rho \]

\[ \nabla \cdot \vec{B} = 0 \]

*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
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 – 0.5 μm.

There are several concepts that may be used for bypassing this inherent limitation -- most of them do not use light.
• **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) → current

*Figure 5.65* 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

\[
J \propto E^2 \exp \left( -\frac{E_{cr}}{E} \right)
\]
• Intense electric field is not a big problem. What is an intense field? Typical for dc

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

• Applying a few volts on the scale of 1\( \mu \)m generates a sufficient electric field

\[ E: 1\text{V/1}\mu\text{m} = 1\text{[MV/m]} \]

• 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.\textsuperscript{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 x 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
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**

![Graph showing focal length variability (SEM) in mm over days of culture.](image)

- Exposed (192 cycles)
- Control

![Microscopic images of bio-systems.](images)
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
The opposite is also possible: Electron moving in the vicinity of an excited atom may be accelerated.
**Dynamics: Inverse Frank-Hertz Effect**

**PASER:** Particle Acceleration by Stimulated Emission of Radiation

Experiment to be performed at the Brookhaven National Laboratory
Double Doppler shift

Why accelerator

“Quality” of the radiation is set by the quality of the electrons - coherence

\[ \lambda \approx \frac{\lambda_w}{2\gamma^2} \Rightarrow \lambda_w \sim 10[\text{cm}] \& \gamma \sim 7 \times 10^3 \Rightarrow \lambda \sim 1[\text{nm}] \]
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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  - Photonic Band Gap Structures
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