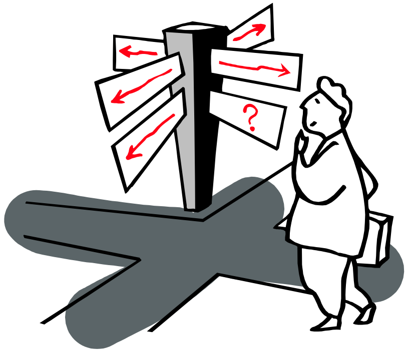
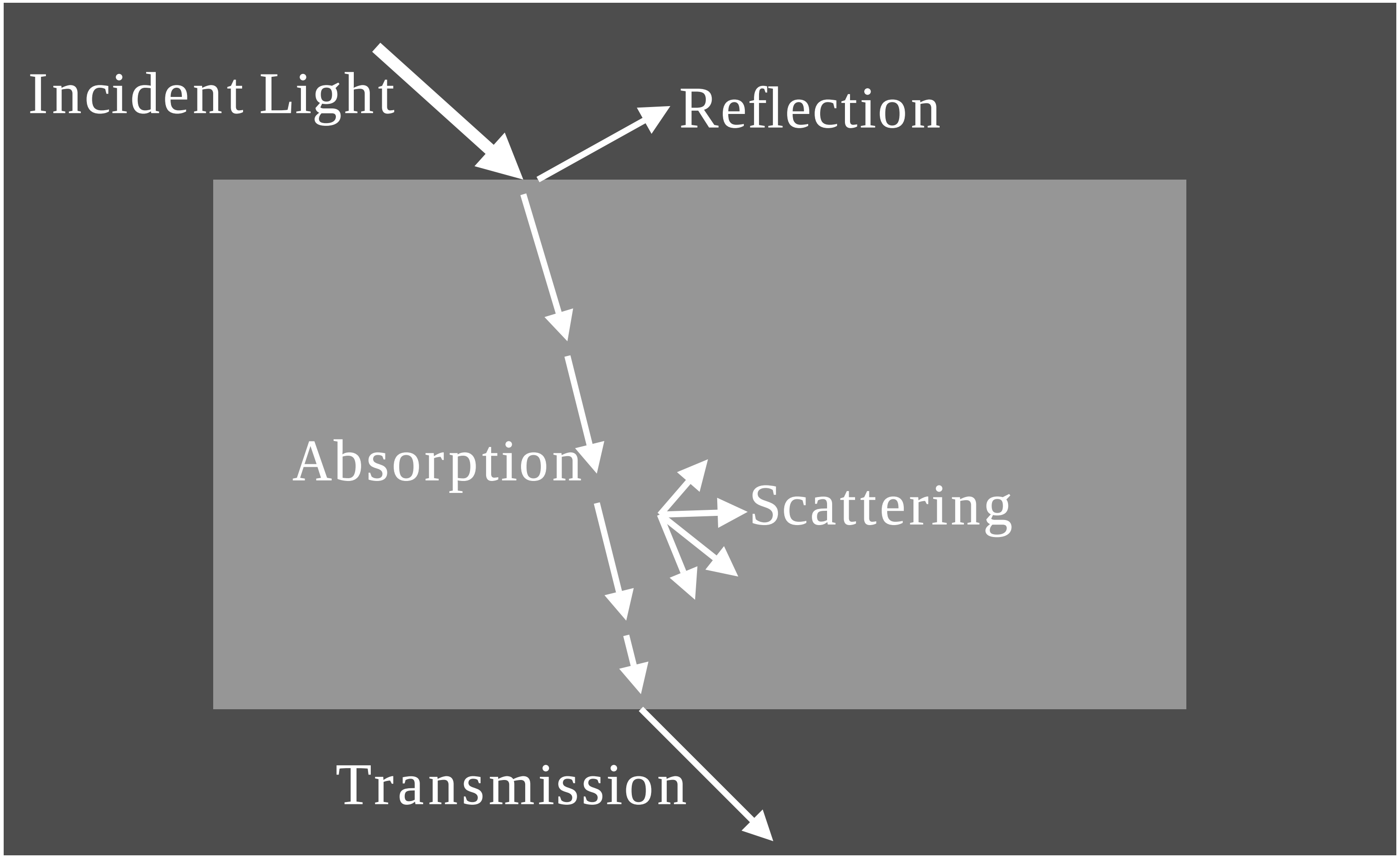
~Laser-Tissue Interactions~

Outline



- Introduction: fundamentals, commonly used laser systems and basic terminology
- Mechanisms of laser-tissue interactions
- Heat transfer models - Numerical results
- Conclusions and Applications

Interaction of matter with EM waves



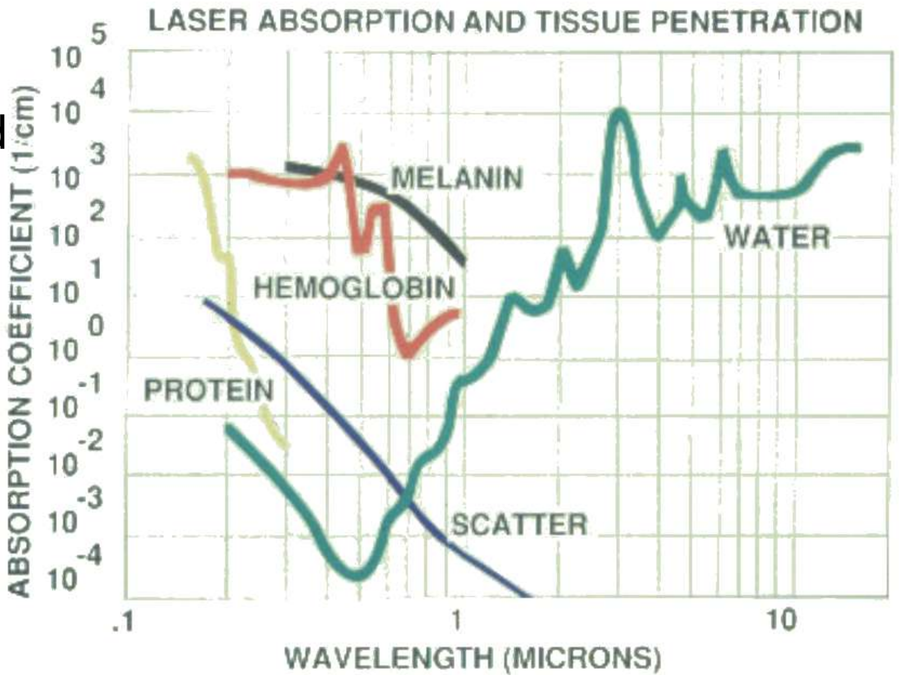
Absorption

Beer-Lambert's Law → $I(z) = I_0 \exp(-\alpha z)$

Absorption curves for tissues

→Water, proteins, pigments and other macromolecules

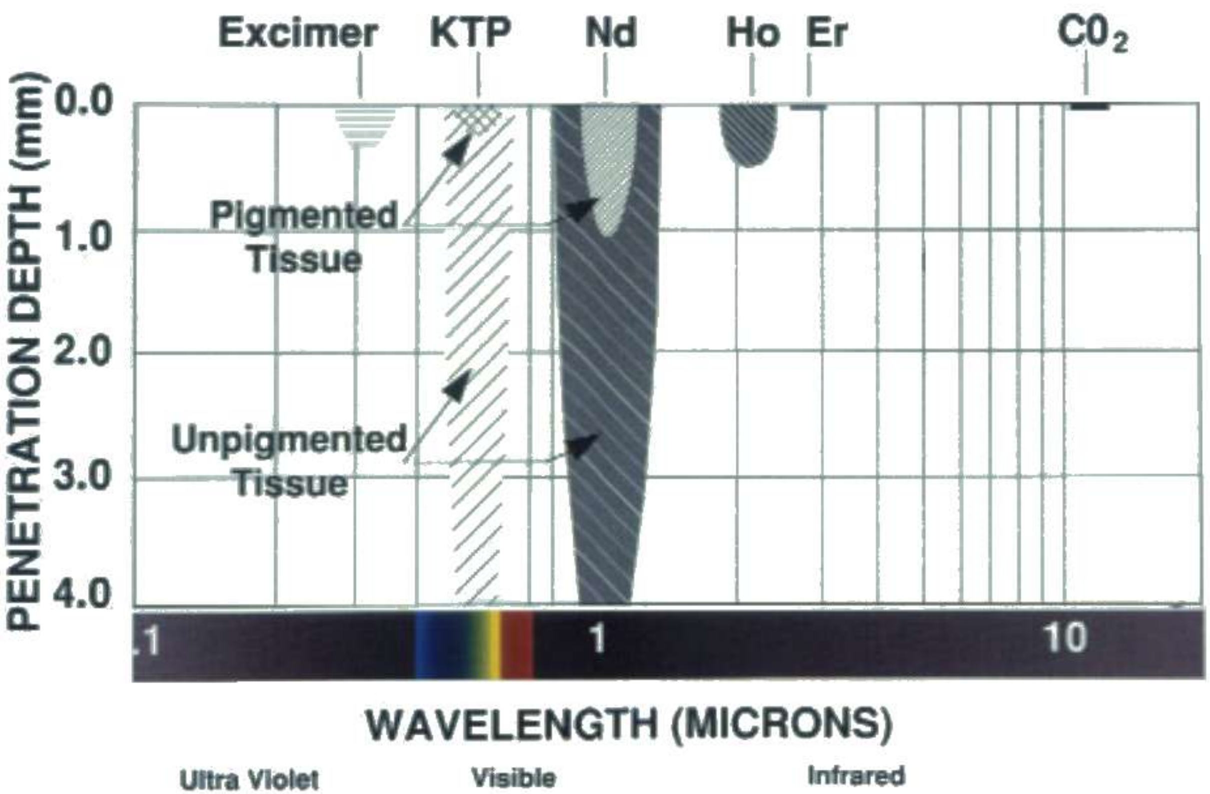
- Towards the IR region of the spectra, water molecules are dominant absorbers
- In the UV and visible spectra, absorption by macromolecules like melanin and hemoglobin is more pronounced.



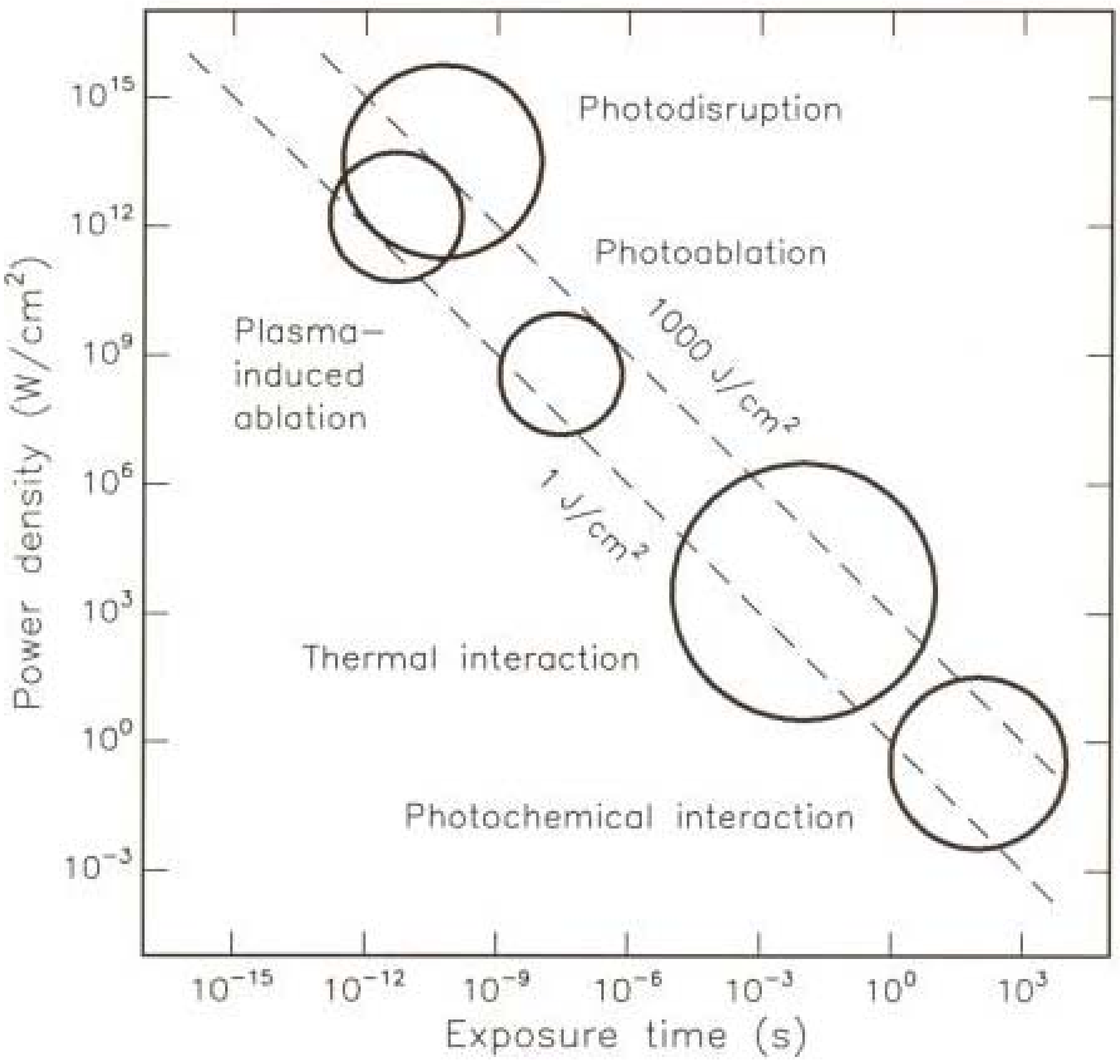
Some lasers in medical use

CO_2	10.6 micron
Er:YAG	2.94 miron
Ho:YAG	2.12 micron
Nd:YAG	1064 nm
Argon ion	488/514 nm
Kr	647 nm
Cu vapour	511/578 nm
Dye	630/675 nm
Diode	600 / 905 nm
KrF	248nm

Absorption depths for various lasers



Map of laser-tissue interactions



a. Photochemical Interactions

i) Photodynamic Therapy:

Laser

Photosensitizers acting as a catalyst – Hematoporphyrin Derivative (HpD)

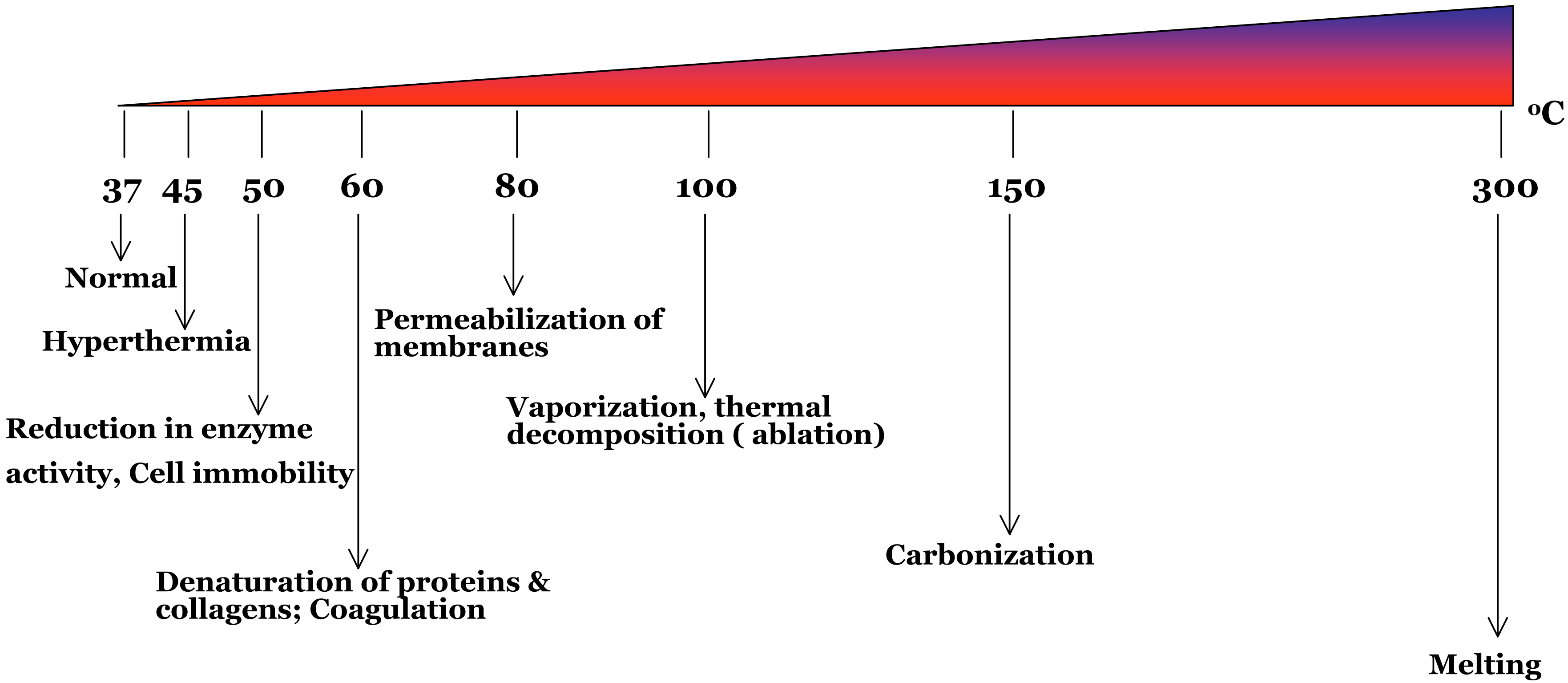
ii) Biostimulation:

Extremely low laser powers (1-5 mW) for wound healing, anti-inflammatory etc effects. – Results are debatable.

Typical laser parameters:

Red dye lasers, diode lasers ; 1 sec …CW ; 0.01 … 50W/cm^2

b. Thermal Interaction



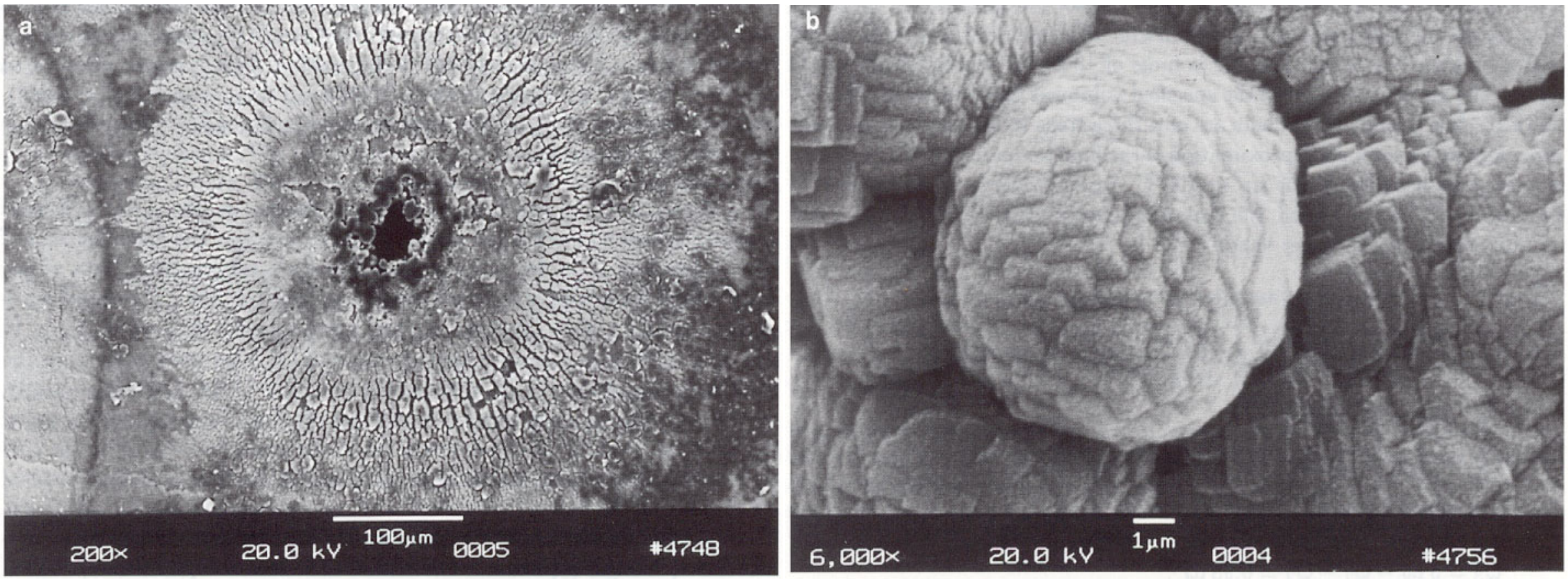
Typical Laser Parameters and applications:

CO_2, Nd:YAG, Er:YAG, Ho:YAG, Argon ion and Diode lasers ; 1μs…1 min; 10…10^6 W/cm^2 power densities. Treatment for retinal detachment, laser induced interstitial thermotherapy

Heat Effects on tissues

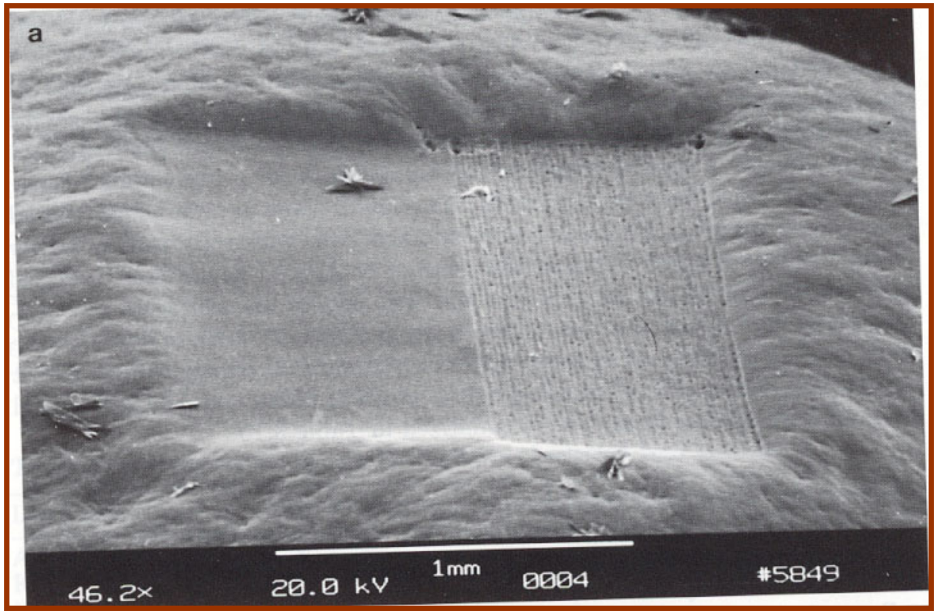
Effect of multiple laser pulses :

1000 laser pulses from a Nd:YLF laser on the same spot on a tooth



c. Photoablation

Computer simulation of photoablation of PMMA



Human Cornea exposed to 2ω & 4ω Nd:YLF laser pulses

Photoablation (contd…)

- Ablation depth:

$$I_0 \exp(-\alpha z) \geq I_{ph}$$

$$d = \frac{2.3}{\alpha} \log_{10} \frac{I_0}{I_{ph}}$$

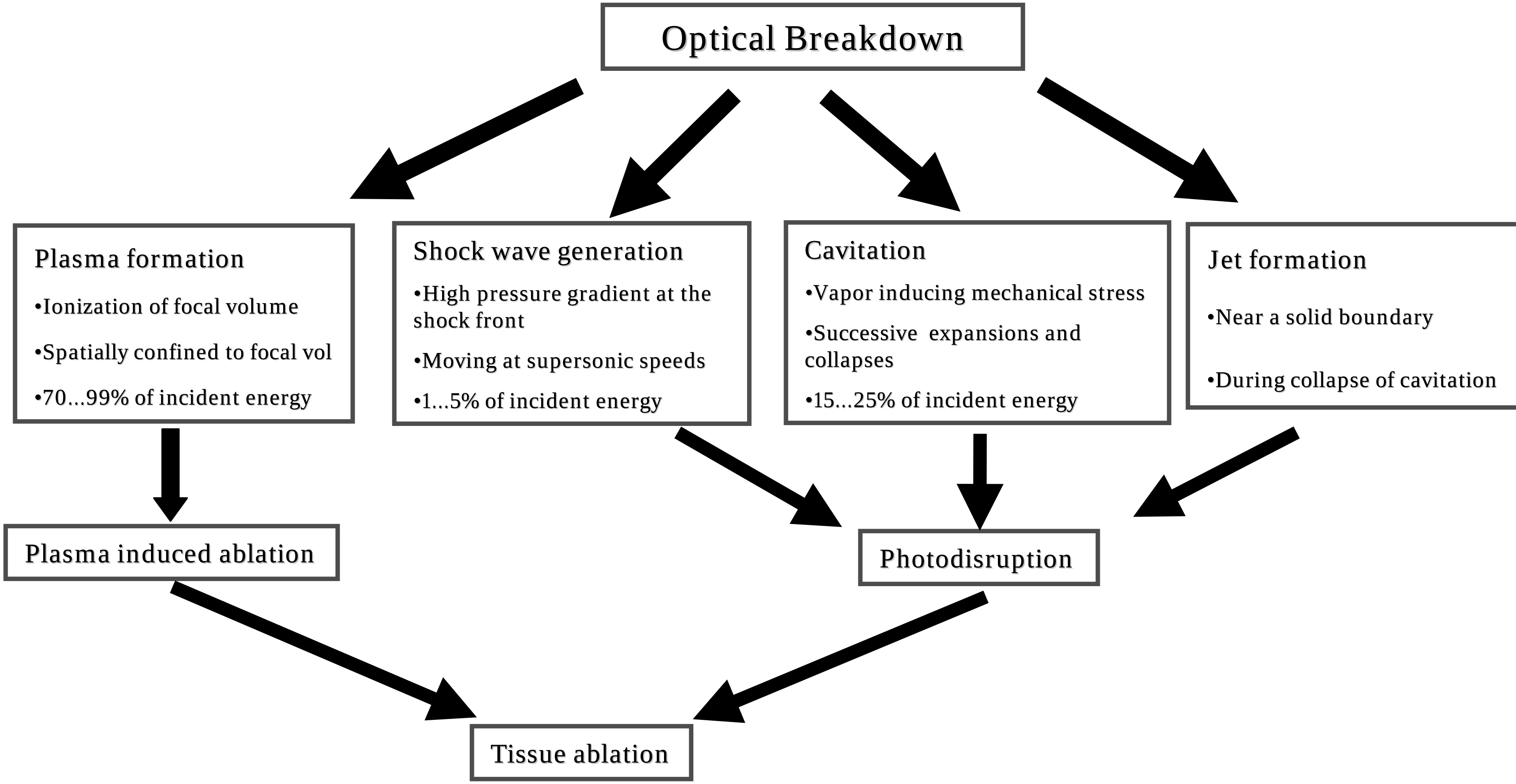
- Typical Laser parameters and applications:
  - Excimer lasers, e.g. ArF, KrF, XeCl, XeF
  - 10….100ns pulse durations
  - $10^7 \ldots 10^{10}$ W/cm^2 power densities
  - Refractive corneal surgery

d. Plasma-induced Ablation

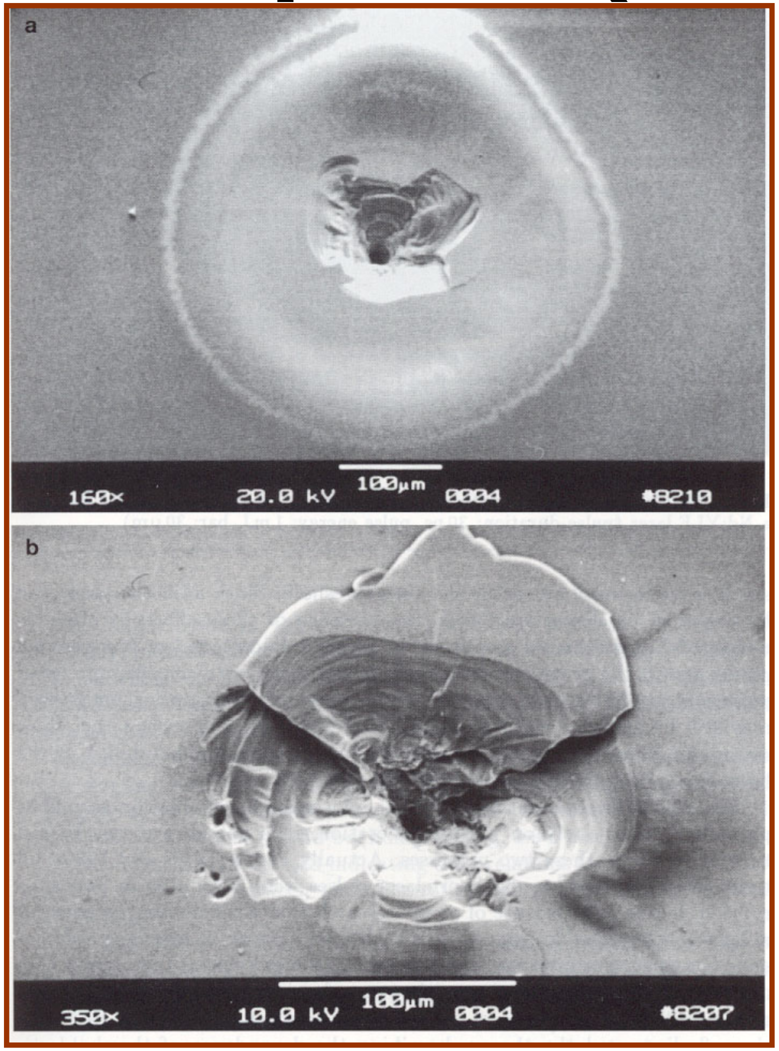
Laser-induced plasma sparking on the tooth surface

a) Human Cornea & b) human tooth exposed to Nd:YLF laser pulses

e. Photodisruption

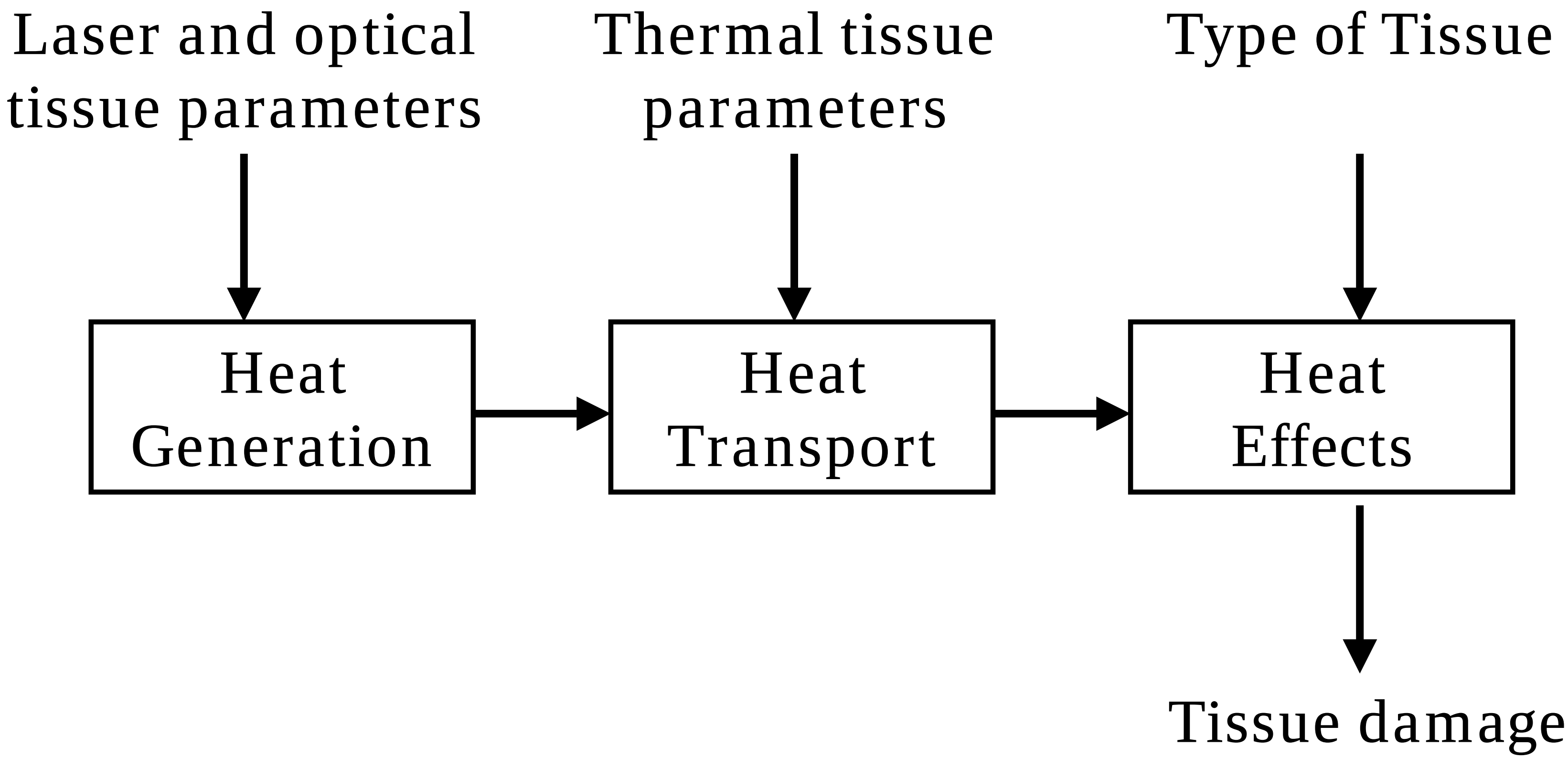


Photodisruption (contd..)



Anterior and posterior surface of a 90µm glass plate exposed to 10 pulses from a Nd:YLF laser

Modeling laser interaction



Important parameters

- *Laser parameters :* Wavelength, Power density, exposure time, pulse duration, focused spot size, repetition rate.
- *Optical properties of the tissue :* absorption and scattering coefficients
- *Thermal properties of the tissue* : thermal capacity and thermal conductivity

Heat transfer model

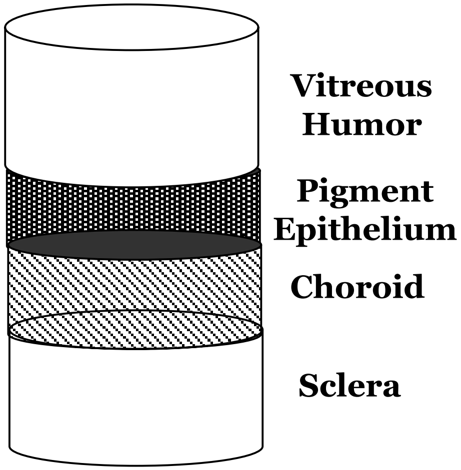
- <u>Basic Assumptions</u>:
  - Laser source term – Gaussian spatially and temporally.
  - Cylindrical coordinate system.
  - No ‘θ’ dependence.
  - No radiation or convection losses.
  - Constant properties.

$$I(r,z,t) = I_0 \times \exp\left(-\frac{2r^2}{w^2} - \alpha z\right) \times \exp\left(-\frac{8t^2}{\tau^2}\right)$$

$$S(r,z,t) = \alpha I(r,z,t)$$

$$\nabla^2 T + \frac{S}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial z^2} + \frac{S}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$



Cylindrical geometry for modeling Eye

Heat transfer modeling (contd…)

- Effect of blood flow:

$$q_c = \rho_b c_b w_b \left(T_b - T\right)$$

  – Outside the vessels

$$\alpha\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial z^2}\right) + \frac{\rho_b c_b w_b \left(T_b - T\right)}{\rho c} + \frac{S}{\rho c} = \frac{\partial T}{\partial t}$$

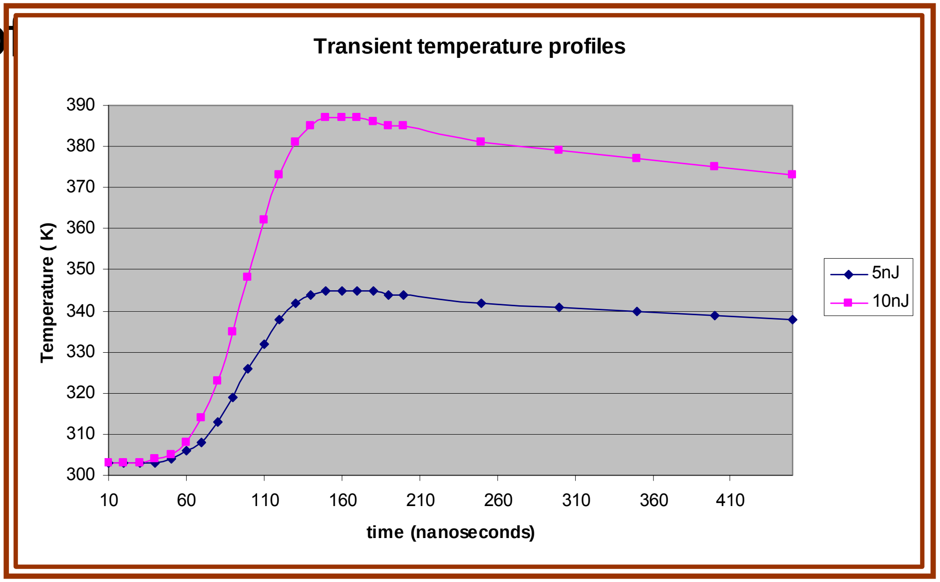
  – Within the blood vessels

$$\alpha_b\left(\frac{\partial^2 T_b}{\partial r^2} + \frac{1}{r}\frac{\partial T_b}{\partial r} + \frac{\partial^2 T_b}{\partial z^2}\right) + \frac{q_c + S}{\rho_b c_b} = \frac{\partial T_b}{\partial t} + v_b \frac{\partial T_b}{\partial y}$$

- Solution methodologies:
  – Integral transformation
  – Green's function method
  – Numerical methods – finite difference, finite volume, FEM

Numerical Simulation results

- <u>Simulation parameters:</u>
  - For Pigment Epithelium of the retina.
  - 100ns laser pulse.
  - Laser spot size = 1um
  - $T_0=30^0C$
  - Other tissue parameters
  - Implicit finite difference scheme.
  - Adiabatic boundary conditions on all sides.
  - No blood flow.



Numerical Simulations (Contd..)

- <u>Ultrashort laser pulse interactions:</u>

$$C_e(T_e)\frac{\partial T_e}{\partial t} = -\left[\frac{q_{er}}{r}+\frac{\partial q_{er}}{\partial r}+\frac{\partial q_{ez}}{\partial z}\right] - G\left[T_e - T_l\right] + S(r,z,t)$$

$$\tau_e\frac{\partial q_{er}}{\partial t} + q_{er} = -k_e\frac{\partial T_e}{\partial r}$$

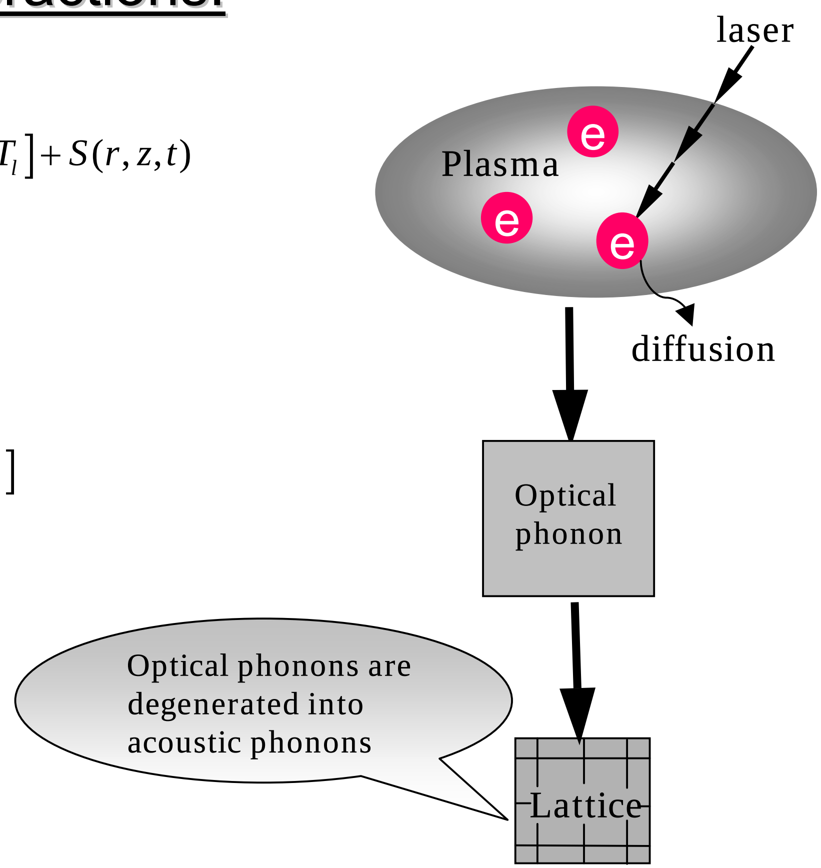
$$\tau_e\frac{\partial q_{ez}}{\partial t} + q_{ez} = -k_e\frac{\partial T_e}{\partial z}$$

$$C_l(T_l)\frac{\partial T_l}{\partial t} = -\left[\frac{q_{lr}}{r}+\frac{\partial q_{lr}}{\partial r}+\frac{\partial q_{lz}}{\partial z}\right] + G\left[T_e - T_l\right]$$

$$\tau_l\frac{\partial q_{lr}}{\partial t} + q_{lr} = -k_l\frac{\partial T_l}{\partial r}$$

$$\tau_e\frac{\partial q_{lz}}{\partial t} + q_{lz} = -k_l\frac{\partial T_l}{\partial z}$$

$$\lim_{r\to o}\left(\frac{q_{er}}{r}\right) = \frac{\partial q_{er}}{\partial r};\lim_{r\to o}\left(\frac{q_{lr}}{r}\right) = \frac{\partial q_{lr}}{\partial r}$$



Conclusions and Applications

- Various laser-tissue interaction mechanisms were reviewed.
- Heat transfer models and numerical solutions for the laser interaction were studied. – More accurate models are required for understanding Ultrashort laser pulse interactions with biological samples.
- Lasers have been put to extensive use in various fields of medicine which include – ophthalmology (e.g. LASIK), Dentistry, Dermatology, Neurosurgery, Angioplasty & Cardiology, Orthopedics , Gasterology……

References

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