Nanotechnologie v bioanalýze

Karel Klepárník

Oddělení bioanalytické instrumentace
Ústav analytické chemie
Akademie věd České republiky
Brno

Single molecule imaging

Issues:

❖ space resolution – diffraction limit

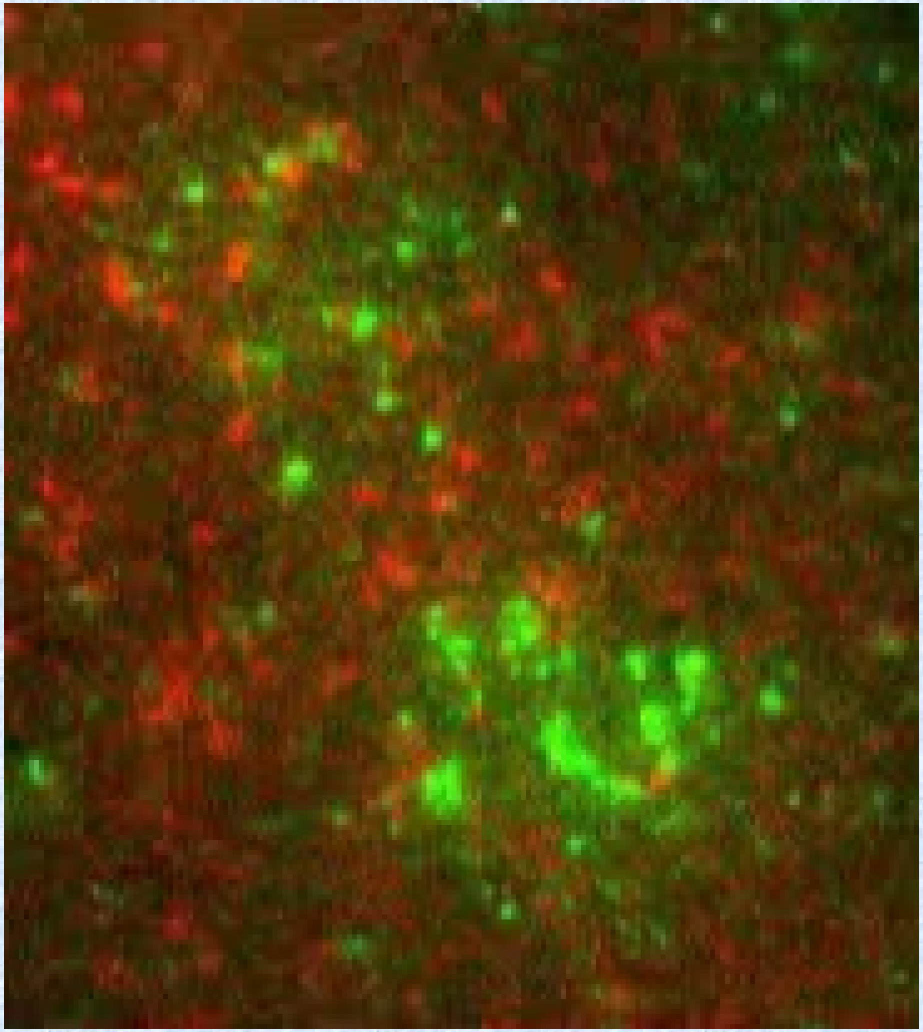
D = λ/(2xN.A.) ≈ 180 nm (for 500 nm)

❖ time resolution – brownian motion

❖ photo bleaching

❖ narrow excited layer (TIRF)

❖ two lasers: 514, 633 nm



Membrane proteins
CD58-Cy3 (*green*)
ICAM-1-Cy5 (*red*)
in a glass-bound planar phospholipid bilayer
under two PMA/ionomycin-treated Jurkat cells.

Quantum dots

Properties of semiconductor quantum dots:

- High photo-stability
- Broad excitation curve
- Narrow emission spectra
- Easy tunability
- High quantum efficiency

Quantum effects

Helmholtz
Planck
Einstein
deBroglie

Erwin Schrödinger
1887 – 1961 Vienna

Time dependent one-dimensional Schrödinger equation

$$i\hbar\frac{\partial}{\partial t}\Psi(x,t) = -\frac{\hbar}{2m}\frac{\partial^2}{\partial x^2}\Psi(x,t) + V(x)\Psi(x,t)$$

$\Psi(x, t)$ wave function
i imaginary unit
$\hbar$ reduced Planck constant ($\hbar = h/2\pi$; $E = h\nu$)
x space
t time
m mass
V(x) time independent potential energy at x

Separation of Variables – Eigenfunction-Eigenvalue Problem

$$i\hbar \frac{\partial}{\partial t}\Psi(x,t) = -\frac{\hbar}{2m}\frac{\partial^2}{\partial x^2}\Psi(x,t) + V(x)\Psi(x,t)$$ 1/[ψ(x) T(t)]

$\Psi(x, t) = \psi(x)\, T(t)$

$$\frac{1}{T} i\hbar \frac{dT(t)}{dt} = \frac{1}{\psi}\left[-\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2} + V(x)\psi(x)\right] = E = \hbar\,\omega$$

$$-\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2} + V(x)\psi(x) = E\psi(x)$$ time-independent equation

Solution to the time independent equation – quantum well

$$-\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2} = E\psi(x)$$

$$\frac{d^2\psi}{dx^2} = -\frac{2m}{\hbar^2}E\psi(x)$$

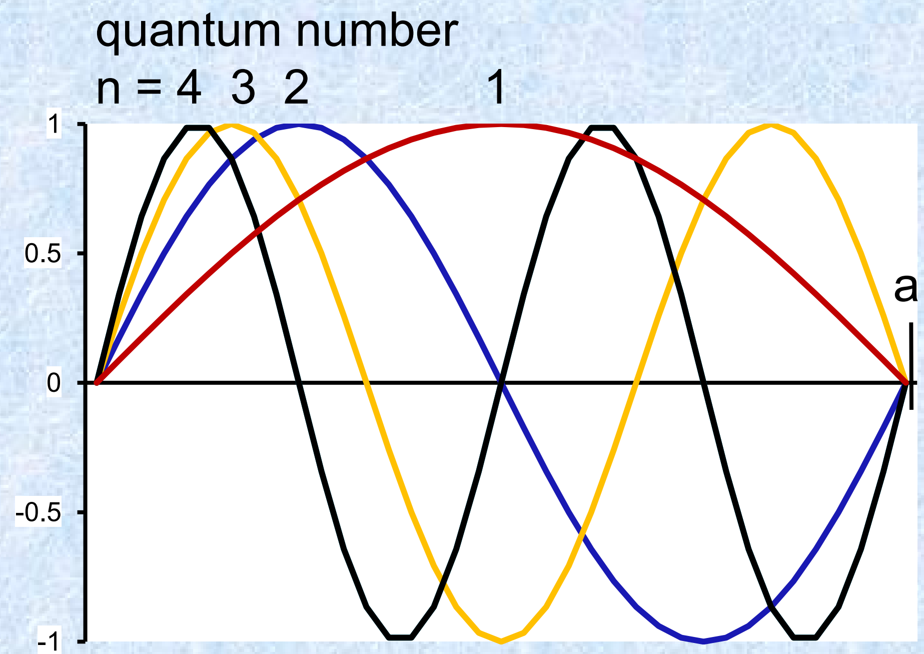
$\psi(x) = \sin(kx)$

$k = n\pi/a$ (wavenumber)

$\psi\ \ (x) = -k^2\sin(kx)$

$$-k^2 = -\frac{2m}{\hbar^2}E$$

$$E = \frac{k^2\hbar^2}{2m} = \frac{n^2h^2}{2ma^2}$$



Infinitely deep quantum well

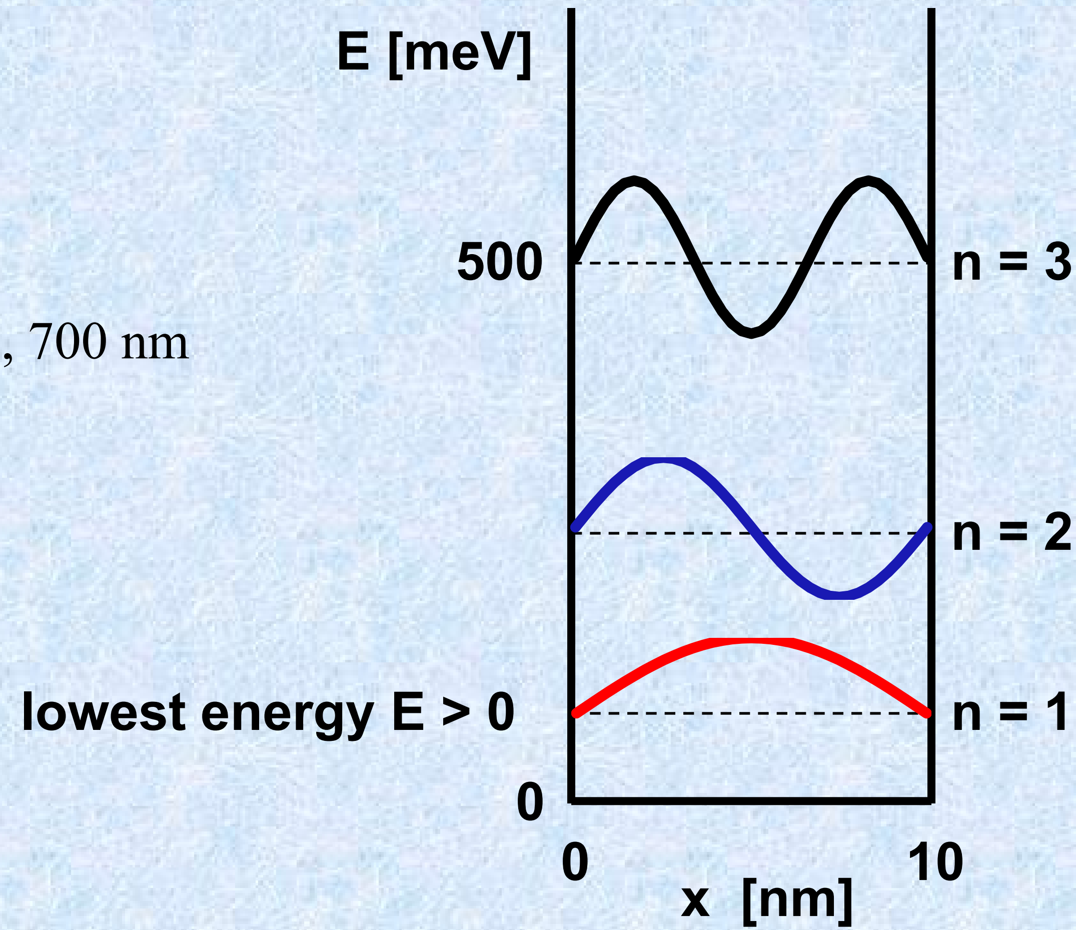
$$E = \frac{\hbar^2 \pi^2 n^2}{2ma^2}$$

$E_{n+1} - E_n = (2n+1)h/(2ma^2)$

3 233, 700 nm

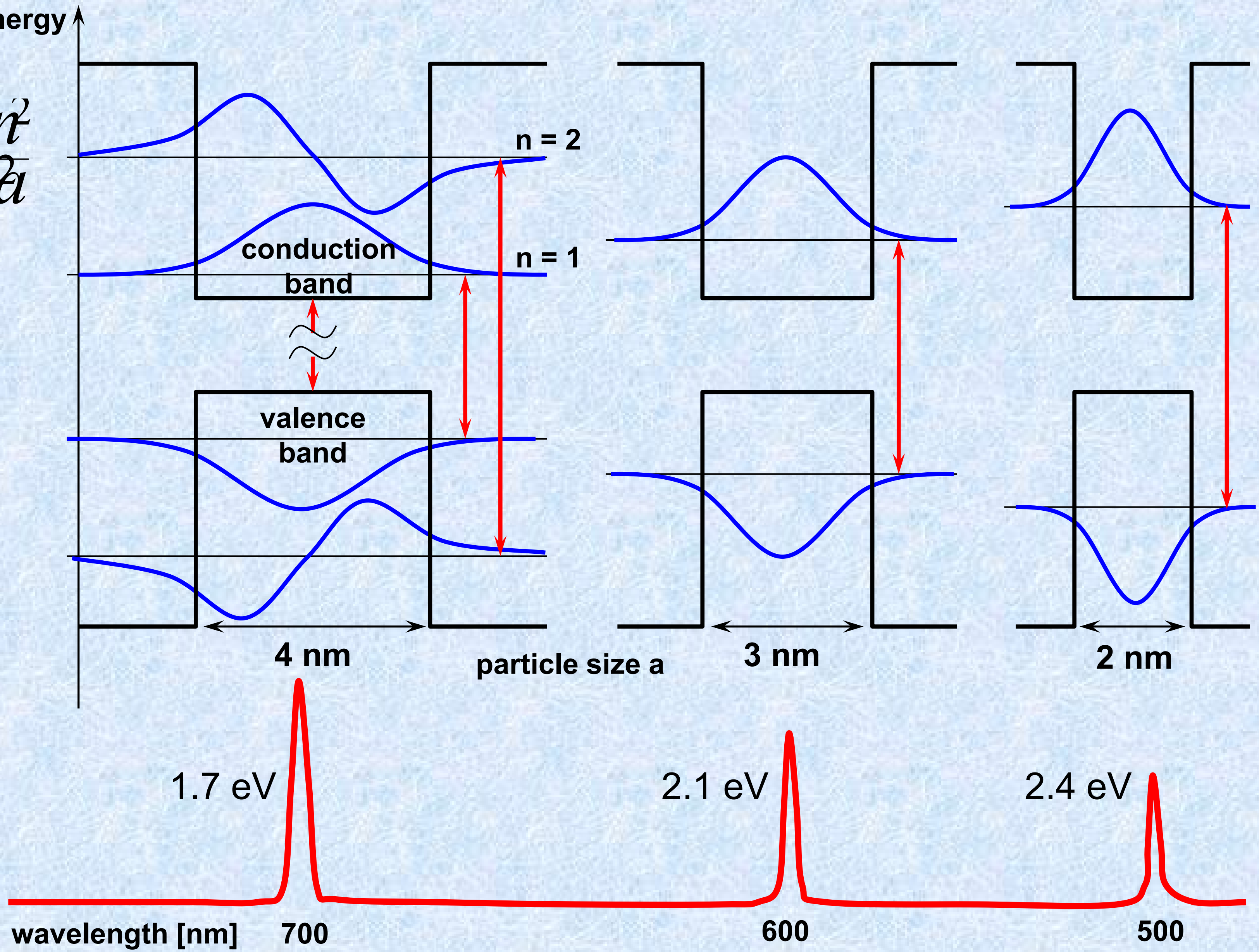
5

7



Quantum dots - size effect of optical properties

$$E = \frac{\hbar^2 \pi^2 n^2}{2 m a^2}$$



Optical properties of quantum dots

$$E = \underbrace{\frac{h^2}{8R^2}\left(\frac{1}{m_e} + \frac{1}{m_h}\right)}_{\text{exciton quantization}} - \underbrace{\frac{1.8e^2}{4\pi\varepsilon R}}_{\text{electrostatic attraction}}$$

E energy of exciton

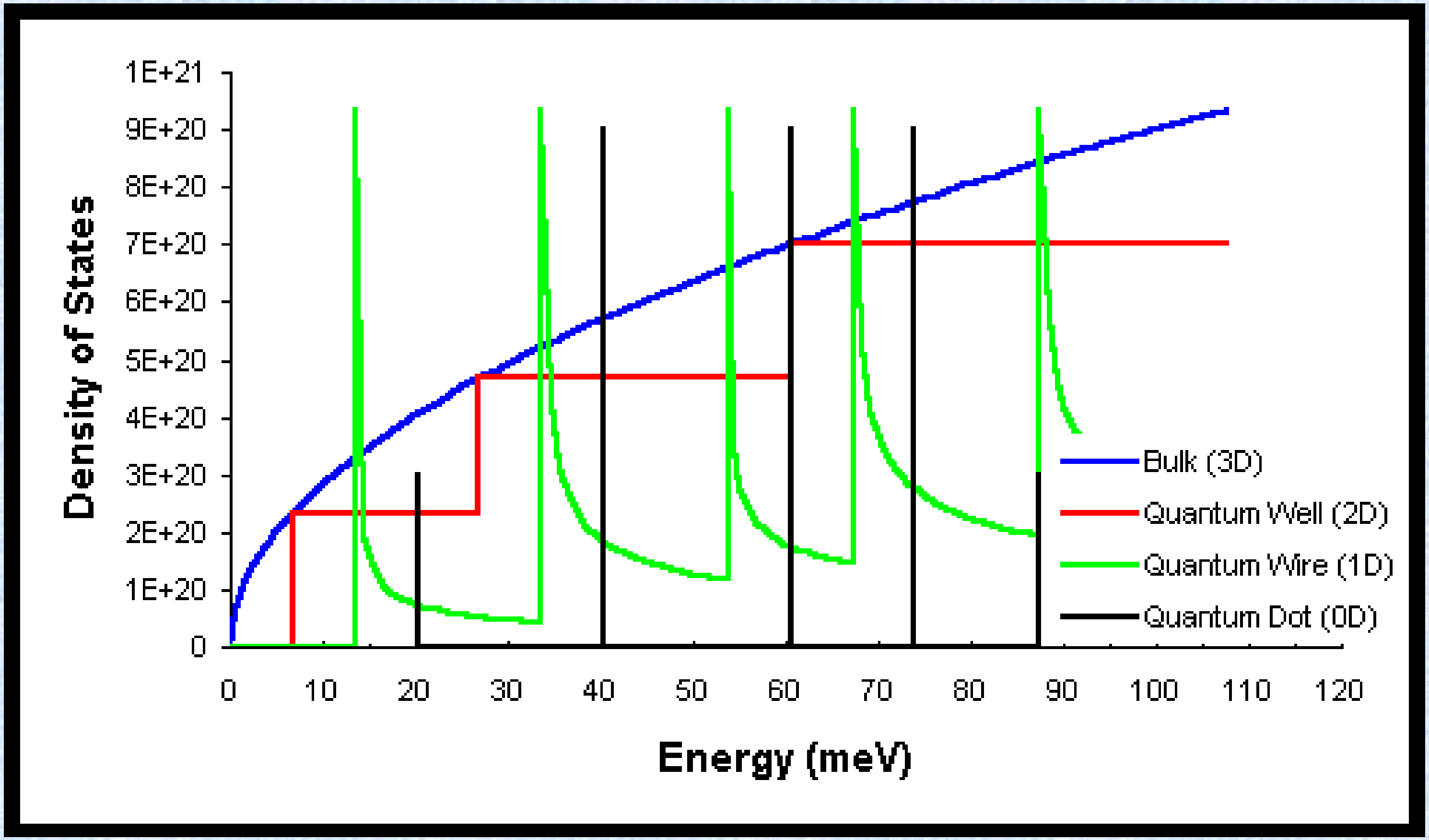
R particle radius

m_e mass of electron

m_h mass of hole

Density of states: bulk, quantum well, wire and dot

$$E = E_C + \frac{\hbar^2 (n_1\pi/a_1)^2}{2m_e} + \frac{\hbar^2 (n_2\pi/a_2)^2}{2m_e} + \frac{\hbar^2 (n_3\pi/a_3)^2}{2m_e}$$



Energy absorption

wide excitation spectra

vs.

narrow emission spectra