Nanostruktury – druty i kropki kwantowe

Struktury niskowymiarowe

Pełen Hamiltonian w naszym wszechświecie ma 3 wymiary przestrzenne $(x, y, z, t) = (\vec{R}, t)$

$$\left[-\frac{\hbar^2}{2m}\nabla^2 + V(\vec{R})\right]\psi(\vec{R}) = E\psi(\vec{R})$$

Dla $V(\vec{R}) = V(z)$ mamy:

$$\left[-\frac{\hbar^2}{2m}\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}\right) + V(z)\right]\psi(x, y, z) = E\psi(x, y, z)$$

Wzdłuż kierunków x i y mamy ruch swobodny:

$$\psi(x, y, z) = \exp(ik_x x)\exp(ik_y y)\,u(z)$$

Można pokazać (przy tablicy!), że ostatecznie energie własne potencjału $V(z)$ są w postaci:

$$\left[-\frac{\hbar^2}{2m}\frac{d^2}{dz^2} + V(z)\right]u(z) = \varepsilon u(z) \qquad \varepsilon = E - \frac{\hbar^2 k_x^2}{2m} - \frac{\hbar^2 k_y^2}{2m}$$

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Struktury niskowymiarowwe

$$\psi_{k_x,k_y,n}(x, y, z) = \exp(ik_x x)\exp(ik_y y)\,u_n(z) = \psi_{\boldsymbol{k},n}(\boldsymbol{r}, z) = \exp(i\boldsymbol{k}\cdot\boldsymbol{r})\,u_n(z)$$

$$E_n(k_x, k_y) = \varepsilon_n + \frac{\hbar^2 k_x^2}{2m} + \frac{\hbar^2 k_y^2}{2m} \qquad E_n(\boldsymbol{k}) = \varepsilon_n + \frac{\hbar^2 \boldsymbol{k}^2}{2m}$$

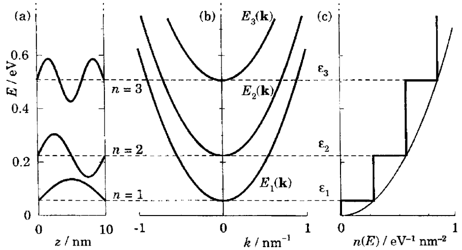


FIGURE 4.7. (a) Potential well with energy levels, (b) total energy including the transverse kinetic energy for each subband, and (c) steplike density of states of a quasi-two-dimensional system. The example is an infinitely deep square well in GaAs of width 10 nm. The thin curve in (c) is the parabolic density of states for unconfined three-dimensional electrons.

Komentarz o paśmie przewodnictwa

W zależności od półprzewodnika dno pasma przewodnictwa może być zbudowane z różnych dolin – ta sama hetereostruktura może być studnią w jednym paśmie (np. Γ) i barierą w innym (np. X)

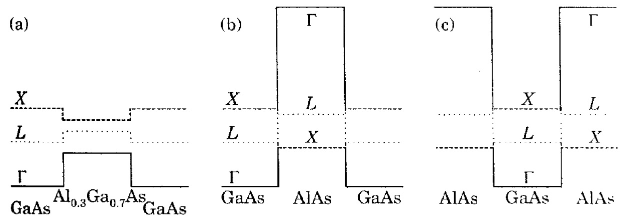


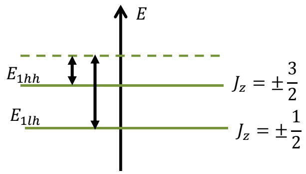
FIGURE 3.8. Barriers and wells in GaAs–$Al_xGa_{1-x}As$, showing the three lowest conduction bands. (a) Barrier of $Al_{0.3}Ga_{0.7}As$, where Γ is the lowest minimum throughout. (b) Barrier of AlAs, where X is the lowest minimum in the barrier. (c) Well of GaAs surrounded by AlAs.

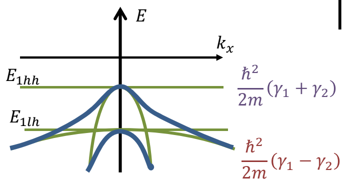
Komentarz o paśmie walencyjnym

Obecność studni zmieni a symetrię kryształu (np. studnia kwantowa na kierunku [001] odpowiada ciśnieniu jednoosiowemu przyłożonemu prostopadle do warstwy). Trzeba rozwiązać równanie $\boldsymbol{kp}$ (Chemla 1983):

$$E_{hh}(\boldsymbol{k}) = -\frac{\hbar^2}{2m}[(\gamma_1+\gamma_2)\boldsymbol{k}_\perp^2 + (\gamma_1 - 2\gamma_2)k_z^2]$$

$$E_{lh}(\boldsymbol{k}) = -\frac{\hbar^2}{2m}[(\gamma_1-\gamma_2)\boldsymbol{k}_\perp^2 + (\gamma_1 + 2\gamma_2)k_z^2]$$



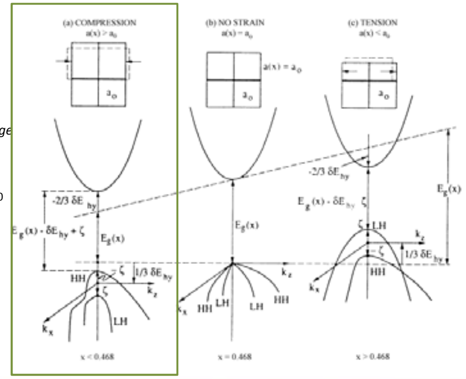


Komentarz o paśmie walencyjnym

Obecność studni zmieni a symetrię kryształu (np. studnia kwantowa na kierunku [001] odpowiada ciśnieniu jednoosiowemu przyłożonemu prostopadle do warstwy). Trzeba rozwiązać równanie $\boldsymbol{kp}$ (Chemla 1983):

Effects of biaxial strain: decrease of the degeneracy of the valence band and change of the effective masses in the $Ga_xIn_{1-x}As$ / $Ga_xIn_{1-x}As_yP_{1-y}$ *material system.*

S.L. Chuang, *Phys. Rev. B* 43, p. 9649 (1991). 9, 10



Potencjał harmoniczny

$$\left[-\frac{\hbar^2}{2m}\frac{d^2}{dz^2} + \frac{1}{2}m\omega_0^2 z^2\right]\psi(z) = E\psi(z) \qquad \varepsilon = \frac{E}{\hbar\omega_0} \qquad \xi = \sqrt{\frac{m\omega_0}{\hbar}}z$$

$$\left(\frac{d}{d\xi} - \xi\right)\left(\frac{d}{d\xi} + \xi\right)\mathrm{A}\,\mathrm{e}^{\frac{\xi^2}{2}} = (-2\varepsilon_0 + 1)\mathrm{A}\,\mathrm{e}^{\frac{\xi^2}{2}} = 0 \qquad \Rightarrow -2\varepsilon_0 + 1 = 0 \;\Rightarrow\; \varepsilon_0 = \frac{1}{2}$$

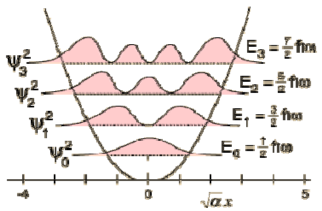
$$\varepsilon_n = n + \frac{1}{2}$$

$$E_n = \hbar\omega_0\left(n + \frac{1}{2}\right)$$

$$\psi_n(z) = A_n H_n\left(\sqrt{\frac{m\omega_0}{\hbar}}z\right)\exp\left(-\frac{m\omega_0}{2\hbar}z^2\right)$$

H_n - wielomiany Hermite'a

$$A_n = \left(2^n n! \sqrt{\frac{\pi\hbar}{m\omega}}\right)^{-1/2}$$



Kropki kwantowe

Struktury niskowymiarowe

$$\psi_{k_x,k_y,n}(x,y,z) = \exp(ik_x x)\exp(ik_y y)\,u_n(z) = \psi_{\boldsymbol{k},n}(\boldsymbol{r},z) = \exp(i\boldsymbol{k}\cdot\boldsymbol{r})\,u_n(z)$$

$$E_n(k_x,k_y) = \varepsilon_n + \frac{\hbar^2 k_x^2}{2m} + \frac{\hbar^2 k_y^2}{2m} \qquad E_n(\boldsymbol{k}) = \varepsilon_n + \frac{\hbar^2 \boldsymbol{k}^2}{2m}$$

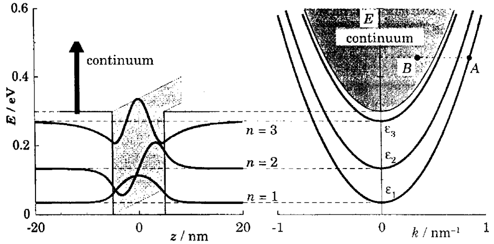
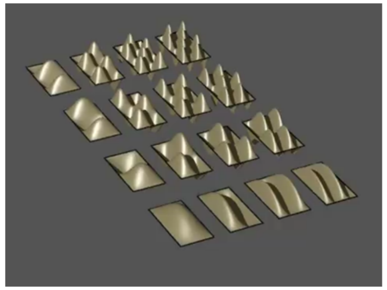


FIGURE 4.9. Quasi-two-dimensional system in a potential well of finite depth. Electrons with the same total energy can be bound in the well (A) or free (B).

Cząstki A i B mają tę samą energię!

Studnie 2D i 3D

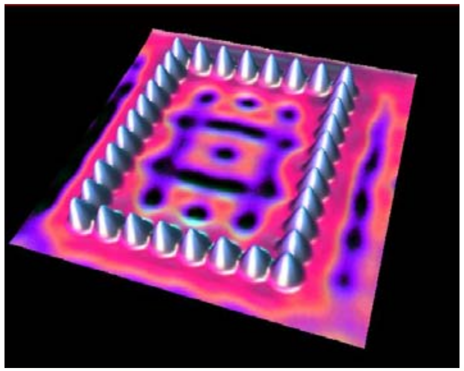
Drut prostokątny ($a \times b$)– rozwiązania typu: $\varepsilon_{n_x,n_y} = \frac{\hbar^2\pi^2}{2m}\left(\frac{n_x^2}{a^2} + \frac{n_y^2}{b^2}\right)$



http://wn.com/2d_and_3d_standing_wave

Studnie 2D i 3D

Drut prostokątny ($a \times b$)– rozwiązania typu: $\varepsilon_{n_x,n_y} = \frac{\hbar^2\pi^2}{2m}\left(\frac{n_x^2}{a^2} + \frac{n_y^2}{b^2}\right)$



http://www.almaden.ibm.com/vis/stm/images/stm14.jpg

Studnie 2D i 3D

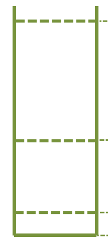
Studnia cylindryczna (o nieskończonych ścianach)

$$-\frac{\hbar^2}{2m}\left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r} + \frac{1}{r^2}\frac{\partial^2}{\partial\theta^2} + V_0\right)\psi(r,\theta) = E\psi(r,\theta)$$

$$\psi(r,\theta) = u(r)\exp(il\theta)$$

głębokość potencjału zależy od l^2

$$\left[-\frac{\hbar^2}{2m}\left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r}\right) + \frac{\hbar^2 l^2}{2mr^2} + V_0\right]u(r) = Eu(r)$$



Co daje rozwiązania w postaci f. Bessla

$$r^2\frac{d^2u}{dr^2} + r\frac{du}{dr} + [(kr)^2 - l^2]u = 0 \qquad J_l(kr) \sim \sqrt{\frac{2}{\pi kr}}\cos\left(kr - \frac{1}{2}l\pi - \frac{1}{4}\pi\right)$$

$$k = \sqrt{2m(E - V_0)}/\hbar$$

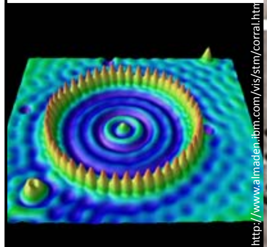
$$\phi_{nl}(r) \propto J_l\left(\frac{j_{l,n}r}{a}\right)\exp(il\theta) \qquad \varepsilon_{nl} = \frac{\hbar^2 j_{l,n}^2}{2ma}$$

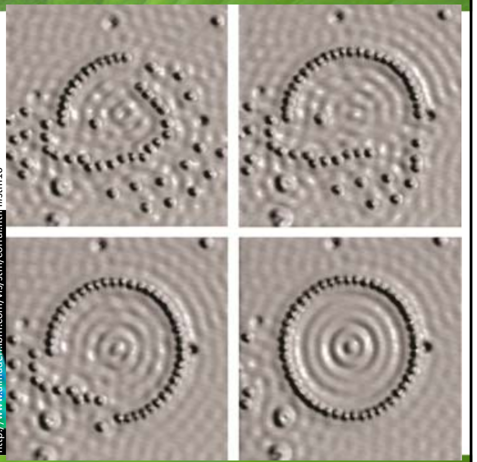
Miejsca zerowe f. Bessela są w $j_{l,n}$

Studnie 2D i 3D

Studnia Cylindryczna

low temperature scanning tunneling microscope (STM)



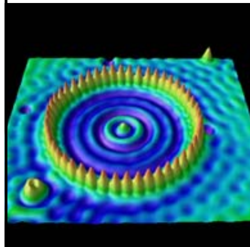


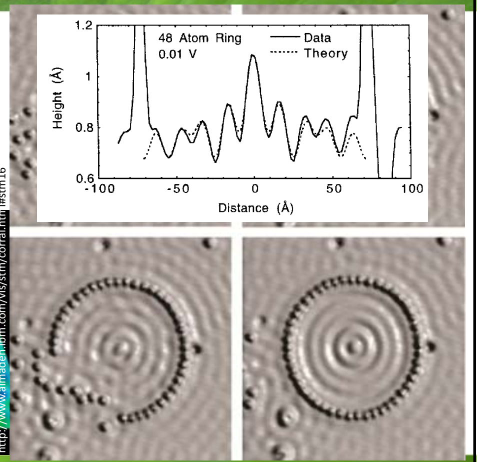
http://www.almaden.ibm.com/vis/stm/corral.html#stm16

Studnie 2D i 3D

Studnia Cylindryczna

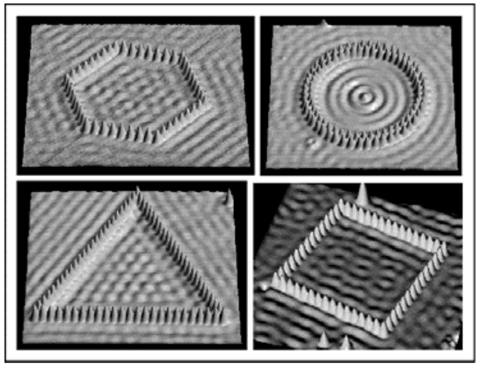
low temperature scanning tunneling microscope (STM)





http://www.almaden.ibm.com/vis/stm/corral.html#stm16

Studnie 2D i 3D



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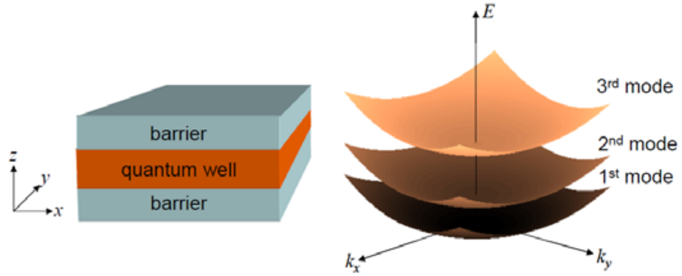
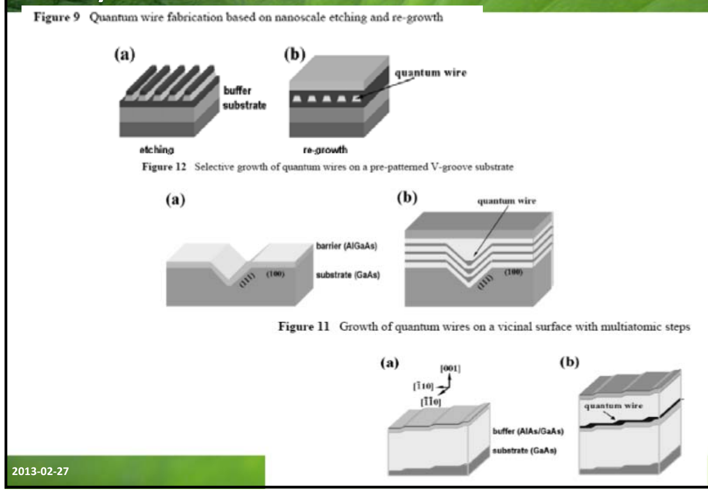
Studnie 2D i 3D

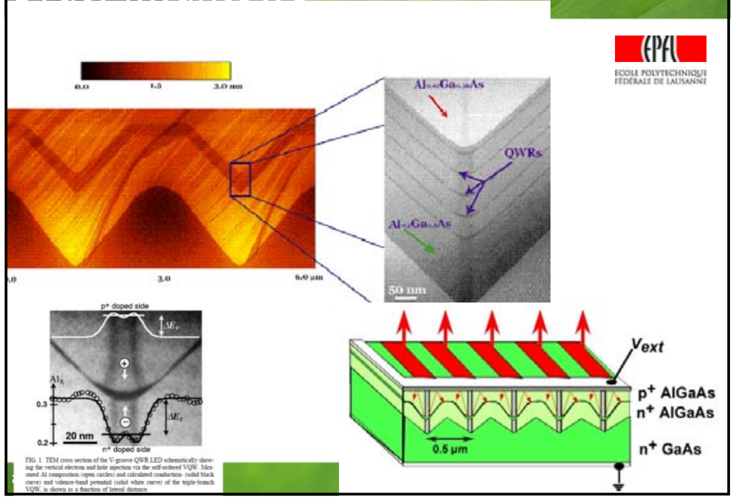


Marc Baldo MIT OpenCourseWare Publication May 2011

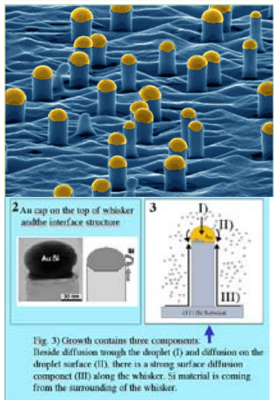
Druty kwantowe



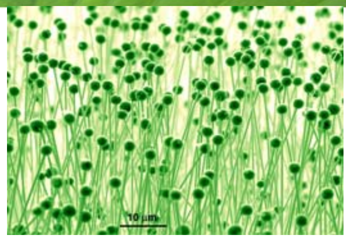
Druty kwantowe



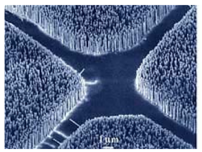
Druty kwantowe



http://www.mpi-halle.mpg.de/~mbe/



www.ece.odu.edu/g_seminar.htm



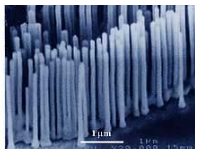
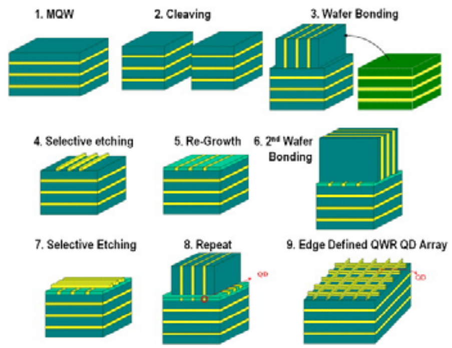


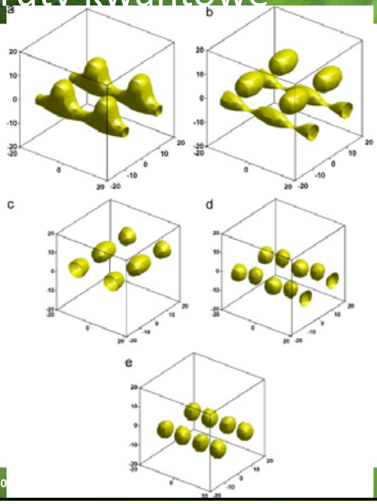
Photo by Peidong Yang/UC Berkeley, courtesy of *Science*

Druty kwantowe



Microelectronics Journal 39, 2008, 369–374

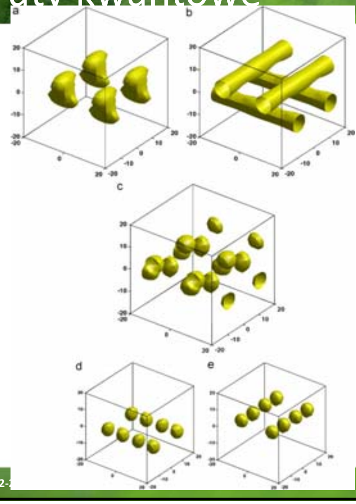
Druty kwantowe



Miniband properties of superlattice quantum dot arrays fabricated by the edge-defined nanowires

Microelectronics Journal 39, 2008, 369–374

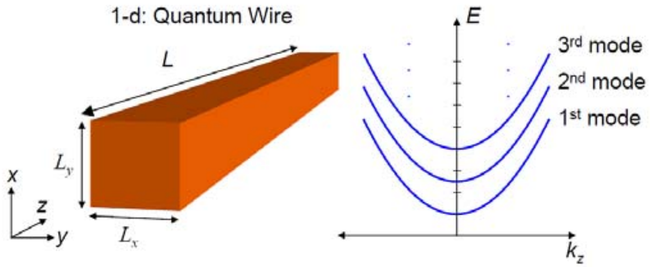
Druty kwantowe



Miniband properties of superlattice quantum dot arrays fabricated by the edge-defined nanowires

Microelectronics Journal 39, 2008, 369–374

Druty kwantowe



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Druty kwantowe

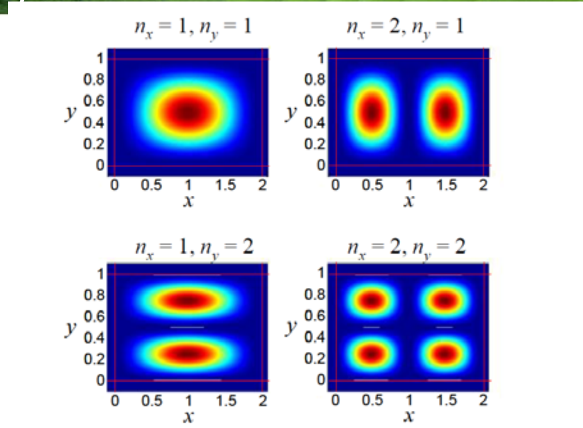

Fig. 2.13. The first four modes of the quantum wire. Since in this example, $L_x > L_y$ the $n_x = 2$, $n_y = 1$ mode has lower energy than the $n_x = 1$, $n_y = 2$ mode.

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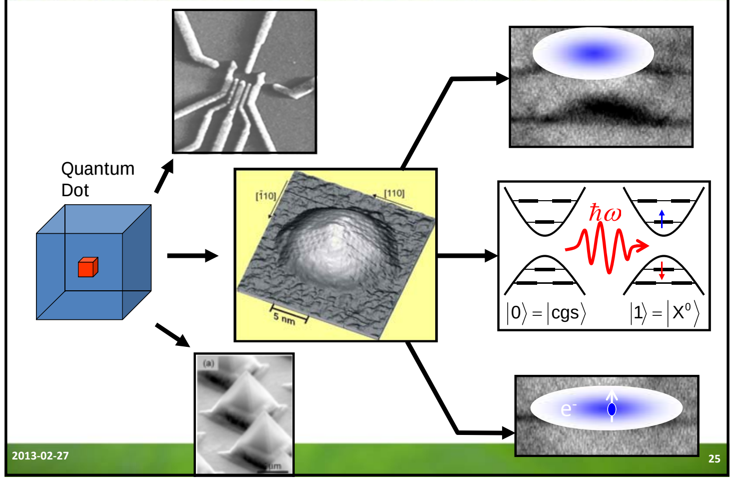
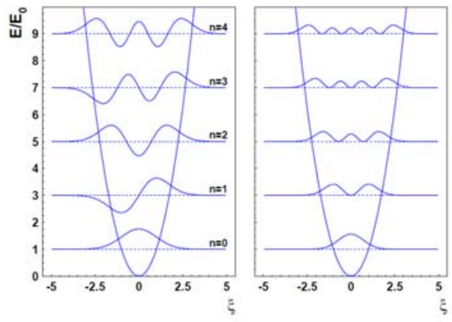
Kropki kwantowe



Potencjał harmoniczny

$$\left[-\frac{\hbar^2}{2m}\frac{d^2}{dx^2}+\frac{1}{2}m\omega_0^2x^2\right]\psi(x)=E\psi(x)$$

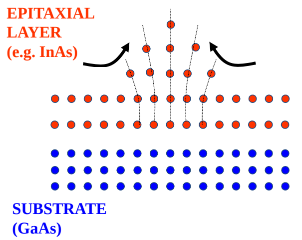
$$E_n=\hbar\omega_0\left(n+\frac{1}{2}\right)$$

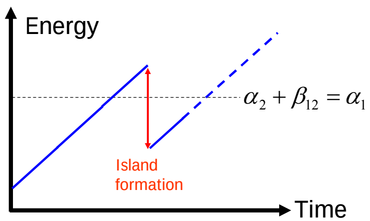


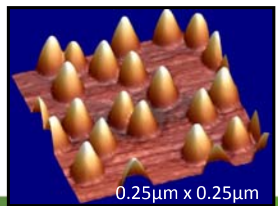
http://phoebe.ifj.edu.pl/wyklady/mk.pdf

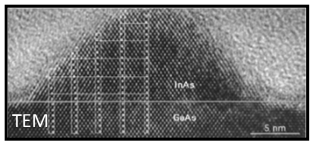
Rysunek 10.3: Funkcje własne i gęstości prawdopodobieństwa oscylatora harmonicznego.

Potencjał harmoniczny



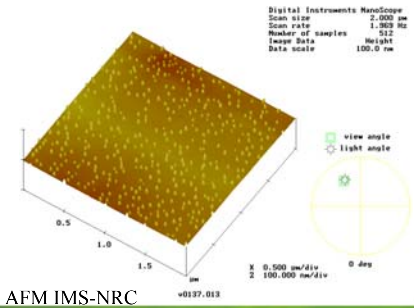




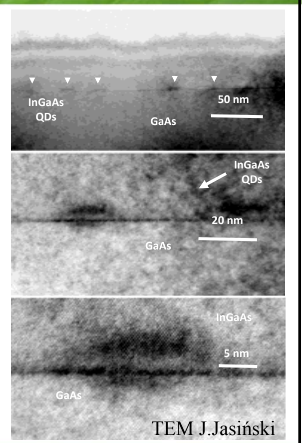


- Defect-free semiconductor “clusters“ on a 2D quantum well wetting layer

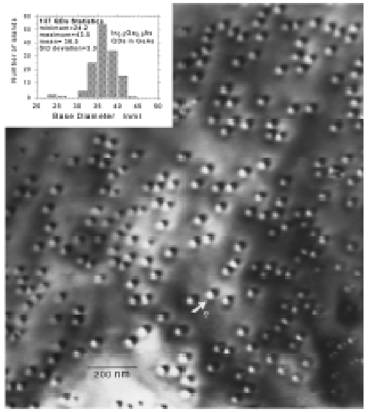
Potencjał harmoniczny 2D



AFM IMS-NRC



Potencjał harmoniczny 2D



Kropki kwantowe InGaAs/GaAs

S.Raymond et al *Phys. Rev. B* **54**; 11548 (1995)

Potencjał harmoniczny 2D

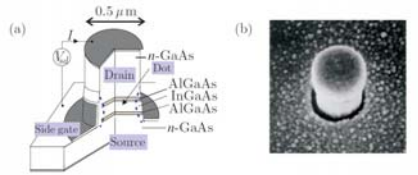


Figure 1.4: (a) Schematic diagram of a semiconductor heterostructure. The dot is located between the two AlGaAs tunnel barriers. A negative voltage applied to the side gate squeezes the dot thus reducing the effective diameter of the dot (dashed curves). (b) Scanning electron micrographs of a circular quantum dot pillar. The pillar has width of about 0.5 μm. After Kouwenhoven *et al.* [2001].

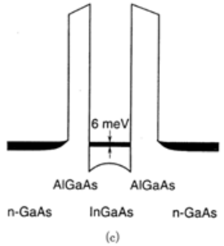


Fig. 1. (a) Schematic diagram of the gated DBH. (b) Scanning electron micrograph image of a typical section of part of a wire test mesa. There is no short between the metal on the top (A), and the gate metal on the etched surface (B). The two white parallel markers show the position of the DBH. (c) One-dimensional self-consistent band diagram calculated for the DBH with no lateral confinement.

Jpn. J. Appl. Phys. Vol. 36 (1997) pp. 3917–3923
Part 1, No. 6B, June 1997

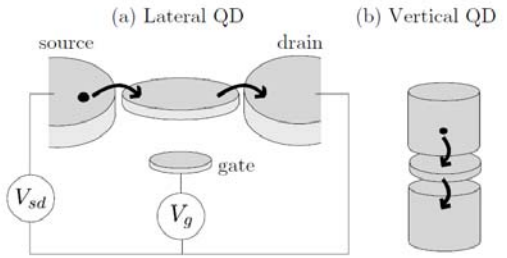


Figure 1.5: Electron flow in planar (a) and vertical (b) QD setup.

Potencjał harmoniczny 2D

$$E_n^x = \hbar\omega_0\left(n_x + \frac{1}{2}\right)$$ w kierunku x i taka sama w y

$$E_n^y = \hbar\omega_0\left(n_y + \frac{1}{2}\right)$$

$$E_n = E_n^x + E_n^y = \hbar\omega_0(N+1)$$

Degeneracja? $N = n_x + n_y$

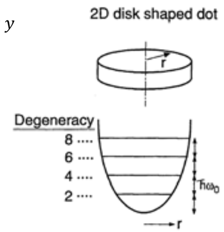


Fig. 5. Schematic model for the vertical dot with a harmonic lateral potential. The single-particle states are laterally confined into discrete equidistant 0D levels whose degeneracies are 2, 4, 6, 8, ··· including spin degeneracy from the lowest level.

Jpn. J. Appl. Phys. Vol. 36 (1997) pp. 3917–3923
Part 1, No. 6B, June 1997

Potencjał harmoniczny 2D

$E_n^x = \hbar\omega_0\left(n_x + \frac{1}{2}\right)$ w kierunku x i taka sama w y

$E_n^y = \hbar\omega_0\left(n_y + \frac{1}{2}\right)$

$E_n = E_n^x + E_n^y = \hbar\omega_0(N+1)$

Degeneracja? $N = n_x + n_y$

$g_N = N + 1$

N	(n_x, n_y)
0	(0,0)
1	(1,0) (0,1)
2	(2,0) (1,1) (0,2)
3	(3,0) (2,1) (1,2) (0,3)

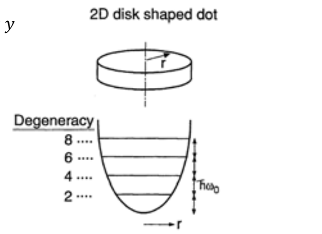
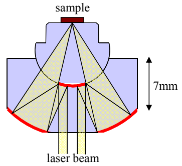
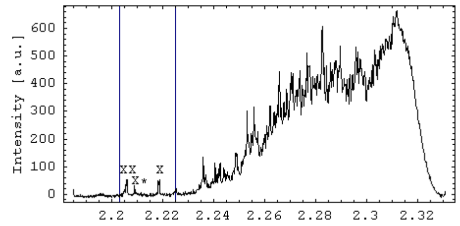


Fig. 5. Schematic model for the vertical dot with a harmonic lateral potential. The single-particle states are laterally confined into discrete equidistant 0D levels whose degeneracies are 2, 4, 6, 8, ··· including spin degeneracy from the lowest level.

Jpn. J. Appl. Phys. Vol. 36 (1997) pp. 3917-3923 Part 1, No. 6B, June 1997

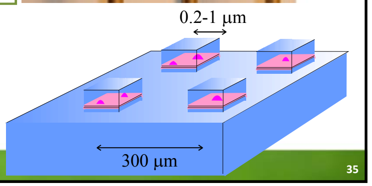
Spektroskopia kropek kwantowych





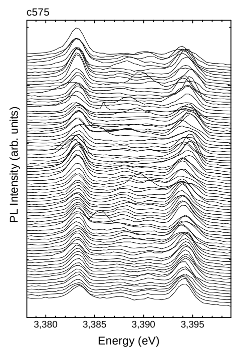
Spektroskopia kropek kwantowych

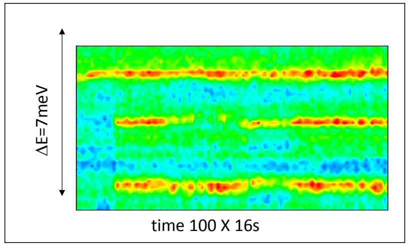
T=300K
Minimum step~50 nm
Maximum step ~1 µm
T=4.2K
Minimum step~5 nm
Maximum step ~100 nm



A.Babinski, et al. Physica E 26 (2005) 190

Spektroskopia kropek kwantowych

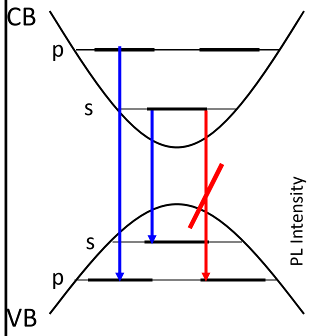




FUW
Hoża 69

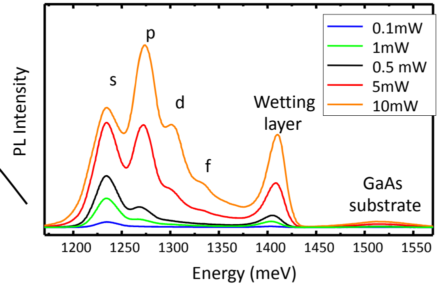
μPL- Katarzyna Surowiecka et al.

Potencjał harmoniczny 2D



Harmonic oscillator model:

- s-, p-, d-,… shells
- Allowed interband transition

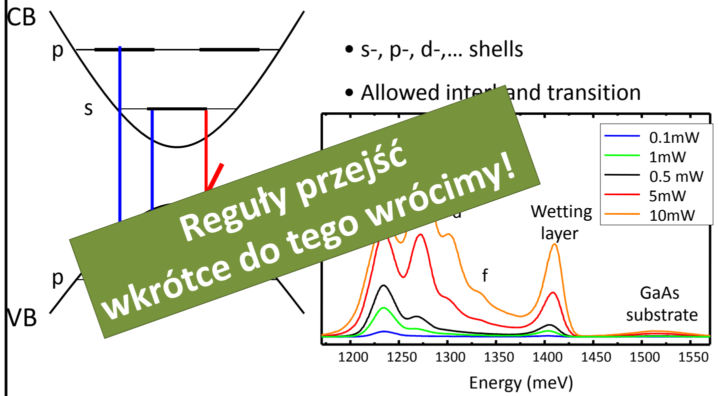


2013-02-27 37

Potencjał harmoniczny 2D

Harmonic oscillator model:

- s-, p-, d-,… shells
- Allowed interband transition



2013-02-27 38

Potencjał harmoniczny 2D

Szkic dowodu

Funkcja Blocha nośnika w krysztale::

$$\Psi(\vec{r}) = \sum_{n,k} c_{n,k} u_{n,k}(\vec{r}) e^{i\vec{k}\vec{r}}$$

Dla elektronu:

$$\Psi_c(\vec{r}) \approx \sum_{k} c_{1,k} u_{\Gamma_6,0}(\vec{r}) e^{i\vec{k}\vec{r}} = u_{\Gamma_6,0}(\vec{r}) F_e(\vec{r})$$

Dla dziury:

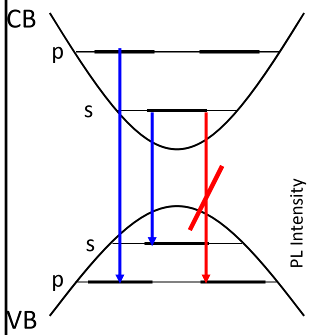
$$\Psi_v(\vec{r}) \approx \sum_{J_z=\pm 3/2,\pm 1/2,k} c_{J_z,k} u_{\Gamma_8,J_z}(\vec{r}) e^{i\vec{k}\vec{r}} = \sum_{J_z=\pm 3/2,\pm 1/2,k} u_{\Gamma_8,J_z}(\vec{r}) F_{J_z}(\vec{r})$$

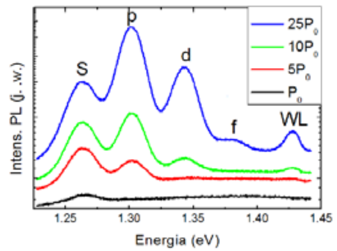
Dipolowe przejścia optyczne międzypasmowe:

$$\langle \Psi_c(\vec{r}) | \vec{p} | \Psi_{v,J_z}(\vec{r}) \rangle = \underbrace{\langle u_{\Gamma_6,0}(\vec{r}) | u_{\Gamma_8,J_z}(\vec{r}) \rangle}_{=0} \langle F_e(\vec{r}) | \vec{p} | F_{J_z}(\vec{r}) \rangle + \langle u_{\Gamma_6,0}(\vec{r}) | \vec{p} | u_{\Gamma_8,J_z}(\vec{r}) \rangle \langle F_e(\vec{r}) | F_{J_z}(\vec{r}) \rangle$$

2013-02-27 39

Potencjał harmoniczny 2D

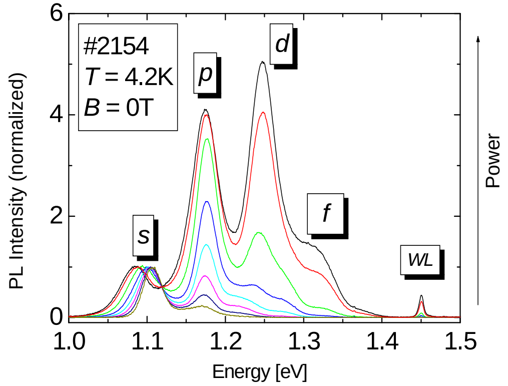




Zależność od mocy pobudzania widm fotoluminescencji otrzymanych w temperaturze bliskiej temperatury ciekłego helu (ok. 5 K) dla licznego (wielomilionowego) zbioru kropek kwantowych InAs/GaAs.

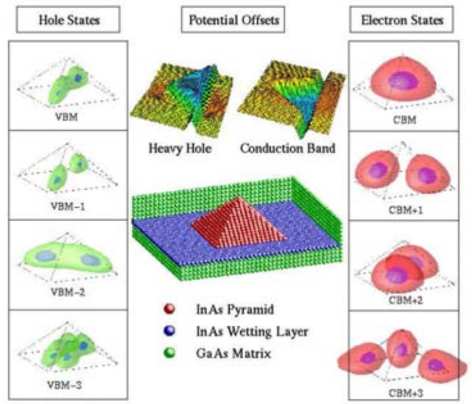
2013-02-27 40

Potencjał harmoniczny 2D



Adam Babiński

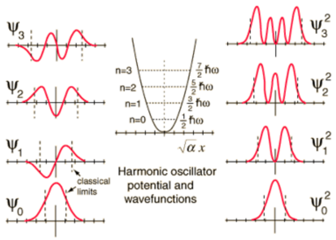
Potencjał harmoniczny 2D

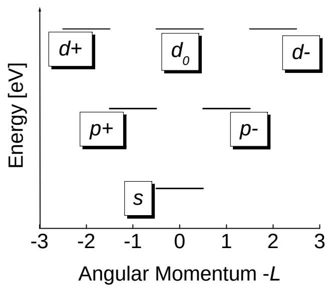


The electronic structure of a strained InAs (110) pyramidal quantum dot embedded within GaAs. The strain-modified band offsets are shown above the atomic structure. They exhibit a well for both heavy holes and electrons. Isosurface plots of the four highest hole states and four lowest electron states, as obtained from pseudopotential calculations, appear on the left and right. CBM means conduction band minimum and VBM valence band minimum

MRS Bulletin Vol. 23 No. 2, p. 35 (1998).

Potencjał harmoniczny 2D

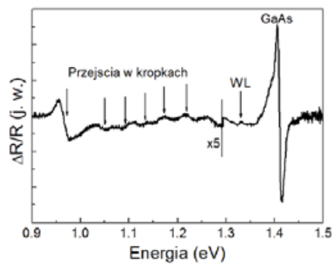




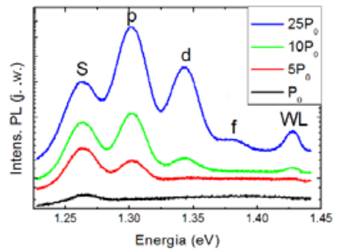
$n, m = 0,1,2...$
$L = n - m$ (elektron)

Adam Babiński

Potencjał harmoniczny 2D



Widmo fotoodbicia z temperatury pokojowej dla struktury z kropkami kwantowymi In-As/GaAs [W. Rudno-Rudziński, et al. Solid State Commun. 135, 232 (2005)]



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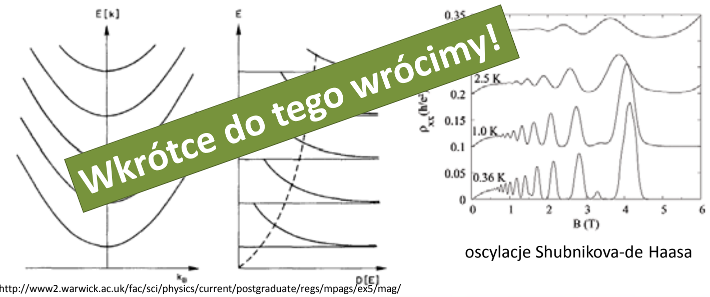
Potencjał harmoniczny 2D

$$\left[-\frac{\hbar^2}{2m}\frac{d^2}{dx^2}+\frac{1}{2}m\omega_0^2x^2\right]\psi(x)=E\psi(x) \qquad \omega_0=\omega_c=\frac{eB}{m^*}$$

Ważny przykład – cząstka w polu magnetycznym. Częstość cyklotronowa ω_c



oscylacje Shubnikova-de Haasa

http://www2.warwick.ac.uk/fac/sci/physics/current/postgraduate/regs/mpags/ex5/mag/

Potencjał harmoniczny 3D

$E_n^x=\hbar\omega_0\left(n_x+\frac{1}{2}\right)$ w kierunku x, y i z

$$E_n=E_n^x+E_n^y+E_n^z=\hbar\omega_0\left(N+\frac{3}{2}\right)$$

Degeneracja? $N=n_x+n_y+n_z$

$$g_N=\frac{(N+1)(N+2)}{2}$$

N	(n_x, n_y, n_z)
0	(0,0,0)
1	(1,0,0) (0,1,0) (0,0,1)
2	(2,0,0) (0,2,0) (0,0,2) (1,1,0) (1,0,1) (0,1,1)
3	3x(3,0,0) 1x(1,1,1) 6x(2,0,1)

Sferyczne kropki kwantowe

Przerwa energetyczna w sferycznych kropkach kwantowych [Brus, L. E. J. Phys. Chem. 1986, **90**, 2555, Brus. L. E. J. Chem. Phys. 1984, **80**, 4403]

$$E_g^*(R)=E_g^{bulk}+\frac{\hbar^2\pi^2}{2R^2m_0}\left(\frac{1}{m_e}+\frac{1}{m_h}\right)-\frac{1.8e^2}{4\pi\varepsilon\varepsilon_0R}$$

R – średnica

Lokalizacja kwantowa (quantum localization): mniejsza cząstka – więcej wektorów k potrzebnych do opisu stanu nośnika. Czyli cząstka w studni! ZWIĘKSZA energie przerwy

Część kulombowska oddz. $e-h$ z uwzględnieniem polaryzacji (sfera) OBNIŻA energię. Potencjał obliczony dla funkcji w postaci $\Psi_n(r)$ $(n=1)$:

$$\varepsilon_n=\frac{\hbar^2k_n^2}{2m}=\frac{\hbar^2n^2\pi^2}{2mL^2} \qquad \Psi_n(r)=\frac{C_n}{r}\sin\left(\frac{n\pi r}{R}\right)$$

Sferyczne kropki kwantowe

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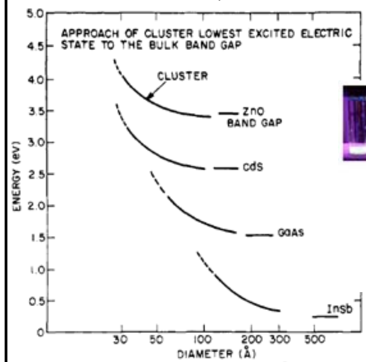
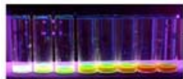
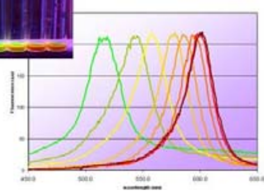


Figure 5. Calculated energy of the cluster lowest excited electronic state in relation to the bulk band gap. Adapted from ref 31.





http://www.sussex.ac.uk/Users/kaf18/QDSpectra.jpg

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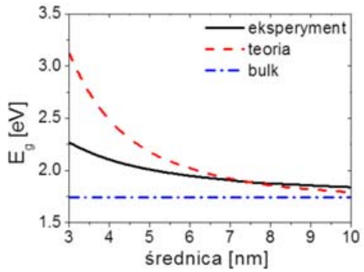
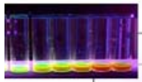
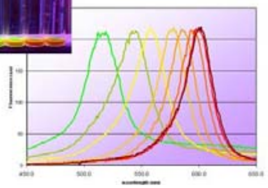


Przerwa energetyczna CdSe





http://www.sussex.ac.uk/Users/kaf18/QDSpectra.jpg

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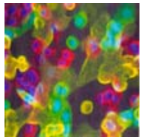
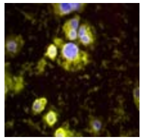
Sferyczne kropki kwantowe

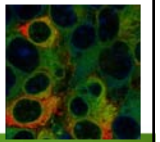
Sferyczne kropki kwantowe

http://www.medicine.tcd.ie/molecular-medicine/gallery/pictures/scientific-pictures.php

Synthesis Techniques
- Vapor phase (molecular beams, flame synthesis etc…
- Solution phase synthesis
- Aqueous Solution
- Nonaqueous Solution
- Typically the rapid reduction of organmetallic precusors in hot organics with surfactants







Semiconductor Nanoparticles

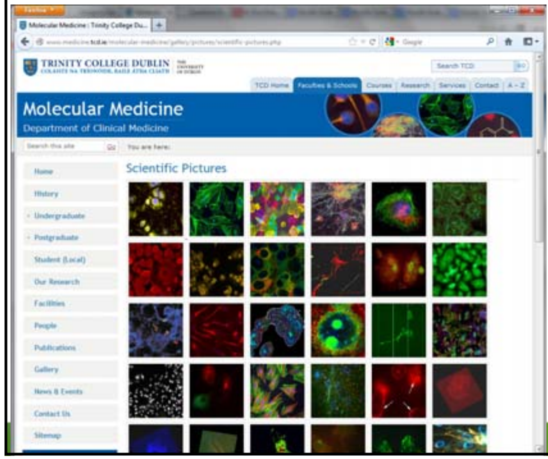
II-VI: CdS, CdSe, PbS, ZnS

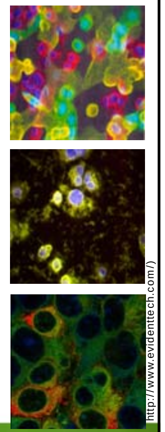
III-V: InP, InAs

MO: TiO_2, ZnO, Fe_2O_3, PbO, Y_2O_3

Sferyczne kropki kwantowe

http://www.medicine.tcd.ie/molecular-medicine/gallery/pictures/scientific-pictures.php

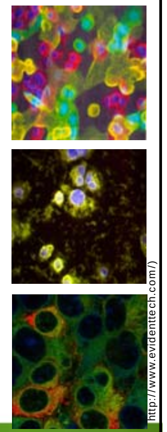




http://www.evidentiech.com/)

Sferyczne kropki kwantowe

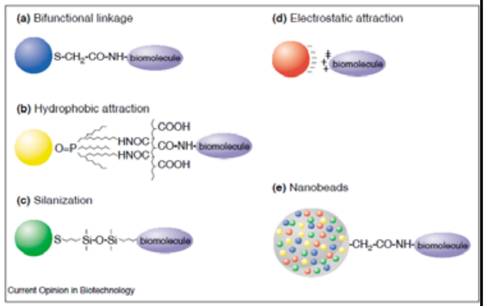
http://www.microscopyu.com/articles/fluorescence/index.html



http://www.evidentiech.com/)

Sferyczne kropki kwantowe

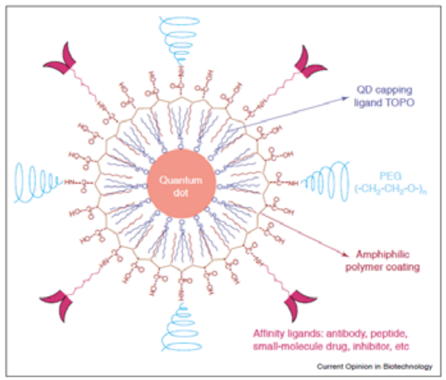
Schematic illustration of bioconjugation methods. **(a)** Use of a bifunctional ligand such as mercaptoacetic acid for linking QDs to biomolecules [8••]. **(b)** TOPO-capped QDs bound to a modified acrylic acid polymer by hydrophobic forces. **(c)** QD solubilization and bioconjugation using a mercaptosilane compound [7••]. **(d)** Positively charged biomolecules are linked to negatively charged QDs by electrostatic attraction [9]. **(e)** Incorporation of QDs in microbeads and nanobeads [20••].



Luminescent quantum dots for multiplexed biological detection and imaging
W. Chan et al. Current Opinion in Biotechnology 2002, 13:40–46

Sferyczne kropki kwantowe

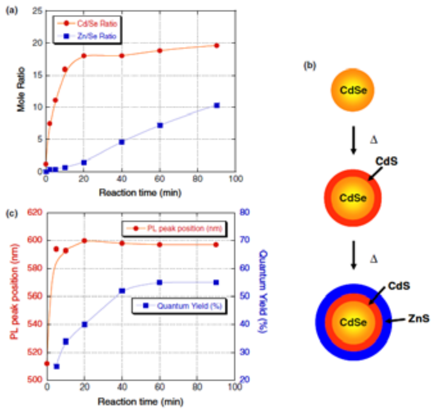
In vivo molecular and cellular imaging with quantum dots Xiaohu Gao Current Opinion in Biotechnology 2005, 16:63–72



The structure of a multifunctional QD probe. Schematic illustration showing the capping ligand TOPO, an encapsulating copolymer layer, tumor-targeting ligands (such as peptides, antibodies or small-molecule inhibitors), and polyethylene glycol (PEG).

Sferyczne kropki kwantowe

Synthesis of multi-shell nanocrystals by a single step coating process, Nanotechnology 2006



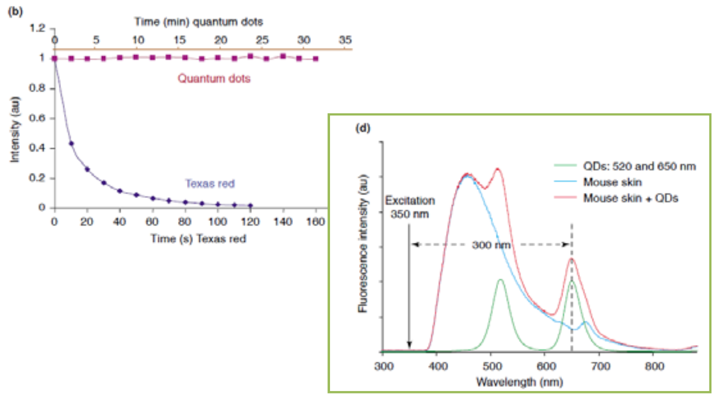
Quantum Yield = wydajność kwantowa

Wydajność kwantową fluorescencji definiuje się jako stosunek liczby wyemitowanych fotonów do liczby fotonów promieniowania wzbudzającego, pochłoniętych przez substancję w tym samym czasie i tej samej objętości.

Figure 1. (a) Elemental ratios of Cd to Se and Zn to Se (measured by ICP), (b) a conceptual drawing of the CdSe core → CdSe/CdS core/shell → CdSe/CdS/ZnS core/multi-shell structure, and (c) PL peak positions, and QYs of CdSe/CdS/ZnS nanocrystals taken at different time intervals during the reaction.

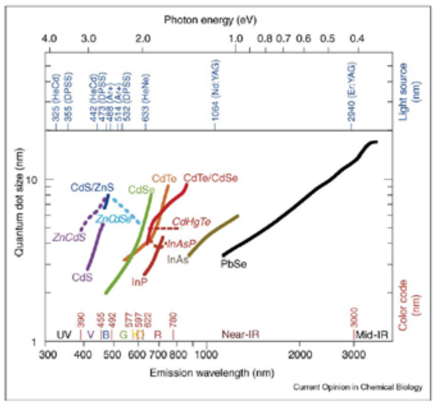
Sferyczne kropki kwantowe

In vivo molecular and cellular imaging with quantum dots Xiaohu Gao Current Opinion in Biotechnology 2005, 16:63–72



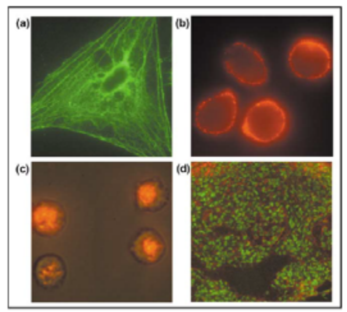
Sferyczne kropki kwantowe

Current Opinion in Chemical Biology 2006, 10:423–429 *Nanoscale controlled self-assembled monolayers and quantum dots*



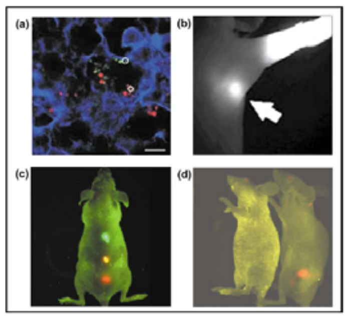
Sferyczne kropki kwantowe

Figure 4



Fluorescence micrographs of QD-stained cells and tissues. **(a)** Actin staining (green QDs) on fixed 3T3 fibroblast cells. **(b)** Live MDA-MB-231 breast tumor cells labeled with a red QD-antibody conjugate targeting the urokinase plasminogen receptor. **(c)** Intracellular labeling of live mammalian cells using QD-Tat peptide conjugates [25**]. **(d)** Frozen tissue specimens stained with QDs (targeting the CXCR4 receptor, red) and a nuclear dye (green).

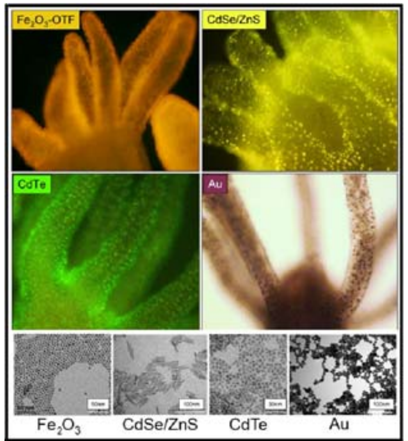
Figure 5



In vivo targeting and imaging with QDs. **(a)** *Ex vivo* tissue examination of QD-labeled cancer cells trapped in a mouse lung [44*]. **(b)** Near-infrared fluorescence of water-soluble type II QDs taken up by sentinel lymph nodes [49**]. **(c)** *In vivo* simultaneous imaging of multicolor QD-encoded microbeads injected into a live mouse [25**]. **(d)** Molecular targeting and *in vivo* imaging of a prostate tumor in mouse using a QD-antibody conjugate (red) [25**].

In vivo molecular and cellular imaging with quantum dots
Xiaohu Gao Current Opinion in Biotechnology 2005, 16:63–72

Sferyczne kropki kwantowe



An Ancient Model Organism to Test In Vivo Novel Functional Nanocrystals

By Claudia Tortiglione

"Biomedical Engineering - From Theory to Applications", Edited by Reza Fazel-Rezai,

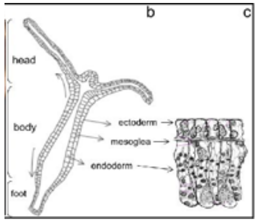
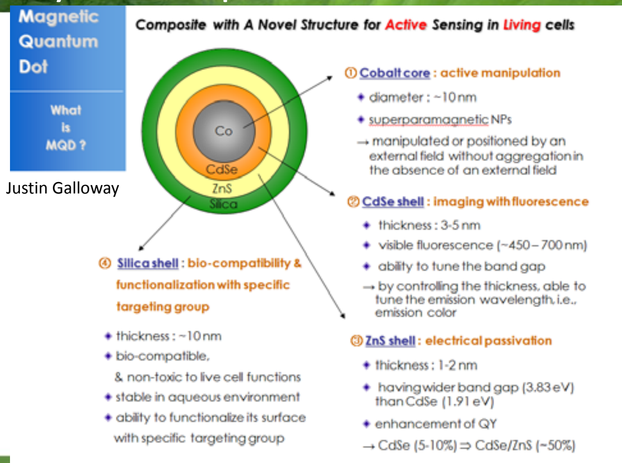


Figure 1.
Anatomical structure of *Hydra vulgaris*

Figure 18.
Labelling Hydra with nanocrystals

http://www.intechopen.com/books/biomedical-engineering-from-theory-to-applications/an-ancient-model-organism-to-test-in-vivo-novel-functional-nanocrystals

Sferyczne kropki kwantowe



Justin Galloway

Sferyczne kropki kwantowe w biol-med

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