



Optyka nanostruktur

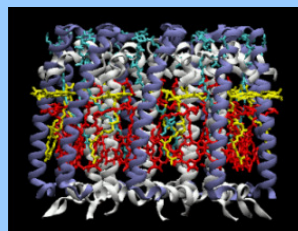
Sebastian Maćkowski

Instytut Fizyki

Uniwersytet Mikołaja Kopernika

Adres poczty elektronicznej: mackowski@fizyka.umk.pl

Biuro: 365, telefon: 611-3250



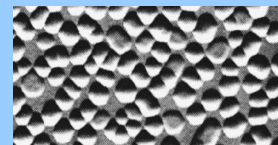
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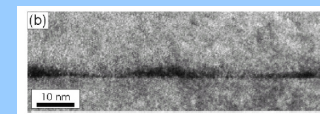
Kropki samorosnące

self-assembled, self-organized quantum dots

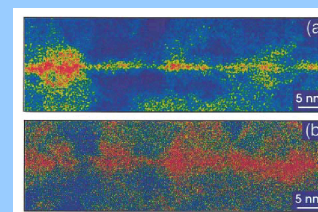
InAs/GaAs QDs



Si/Ge QDs



CdSe/ZnSe QDs



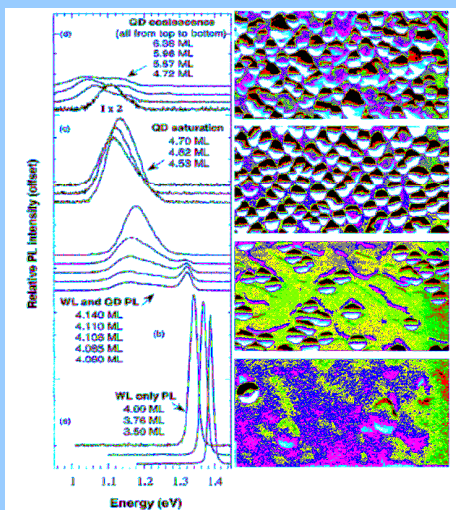
CdTe/ZnTe QDs



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Kropki III-V



brak emisji z WL
słaba intensywność emisji
z kropek kwantowych

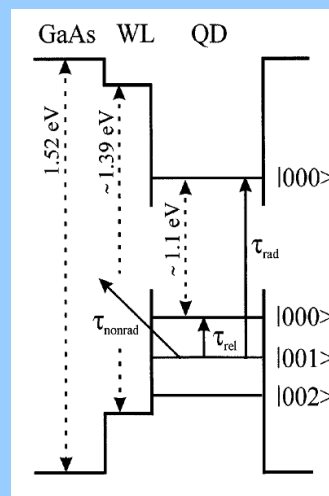
dwie linie:
WL – stała energia, wąska linia
QDs – zmienna energia, szeroka linia

energia przesunęła się ze
wzrostem grubości warstwy
InGaAs

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Struktura pasmowa



WL – dwuwymiarowa studnia
kwantowa o energii **wyższej** niż
energii kropek, fizycznie łączy
wszystkie kropki w strukturze

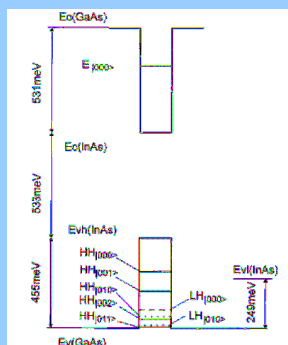
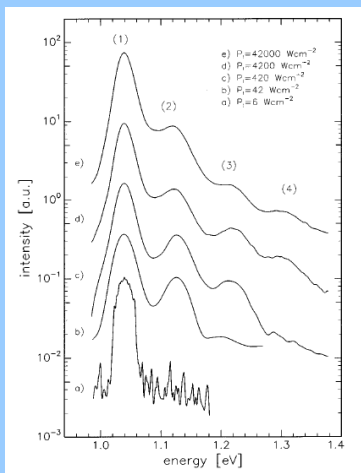
linia emisyjna dla pobudzenia
nie rezonansowego związana
z poszerzeniem niejednorodnym
w zespole kropek kwantowych

- rozmiar
- kształt
- skład chemiczny

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Stany wzbudzone



Calculated PL energy	Optical transition	Experimental PL maximum
1.04 eV	$E_{ 000\rangle} - \text{HH}_{ 000\rangle}$	1.036 eV
1.14 eV	$E_{ 000\rangle} - \text{HH}_{ 001\rangle}$	1.123 eV
1.23 eV	$E_{ 000\rangle} - \text{LH}_{ 000\rangle}$	1.216 eV
1.28 eV	$E_{ 000\rangle} - \text{HH}_{ 002\rangle}$	
1.32 eV	$E_{ 000\rangle} - \text{HH}_{ 011\rangle}$	1.302 eV

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Spektroskopia ansamblu

PHYSICAL REVIEW B

VOLUME 56, NUMBER 16

15 OCTOBER 1997-II

Energy relaxation by multiphonon processes in InAs/GaAs quantum dots

R. Heitz, M. Vent, N. N. Ledentsov, A. Hoffmann, and D. Bimberg
Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany

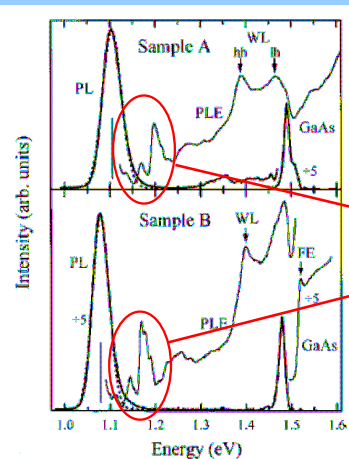
V. M. Ustinov, P. S. Kop'ev, and Zh. I. Alferov
A. F. Joffe Physical-Technical Institute, 194021, St. Petersburg, Russia
(Received 10 January 1997)

Carrier relaxation and recombination in self-organized InAs/GaAs quantum dots (QD's) is investigated by photoluminescence (PL), PL excitation (PLE), and time-resolved PL spectroscopy. We demonstrate inelastic phonon scattering to be the dominant intradot carrier-relaxation mechanism. Multiphonon processes involving up to four LO phonons from either the InAs QD's, the InAs wetting layer, or the GaAs barrier are resolved. The observation of multiphonon resonances in the PLE spectra of the QD's is discussed in analogy to hot exciton relaxation in higher-dimensional semiconductor systems and proposed to be intricately bound to the inhomogeneity of the QD ensemble in conjunction with a competing nonradiative recombination channel observed for the excited hole states. Carrier capture is found to be a cascade process with the initial capture into excited states taking less than a few picoseconds and the multiphonon (involving three LO phonons) relaxation time of the first excited hole state being 40 ps. The $|001\rangle$ hole state presents a relaxation bottleneck that determines the ground-state population time after nonresonant excitation. For the small self-organized InAs/GaAs QD's the intradot carrier relaxation is shown to be faster than radiative (>1 ns) and nonradiative (~ 100 ps) recombination explaining the absence of a "phonon bottleneck" effect in the PL spectra. [S0163-1829(97)09340-5]

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Wzbudzenia kropek



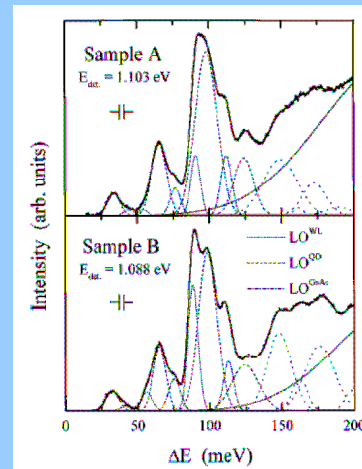
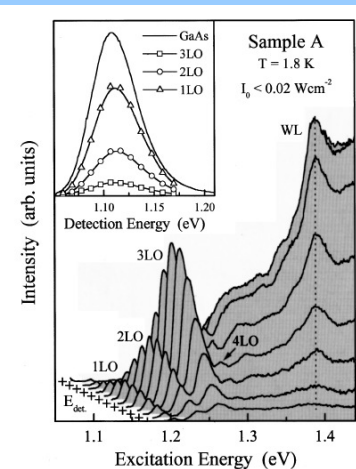
obecność matrycy GaAs, warstwy zwilżającej InAs OK

co to jest ???

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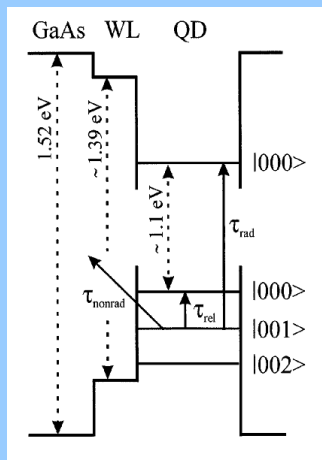
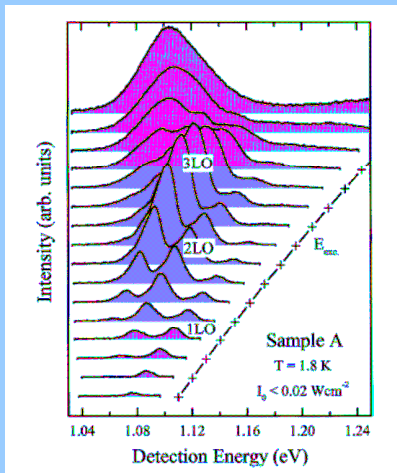
Widmo wzbudzenia



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Widmo emisji



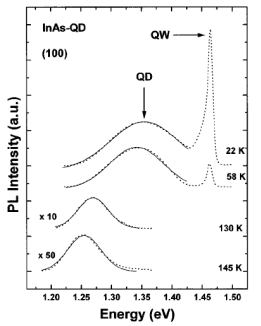
Dopasowane studnie kwantowe

Exciton localization and temperature stability in self-organized InAs quantum dots

D. I. Lubyshv, P.P. González-Borrero, E. Marega, Jr., E. Petitprez, N. La Scala, Jr., and P. Basmaji
 Instituto de Física de São Carlos-Universidade de São Paulo, C.P. 369, CEP 13960-970 São Carlos, São Paulo, Brazil

(Received 14 August 1995; accepted for publication 27 October 1995)

We investigated the Quenching energy fit 7 meV, respectively. the quantum dots wa peak full width at h quantum dot emissio of Physics. [S0003-t

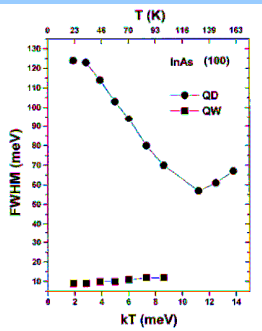
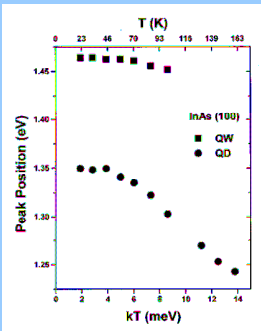
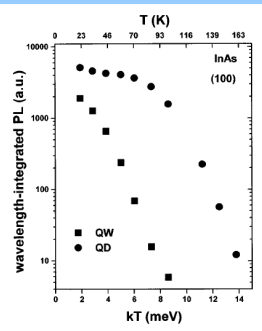


ganized InAs quantum dots. dots was found to be 2 and n through a GaAs barrier in rease of photoluminescence of nonpredominant size © 1996 American Institute

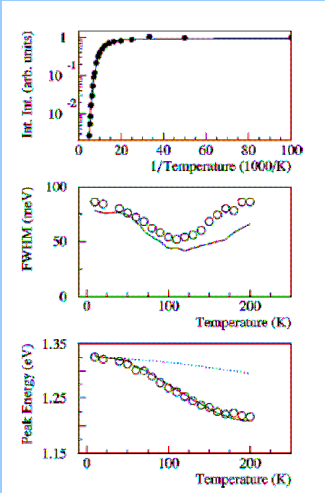
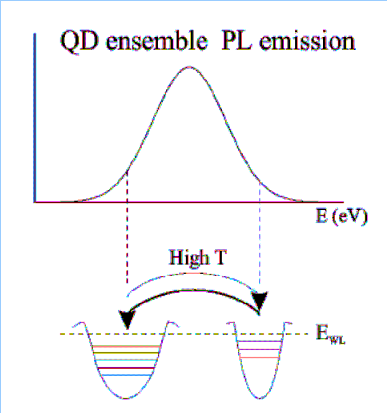


Redystrybucja nośników

aktywowana termicznie redystrybucja nośników między kropkami kwantowymi o różnych energiach



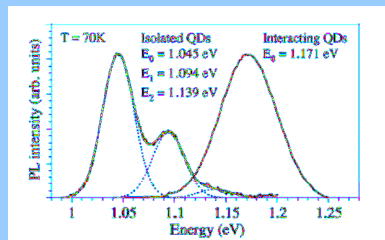
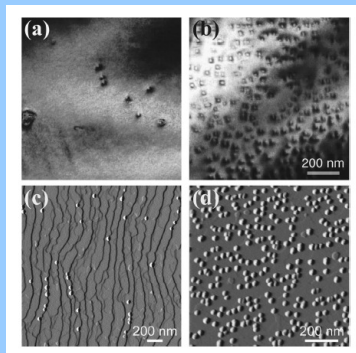
Redystrybucja nośników





Metoda kontroli

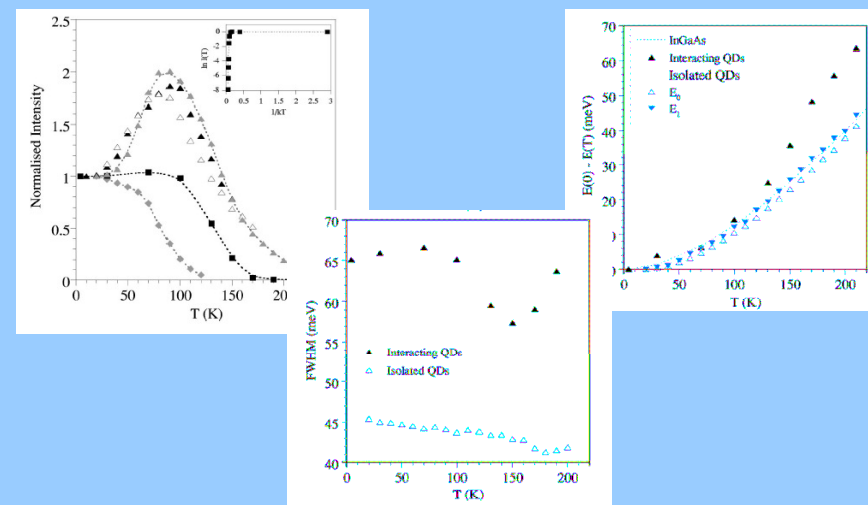
gęstość powierzchniowa kropek



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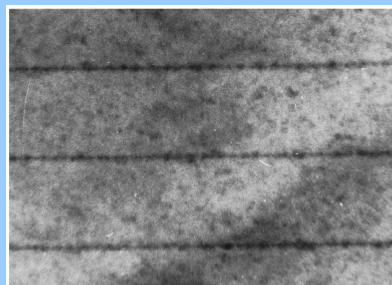
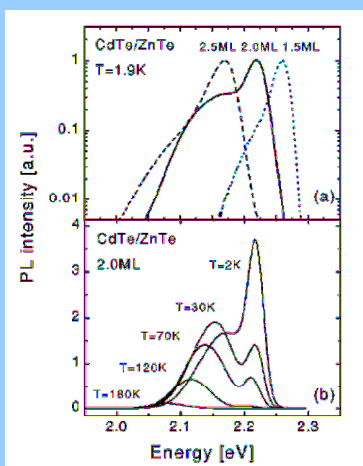
Metoda kontroli



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Kropki kwantowe II-VI



dla kropek II-VI w miarę osadzania materiału powoduje przesuwanie się energii emisji ze studni kwantowej

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Kropki kwantowe II-VI

VOLUME 85, NUMBER 5 PHYSICAL REVIEW LETTERS 31 JULY 2000

Evidence for 2D Precursors and Interdiffusion in the Evolution of Self-Assembled CdSe Quantum Dots on ZnSe

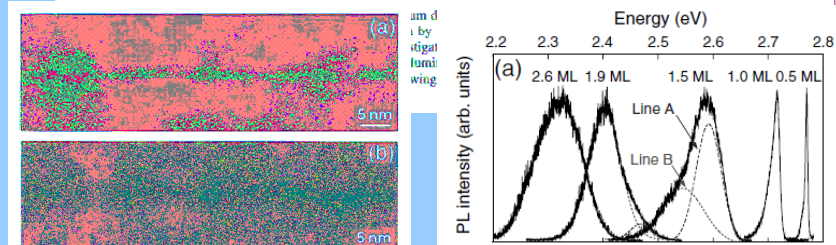
C. S. Kim,¹ M. Kim,¹ J. K. Furdyna,¹ M. Dobrowolska,^{1,4} S. Lee,² H. Rho,³ L. M. Smith,³ Howard E. Jackson,³ E. M. James,⁴ Y. Xin,⁴ and N. D. Browning⁴

¹Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556

²Department of Electronic Materials Engineering, Kwangjuon University, Seoul, 139-701 Korea

³Department of Physics, University of Cincinnati, Cincinnati, Ohio 45221

⁴Department of Physics, University of Illinois at Chicago, Chicago, Illinois 60607
(Received 22 December 1999)



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Kropki kwantowe II-VI



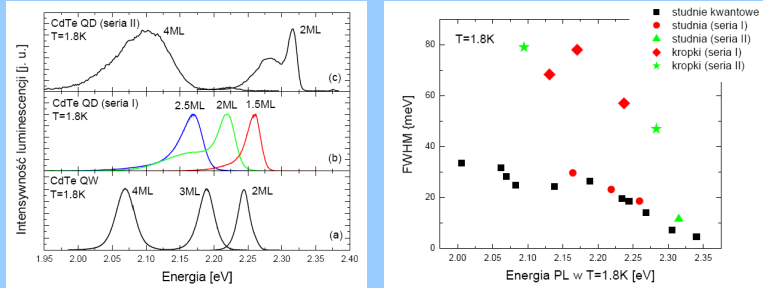
Thin Solid Films 412 (2002) 96–106



CdTe/ZnTe quantum dots—growth and optical properties

Sebastian Mackowski*

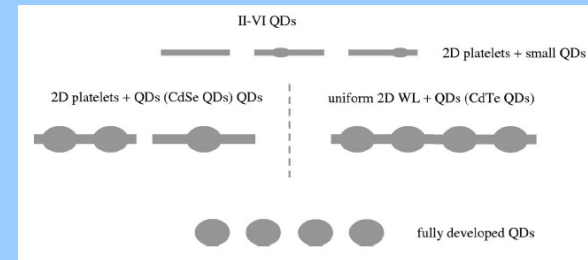
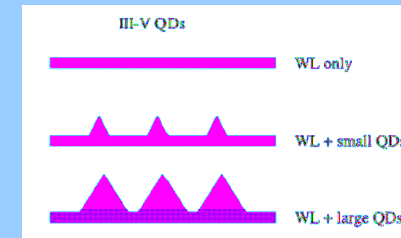
Institute of Physics Polish Academy of Sciences, Al. Lotników 32/46, Warsaw, Poland



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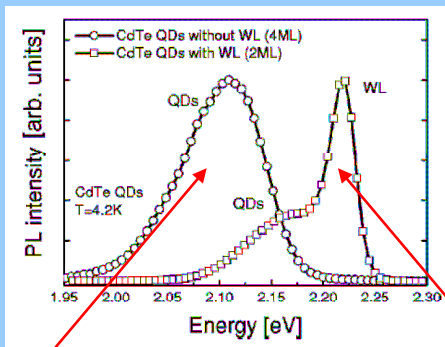
Morfologia kropek



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Dwa rodzaje kropek



kropki izolowane

kropki połączone warstwą zwilżającą

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Redystrybucja nośników

PHYSICAL REVIEW B 69, 205325 (2004)

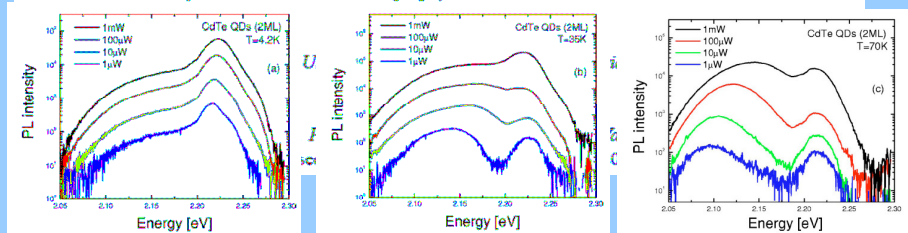
Impact of carrier redistribution on the photoluminescence of CdTe self-assembled quantum dot ensembles

S. Mackowski*

Department of Physics, University of Cincinnati, Cincinnati, Ohio 45221-0011, USA

G. Prechtl and W. Heiss

Institut für Halbleiter- und Festkörperphysik, Universität Linz, 4040 Linz, Austria

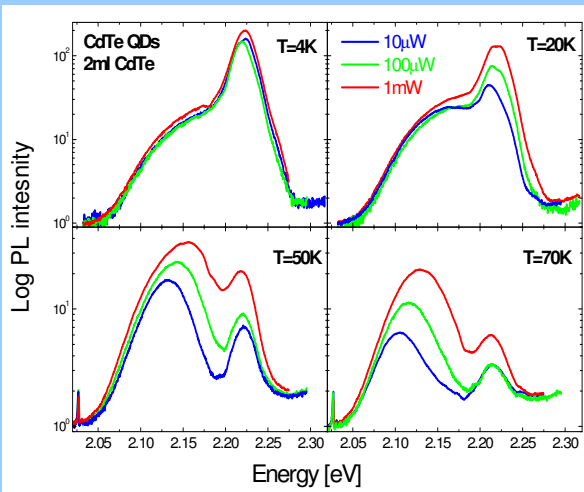


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Widma znormalizowane

uniform 2D WL + QDs (CdTe QDs)



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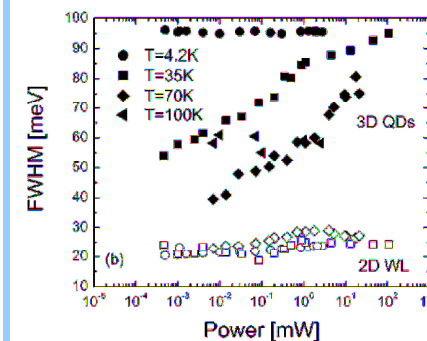
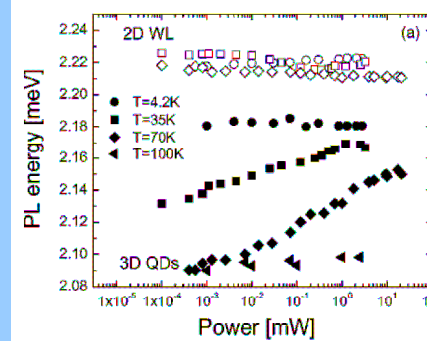


Redystrybucja nośników

uniform 2D WL + QDs (CdTe QDs)



trzy obszary: T=4.2K
30K < T < 70K
T=100K



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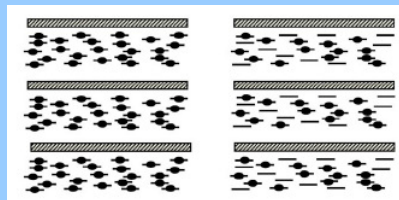


Redystrybucja nośników

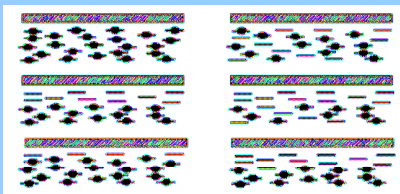
uniform 2D WL + QDs (CdTe QDs)



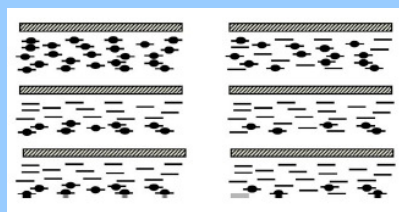
T=4.2K



30K < T < 70K



T=100K

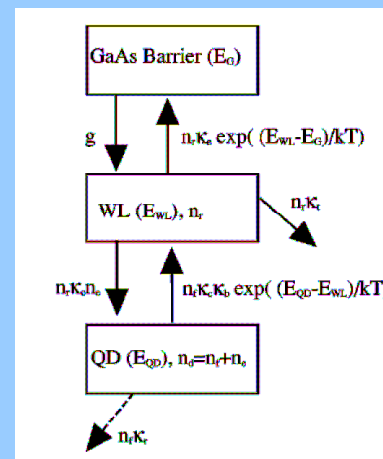
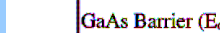


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Model teoretyczny

uniform 2D WL + QDs (CdTe QDs)



założenia modelu

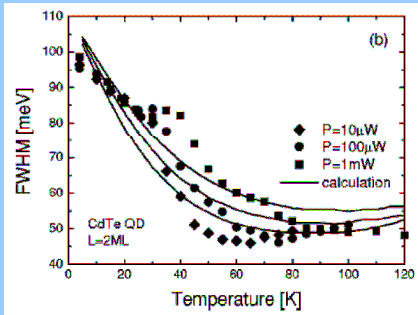
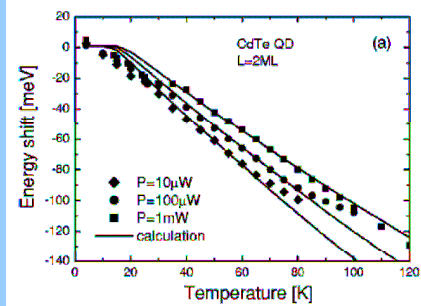
- (a) The capture of photocreated carriers from the ZnTe barrier into the QD's takes place only via the 2D WL. Analogously, we neglect a direct carrier escape out of QD's to the ZnTe barrier.
- (b) The carriers in the WL could either be captured by QD's or they recombine radiatively or nonradiatively in the WL.
- (c) Each QD can be populated by only one electron-hole pair, and the initial QD population is determined by the statistical distribution of QD ground-state energies within the ensemble. The energy distribution of QD's is identical to the PL spectrum measured at $T = 4.2$ K.
- (d) The radiative recombination time of excitons is the same for all QD's, and it does not depend on either size or shape (i.e., the emission energy) of QD's.
- (e) The probability of thermal escape from QD to WL (γ) is proportional to $\exp(-\Delta E/k_B T)$, where ΔE is the difference between the energy of the QD and the energy of the WL.

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Model teoretyczny

uniform 2D WL + QDs (CdTe QDs)



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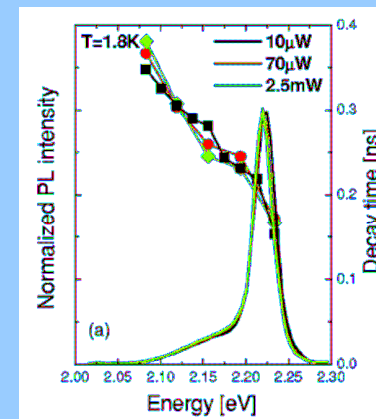
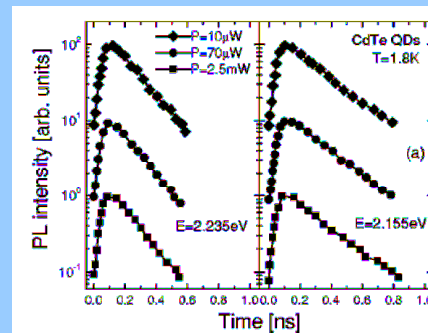


Dynamika ekscytonów

uniform 2D WL + QDs (CdTe QDs)



T=1.8K



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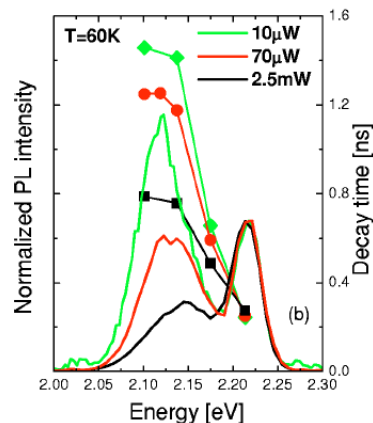
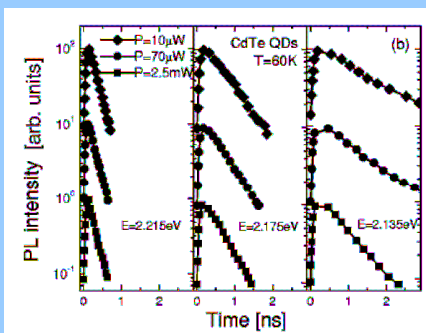


Dynamika ekscytonów

uniform 2D WL + QDs (CdTe QDs)



T=60K



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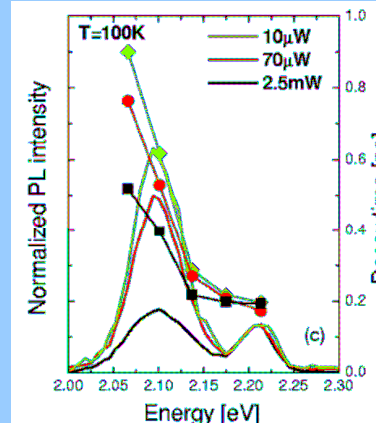
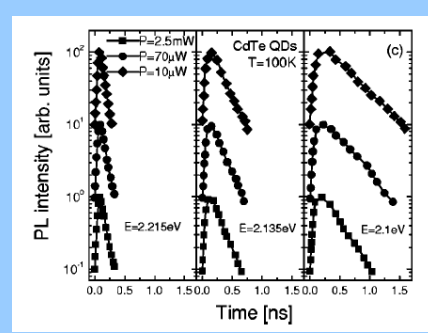


Dynamika ekscytonów

uniform 2D WL + QDs (CdTe QDs)



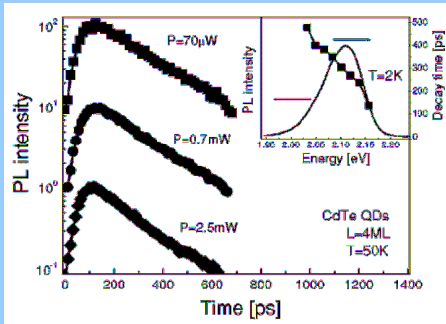
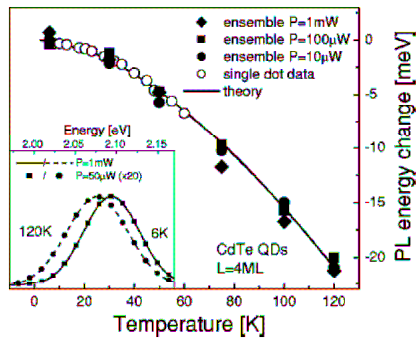
T=100K



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Kropki izolowane



dla izolowanych kropek kwantowych nie występują efekty redystrybucji nośników

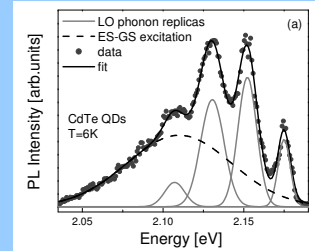
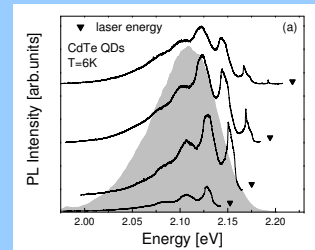
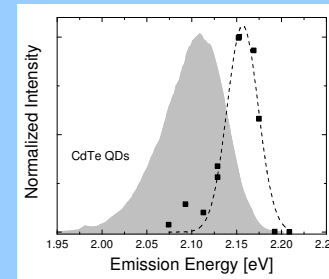
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Kropki izolowane



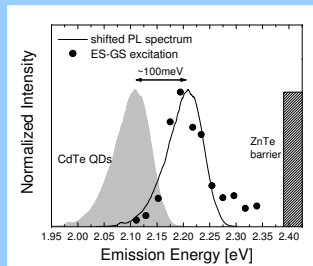
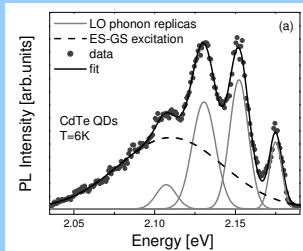
oddziaływanie ekscytynu z fononem optycznym



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Stany wzbudzone



stany wzbudzone mają podobny rozkład do rozkładu stanów podstawowych, są przesunięte o około 100 meV w stronę wyższych energii

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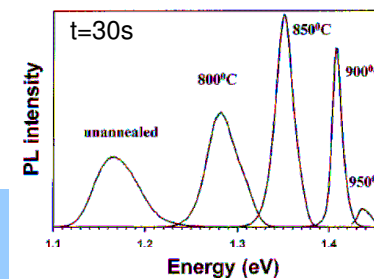
Wyrzewanie kropek

Tuning self-assembled InAs quantum dots by rapid thermal annealing

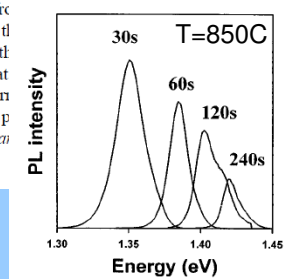
Surama Malik, Christine Roberts, and Ray Murray²⁾
IRC for Semiconductor Materials, The Blackett Laboratory, Imperial College, London SW7 2B7, United Kingdom

Malcolm Pate
EPSCRC III-V Central Facility, University of Sheffield, Sheffield S1 3JD, United Kingdom

(Received 27 May 1997; accepted for publication 4 August 1997)



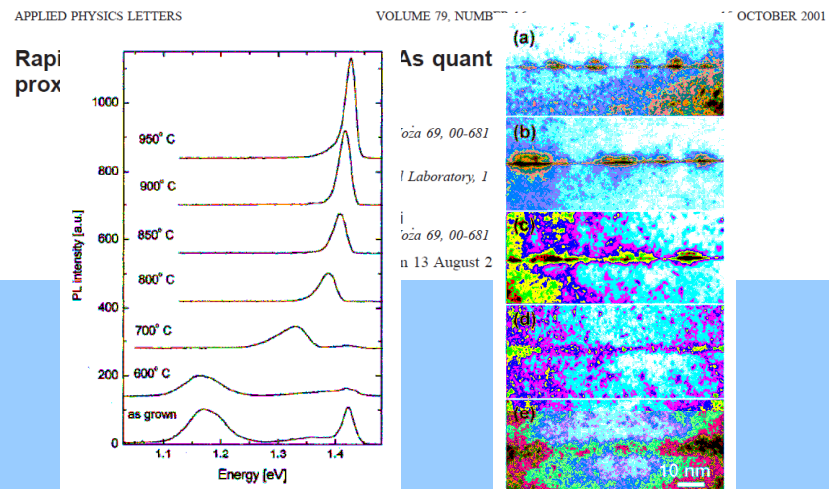
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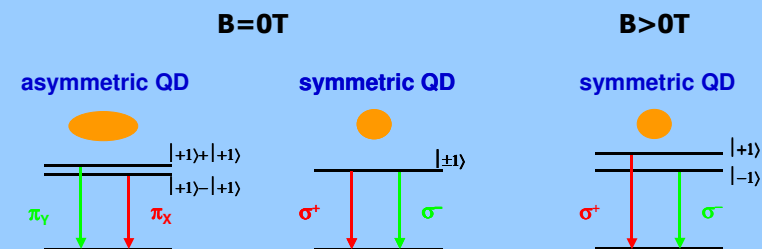
Wyrzewanie kropek



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Spin ekscytonu



o poziomach energetycznych dokładniej – za dwa tygodnie

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Spin ekscytonu

VOLUME 86, NUMBER 8 PHYSICAL REVIEW LETTERS 19 FEBRUARY 2001

Spin Relaxation Quenching in Semiconductor Quantum Dots

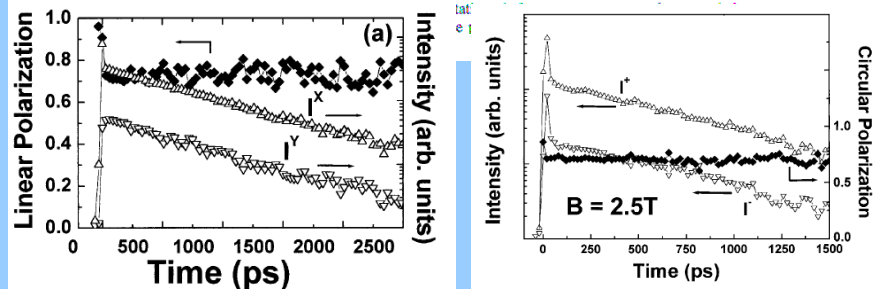
M. Paillard,¹ X. Marie,¹ P. Renucci,¹ T. Amand,¹ A. Jbeli,¹ and J.M. Gérard²

¹Laboratoire de Physique de la Matière Condensée, INSA-CNRS, 135 Avenue de Rangueil, 31077 Toulouse cedex, France

²France Télécom R&D, 196 Avenue H. Ravera 92220 Bagneux, France

(Received 28 June 2000)

We have studied the spin dynamics in self-organized InAs/GaAs quantum dots by time-resolved photoluminescence.

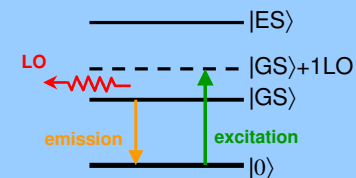


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Spektroskopia rezonansowa

absorpcja z wykorzystaniem fononów optycznych



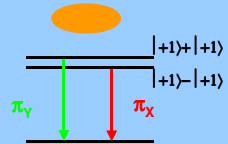
kontrola polaryzacji światła pobudzającego daje możliwość pomiaru dynamiki spinowej ekscytonu

SL 2008/2009

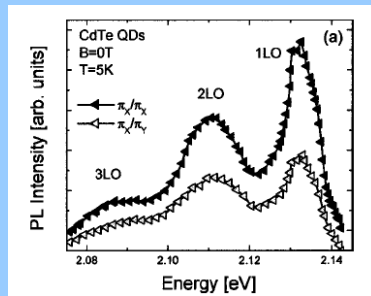
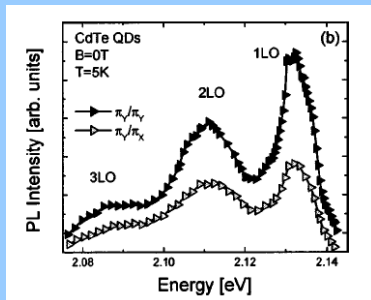


Spin ekscytonu

asymmetric QD



czas relaksacji spinu >> czas rekombinacji

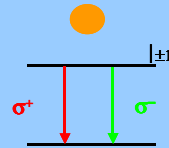


SL 2008/2009

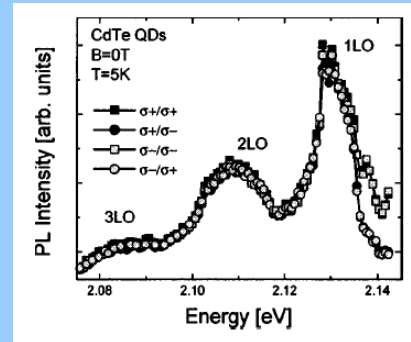


Spin ekscytonu

symmetric QD



czas relaksacji spinu << czas rekombinacji

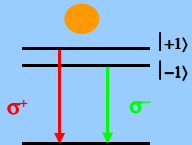


SL 2008/2009

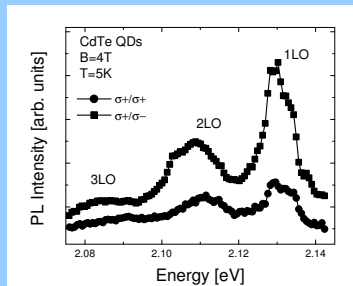
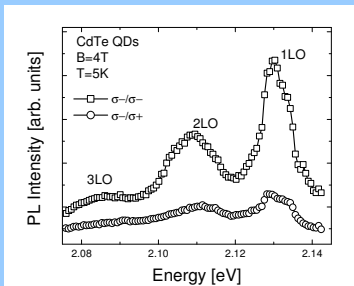


Spin ekscytonu

symmetric QD



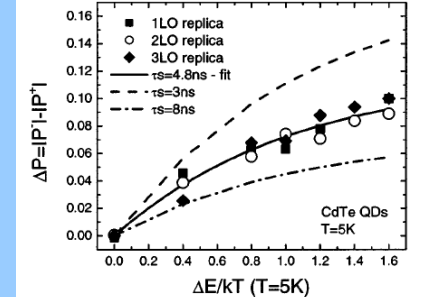
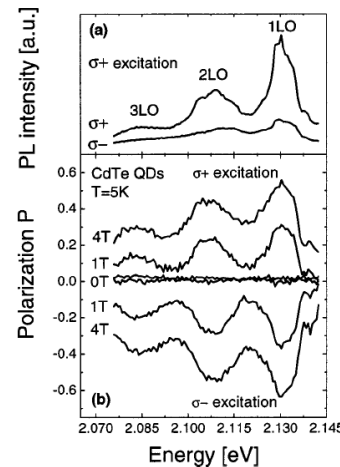
czas relaksacji spinu >> czas rekombinacji



SL 2008/2009



Spin ekscytonu



$$\Delta P = |P^-| - |P^+| = \frac{n_-^- - n_+^- - n_-^+ - n_+^+}{n_-^- + n_+^- + n_-^+ + n_+^+}$$
$$= \frac{2\tau_R(e^{\Delta E/kT} - 1)}{\tau_R + e^{\Delta E/kT}(\tau_R + \tau_S)}$$

SL 2008/2009