



Optyka nanostruktur

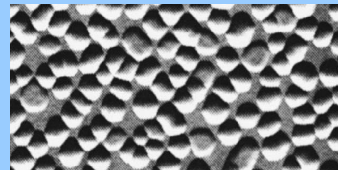
Sebastian Maćkowski

Instytut Fizyki

Uniwersytet Mikołaja Kopernika

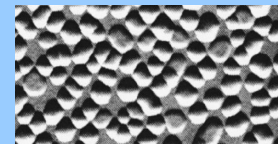
Adres poczty elektronicznej: mackowski@fizyka.umk.pl

Biuro: 365, telefon: 611-3250

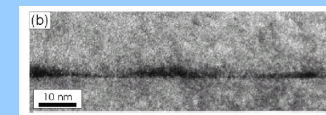


Kropki samorosnące

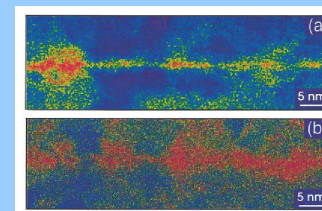
InAs/GaAs QDs



Si/Ge QDs



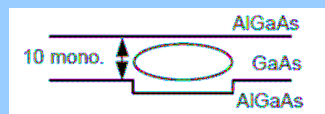
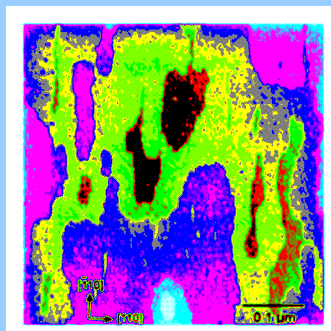
CdSe/ZnSe QDs



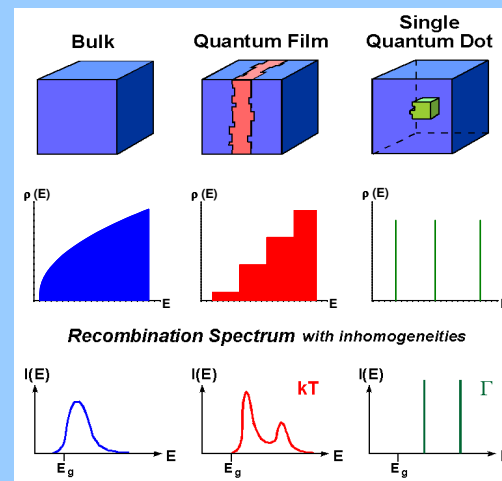
CdTe/ZnTe QDs



Kropki – fluktuacje szerokości



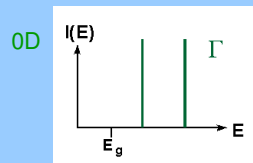
Gęstość stanów





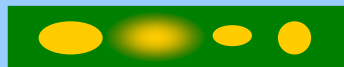
Różnorodność kropek

recombination spectrum of a single quantum dot

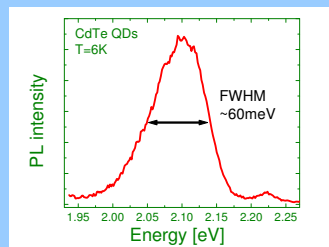


δ -like density of states

quantum dots in the ensemble are not identical



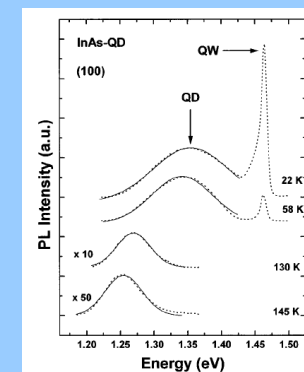
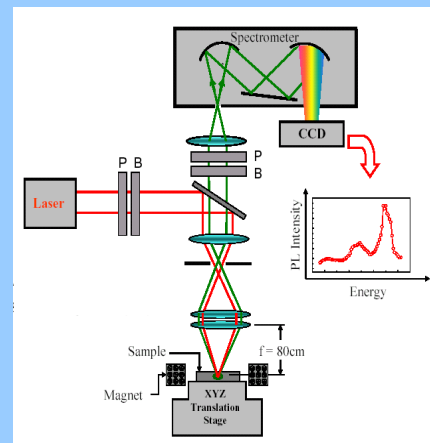
the ensemble QD emission shows strong inhomogeneous broadening



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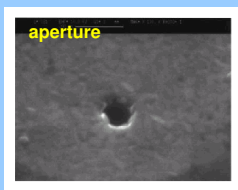
Techniki eksperymentalne



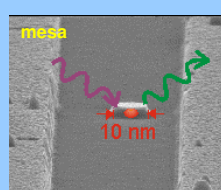
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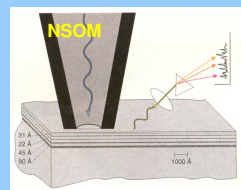
Techniki eksperymentalne



D. Park, et al.,
JVST B 16 (1998) 3891



<http://www.physik.uni-wuerzburg.de/TEP/index.html>



H. F. Hess, et al.,
Science 264 (1996) 1740

-) low throughput
-) no mapping possible
-) fabrication
-) no statistical information about QD properties

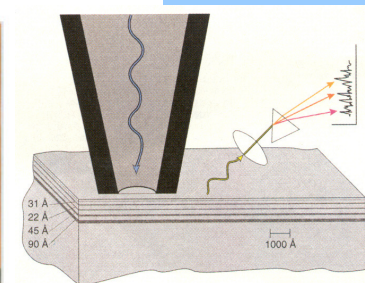
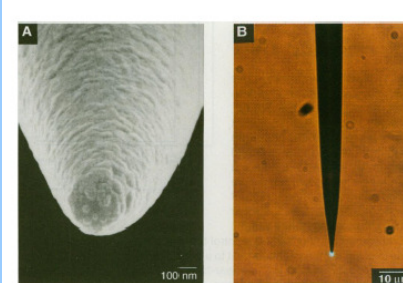
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Mikroskopia bliskiego pola

Near-Field Optics: Microscopy, Spectroscopy, and Surface Modification Beyond the Diffraction Limit

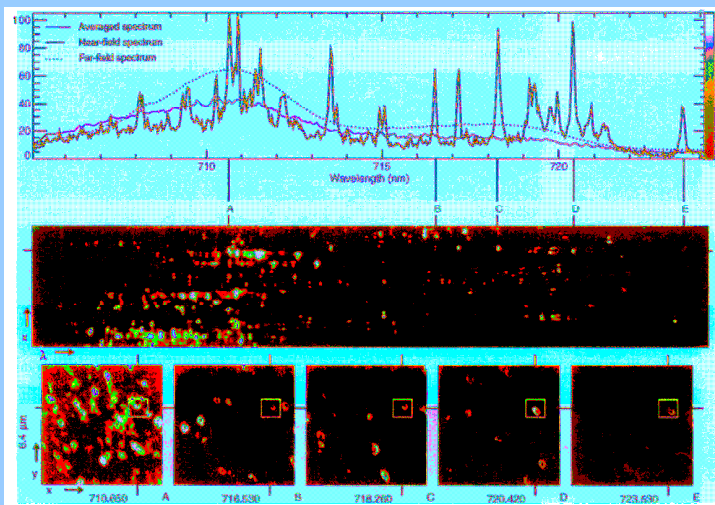
Eric Betzig and Jay K. Trautman



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Mikroskopia bliskiego pola



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Mikroskopia bliskiego pola

PHYSICAL REVIEW B

VOLUME 54, NUMBER 24

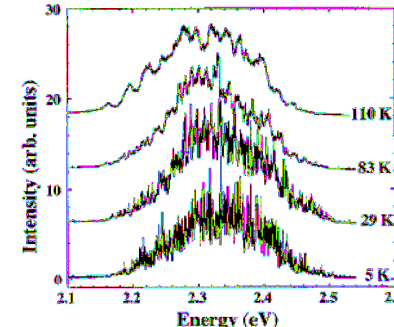
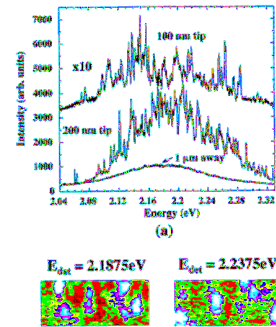
15 DECEMBER 1996-II

Near-field optical spectroscopy of localized excitons in strained CdSe quantum dots

F. Flack and N. Samarth

Department of Physics, The Pennsylvania State University, University Park, Pennsylvania 16802

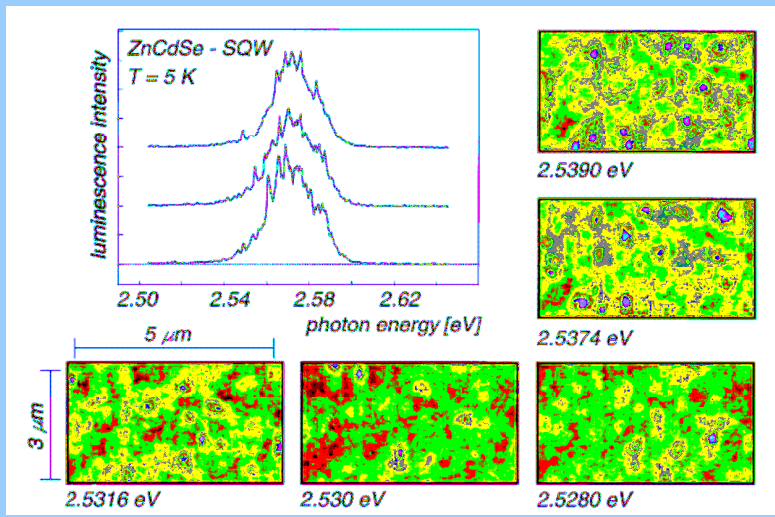
V. Nikitin, P. A. Crowell, J. Shi, J. Levv, and D. D. Awschalom



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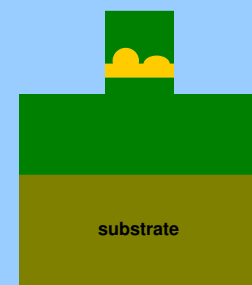
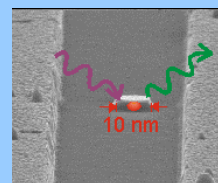
Katodoluminescencja



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Wytrawianie mezo



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Pierwsze wyniki

PHYSICAL REVIEW B

VOLUME 50, NUMBER 11

15 SEPTEMBER 1994-I

Visible photoluminescence from N -dot ensembles and the linewidth of ultrasmall $\text{Al}_x\text{In}_{1-x}\text{As}/\text{Al}_x\text{Ga}_{1-x}\text{As}$ quantum dots

S. Fafard and R. Leon

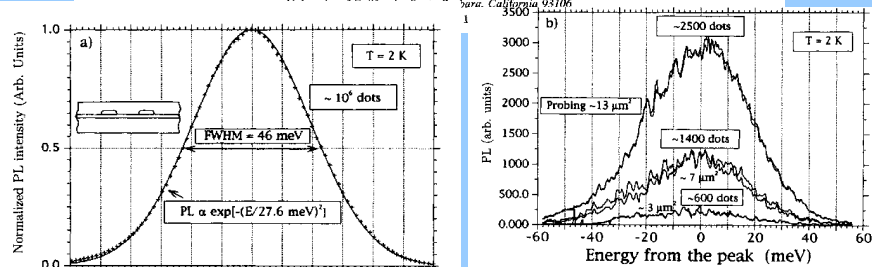
Center for Quantized Electronic Structures (QUEST), University of California, Santa Barbara, California 93106

D. Leonard

Center for Quantized Electronic Structures (QUEST) and Materials Department, University of California, Santa Barbara, California 93106

J. L. Metz and P. M. Petroff

Center for Quantized Electronic Structures (QUEST) and Materials Department and Electrical and Computer Engineering Department, University of California, Santa Barbara, California 93106



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Pierwsze wyniki

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VOLUME 50, NUMBER 11

15 SEPTEMBER 1994-I

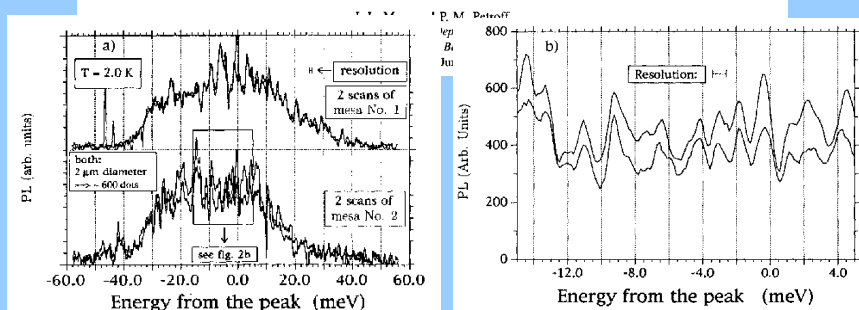
Visible photoluminescence from N -dot ensembles and the linewidth of ultrasmall $\text{Al}_x\text{In}_{1-x}\text{As}/\text{Al}_x\text{Ga}_{1-x}\text{As}$ quantum dots

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D. Leonard

Center for Quantized Electronic Structures (QUEST) and Materials Department, University of California, Santa Barbara, California 93106



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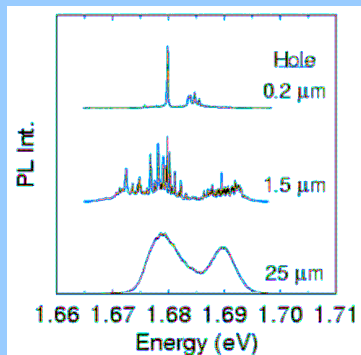
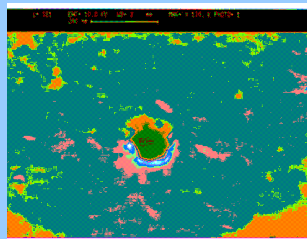
Apertury

Excited state spectroscopy of excitons in single quantum dots

D. Gammon,^{a)} E. S. Snow, and D. S. Katzer

Naval Research Laboratory, Washington, DC 20375-5347

(Received 10 March 1995; accepted for publication 8 August 1995)



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Apertury

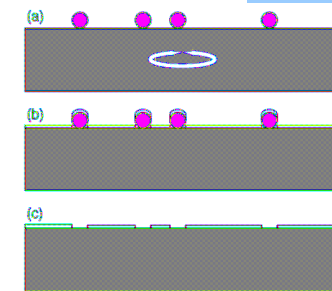
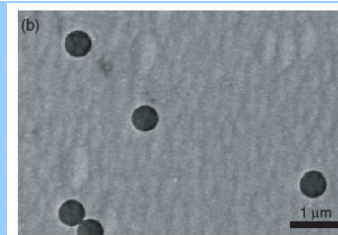
INSTITUTE OF PHYSICS PUBLISHING
Nanotechnology 14 (2003) 675-679

NANOTECHNOLOGY
PII: S0957-4484(03)56738-1

Nano-aperture fabrication for single quantum dot spectroscopy

Ulf Håkanson¹, Jonas Persson, Filip Persson, Hans Svensson, Lars Montelius and Mikael K-J Johansson

Solid State Physics/Nanometer Consortium, Lund University, PO Box 118, SE-221 00 Lund, Sweden



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Najważniejsze wyniki

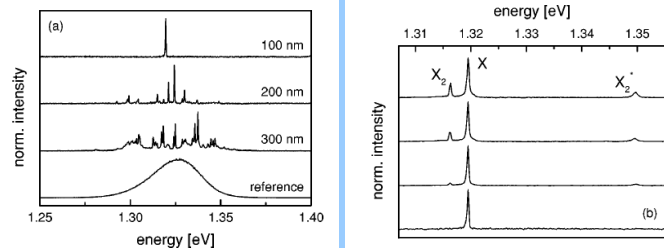
PHYSICAL REVIEW B VOLUME 58, NUMBER 12 15 SEPTEMBER 1998-II

Zeeman splitting of excitons and biexcitons in single $\text{In}_{0.60}\text{Ga}_{0.40}\text{As}/\text{GaAs}$ self-assembled quantum dots

A. Kuther, M. Bayer, and A. Forchel
Technische Physik, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

A. Gorbunov and V. B. Timofeev
Institute of Solid State Physics, Russian Academy of Sciences, 142432 Chernogolovka, Russia

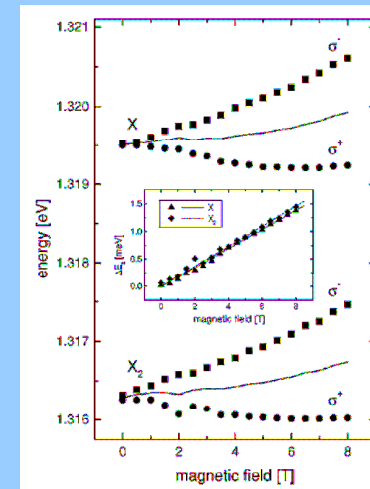
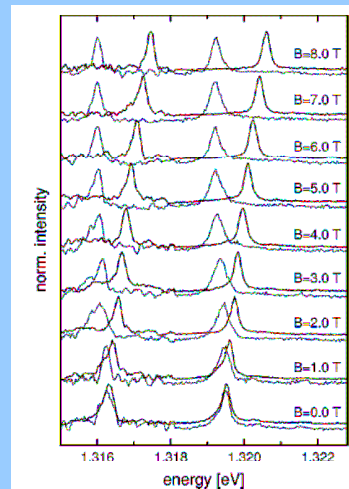
F. Schäfer and J. P. Reithmaier
Technische Physik, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany
(Received 29 May 1998)



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Ekscyton w polu B



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Oddziaływanie wymiany

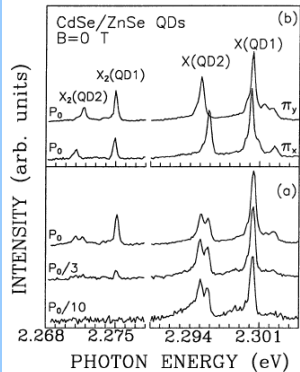
VOLUME 82, NUMBER 8 PHYSICAL REVIEW LETTERS 22 FEBRUARY 1999

Fine Structure of Biexciton Emission in Symmetric and Asymmetric CdSe/ZnSe Single Quantum Dots

Sacher, R. Weigand, T. Kimmell, and A. Forchel
Universität Würzburg, 97074 Würzburg, Germany

E. Borovitskaya
Institute of Physics, RAS, 142432 Chernogolovka, Russia

Leonardi and D. Hommel
Physik, Universität Bremen, 28359 Bremen, Germany
(Received 12 October 1998)

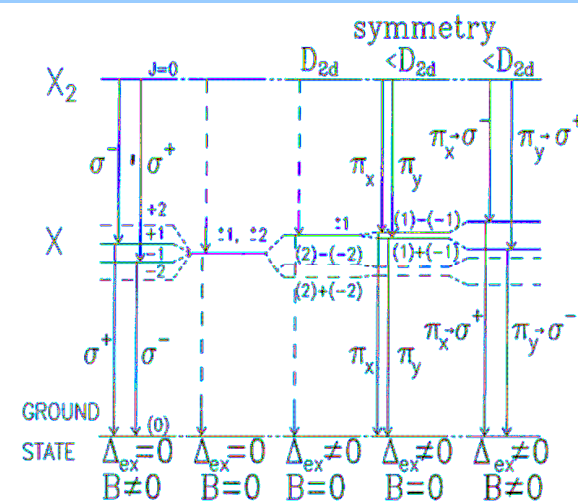


rozszczenie wymiany dla ekscytonu w asymetrycznej kropce

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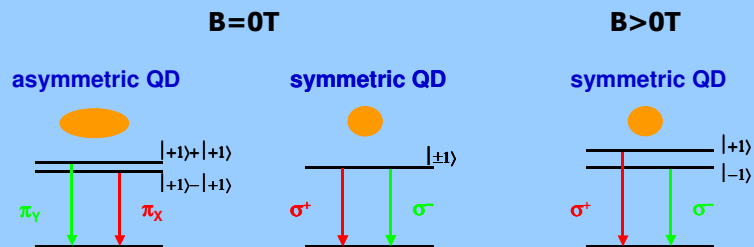
Struktura ekscytonu w kropce



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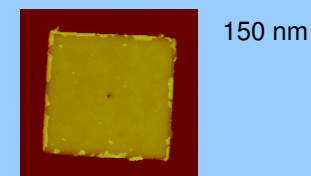
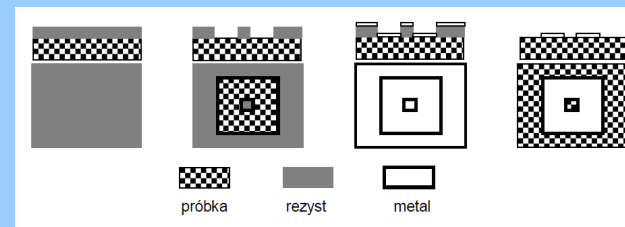
Struktura ekscytonu w kropce



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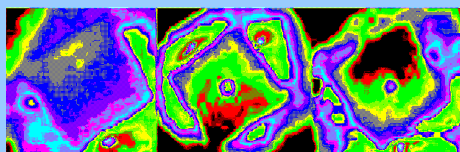
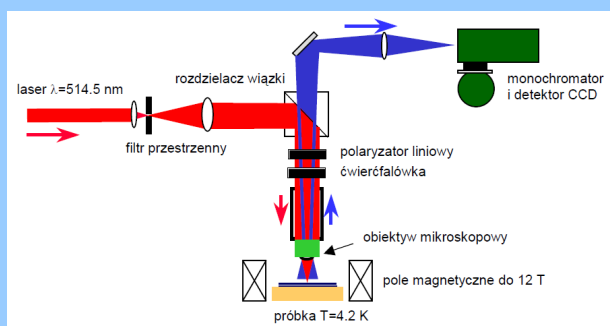
Mikroluminescencja



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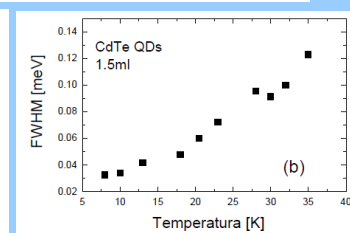
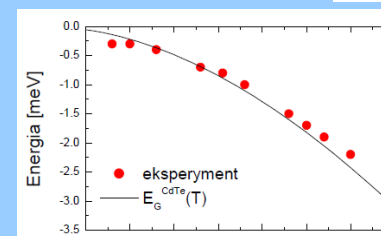
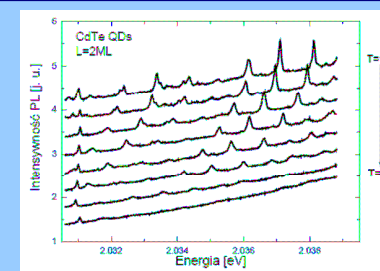
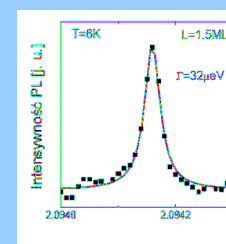
Układ pomiarowy



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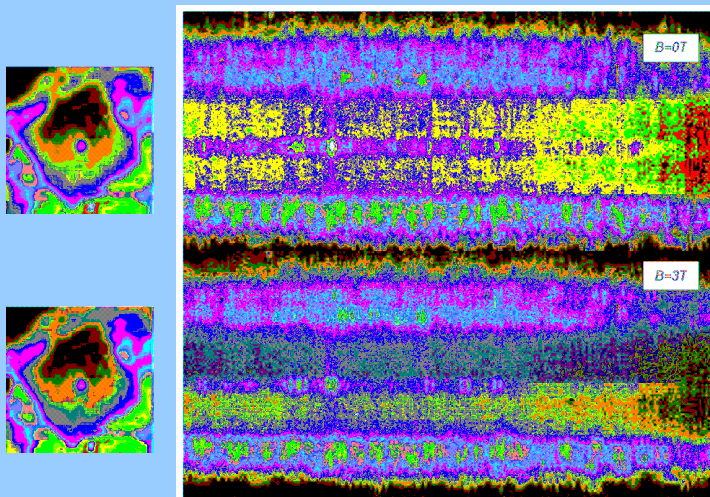


Szerokość linii

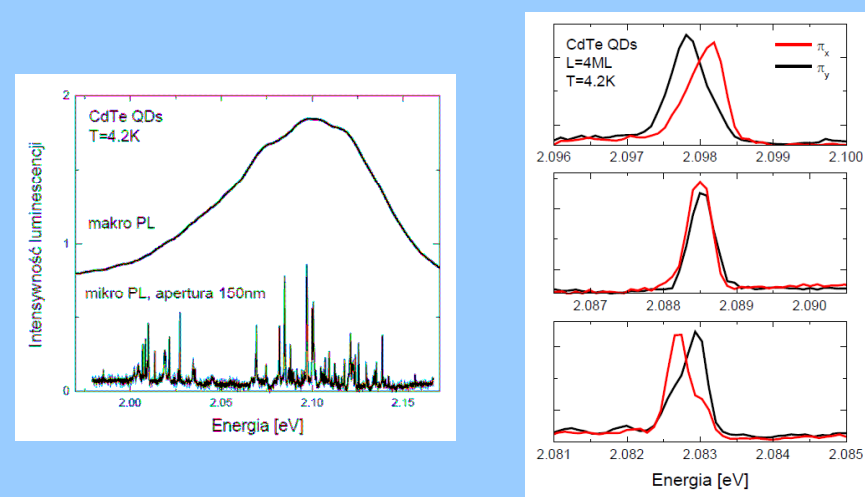


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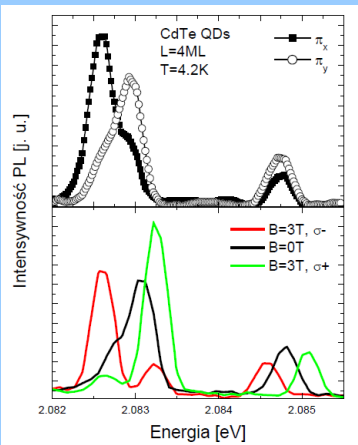
Spektroskopia



Spektroskopia



Ekscyton w kropce kwantowej



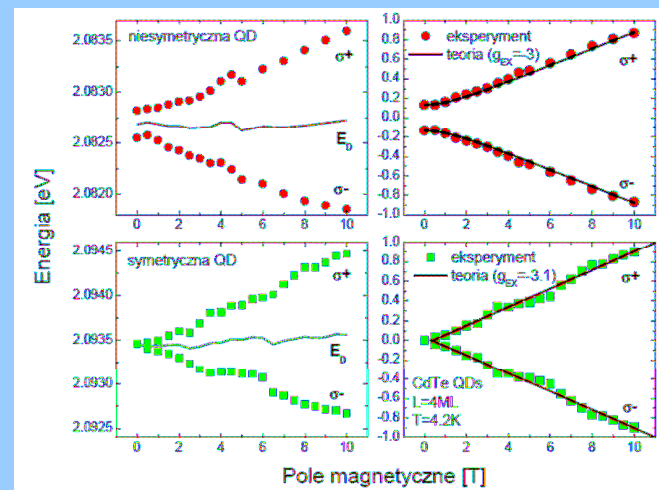
rozszczenie spinowe

$$E_{1,2} = \frac{1}{2} (\delta_0 \pm \sqrt{(g_1 \mu_B B)^2 + \delta_1^2})$$

przesunięcie diamagnetyczne

$$E_D = \frac{e^2}{8} \left(\frac{\langle r_e \rangle}{m_e} + \frac{\langle r_h \rangle}{m_h} \right) B^2$$

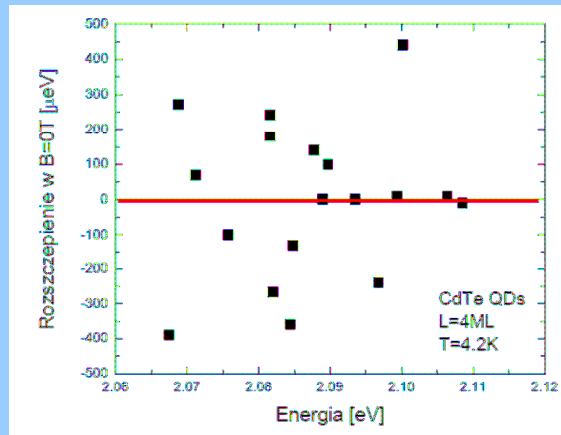
Ekscyton w kropce kwantowej





Statystyka

rozszerzenie wymiany

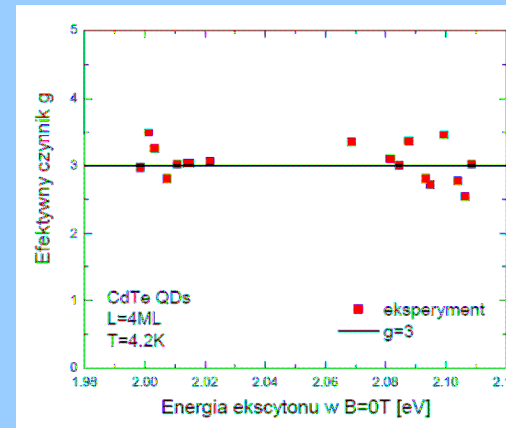


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Statystyka

czynnik g ekscytonu



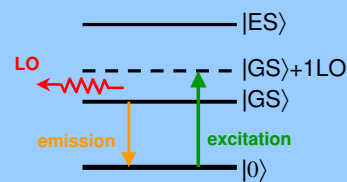
dla $B=4T$
rozszerzenie $\sim 1\text{meV}$

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Spektroskopia rezonansowa

absorpcja z wykorzystaniem fononów optycznych

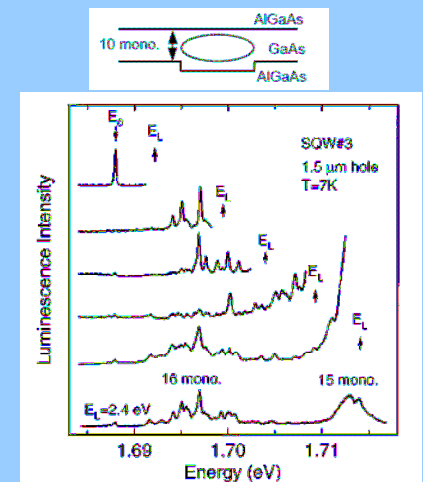
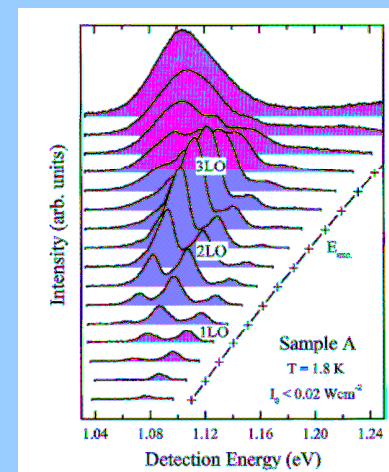


kontrola polaryzacji światła pobudzającego daje
możliwość pomiaru dynamiki spinowej ekscytonu

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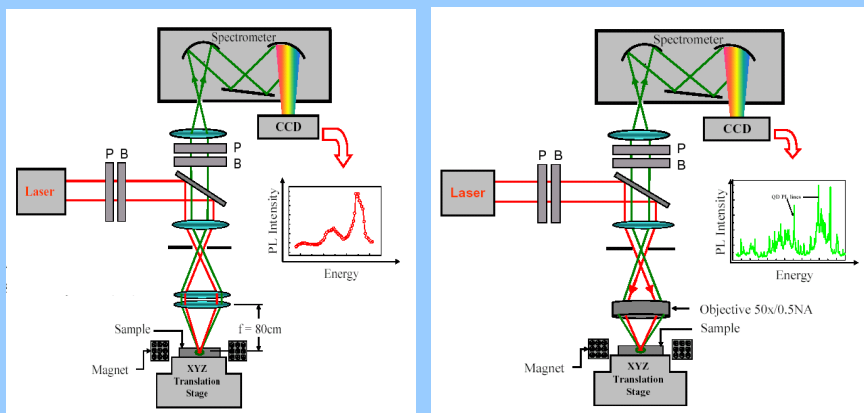
Widmo emisji



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Mikroluminescencja

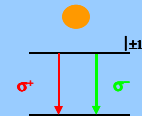


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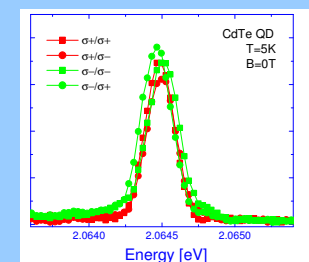
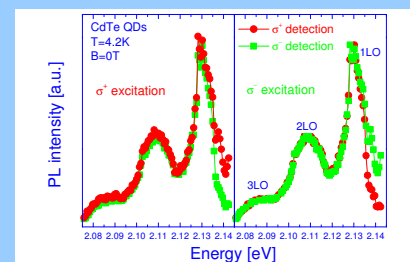


Spin ekscytonu

symmetric QD



czas relaksacji spinu << czas rekombinacji



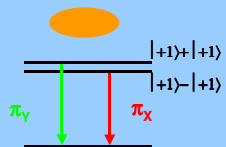
S. Mackowski *et al.*, PRB 70 (2004) 245312

SL 2008/2009

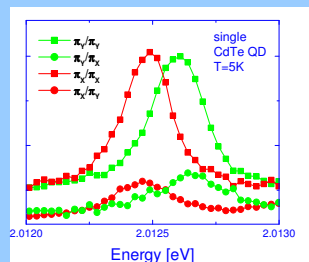
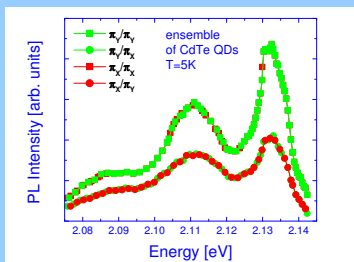


Spin ekscytonu

asymmetric QD



czas relaksacji spinu >> czas rekombinacji



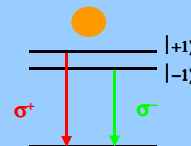
S. Mackowski *et al.*, PRB 70 (2004) 245312

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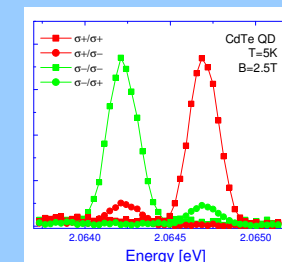
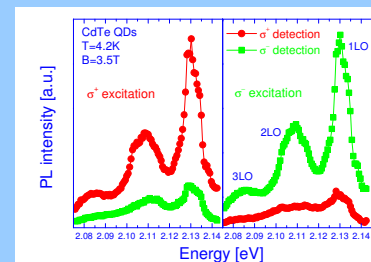


Spin ekscytonu

symmetric QD



czas relaksacji spinu >> czas rekombinacji

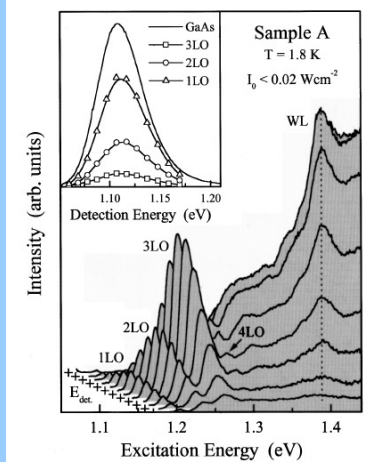
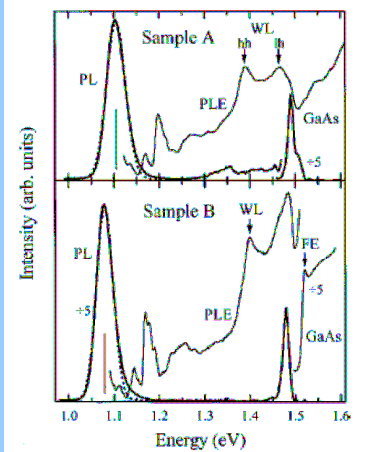


S. Mackowski *et al.*, PRB 70 (2004) 245312

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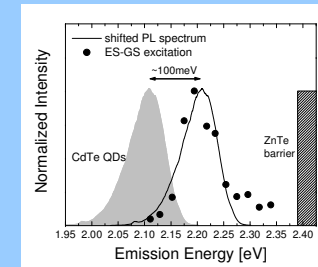
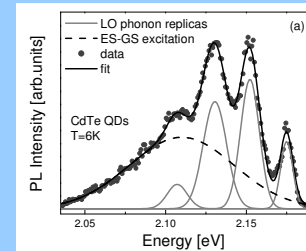
Widmo wzbudzenia kropek



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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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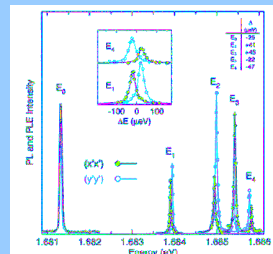
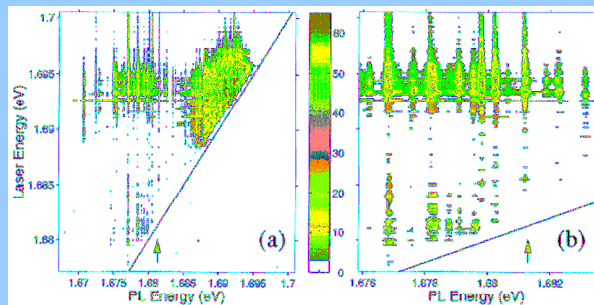
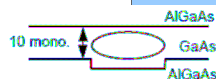


Widmo wzbudzenia

VOLUME 76, NUMBER 16 PHYSICAL REVIEW LETTERS 15 APRIL 1996

Fine Structure Splitting in the Optical Spectra of Single GaAs Quantum Dots

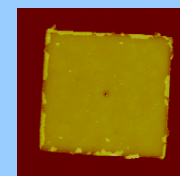
D. Gammon, E. S. Snow, B. V. Shanabrook, D. S. Katzer, and D. Park
Naval Research Laboratory, Washington, D.C. 20375-5347
(Received 17 August 1995)



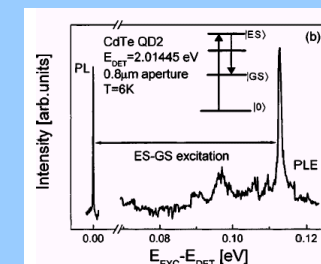
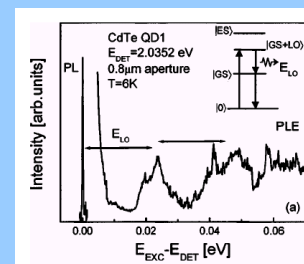
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Spektroskopia rezonansowa



dwa typy rezonansów obserwowane dla kropek kwantowych

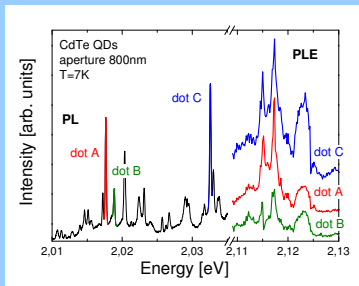


CdTe/ZnTe QDs
T. Nguyen, SM, *et al.*, PRB 2004

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Podobieństwo widm PLE



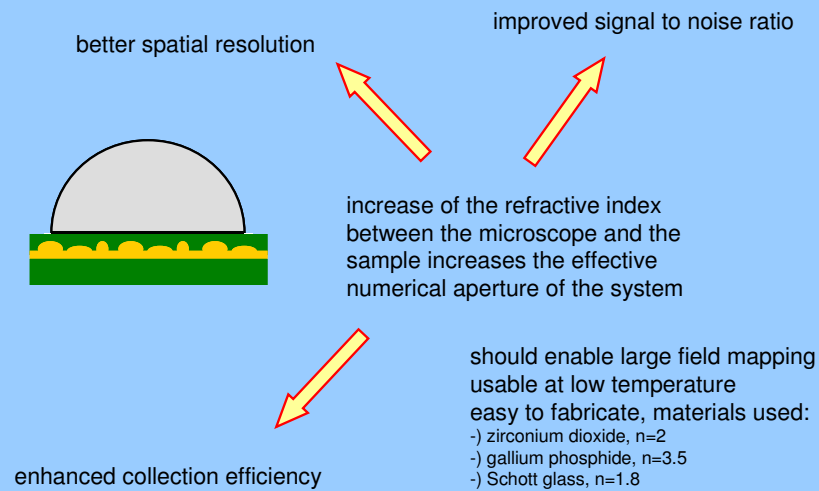
widma PLE wskazują na występowanie identycznych rezonansów dla różnych kropek kwantowych w zespole

T. Nguyen, SM, *et al.*, PRB 2007

SL 2008/2009



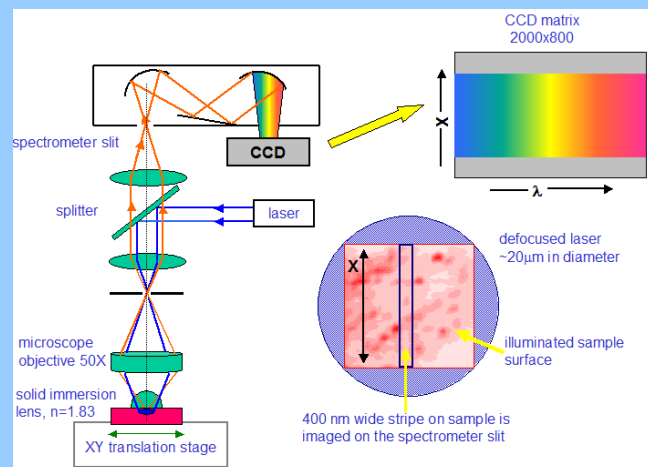
Obrazowanie luminescencji



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Obrazowanie luminescencji

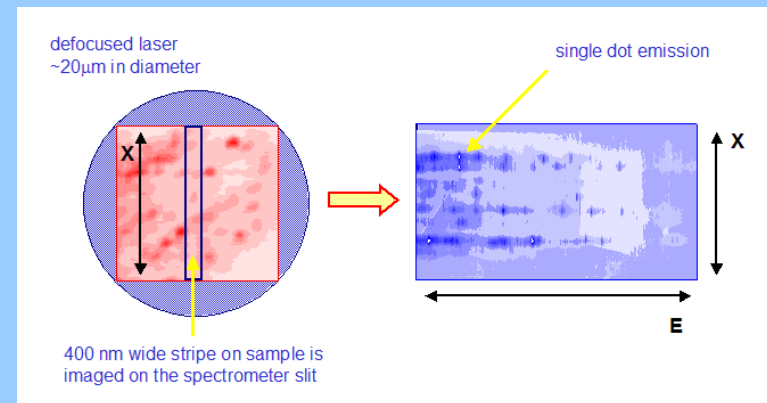


K. Hewaparakrama, SM, *et al.*, APL 2004

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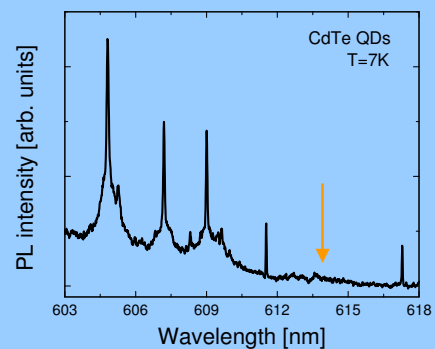
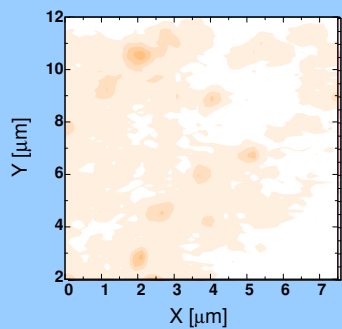
Obrazowanie luminescencji



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Mapowanie luminescencji



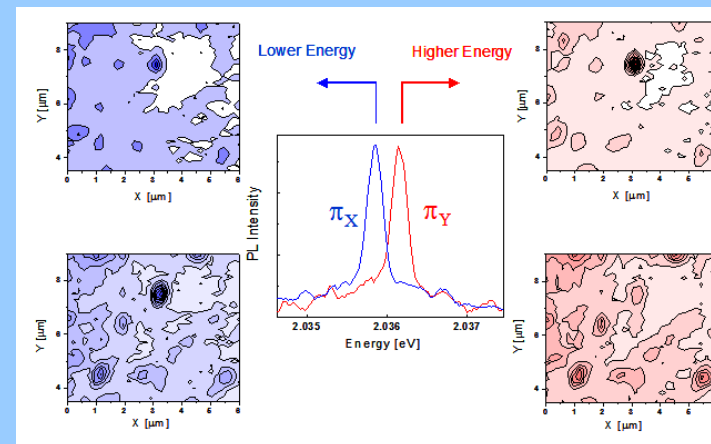
for each emission energy a PL an $\sim 8 \times 8 \mu\text{m}$ map is collected
approximately 10^5 individual dots can be imaged with a very
high signal to noise ration in a single $\frac{1}{2}$ hour acquisition

K. Hewaparakrama, SM, *et al.*, APL 2004

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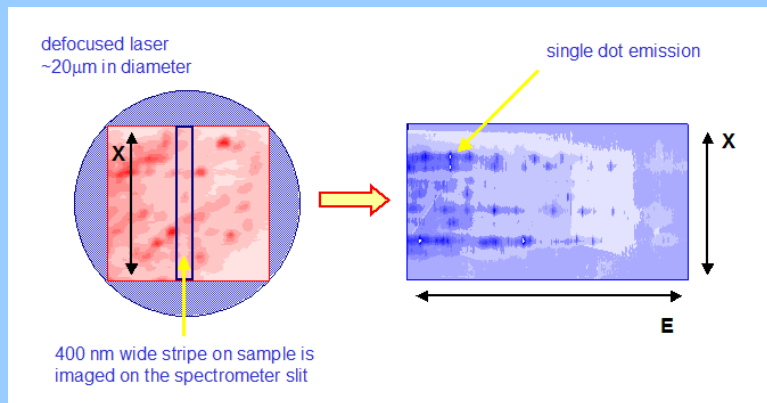
Mapowanie luminescencji



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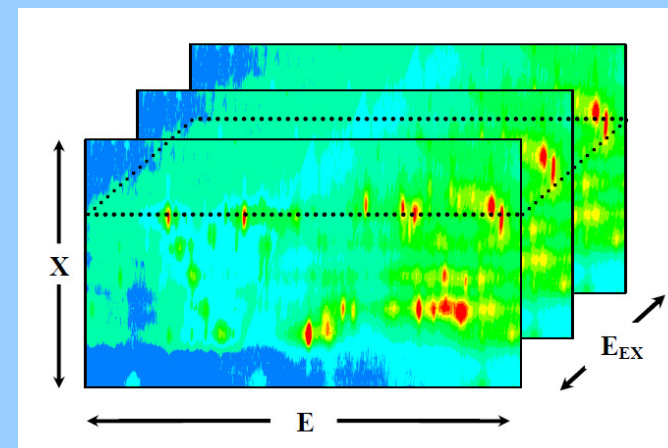
Mapowanie rezonansów



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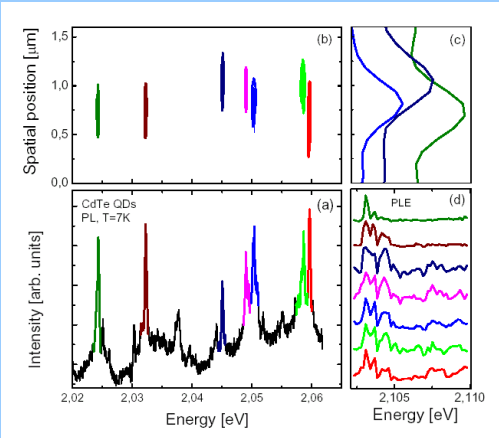
Mapowanie rezonansów



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Mapowanie rezonansów



identyczne rezonanse występują dla kropek o różnym położeniu

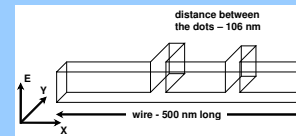
T. Nguyen, SM, *et al.*, PRB 2007

SL 2008/2009

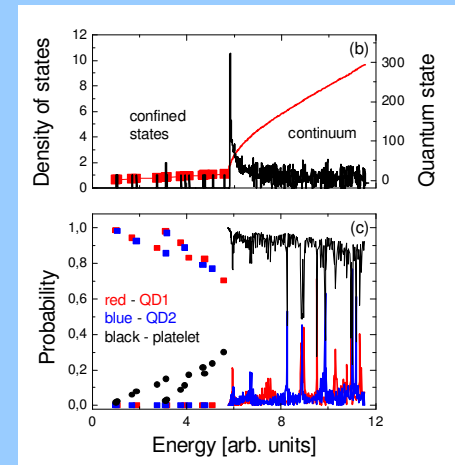


Model układu

druk łączący dwie kropki kwantowe



stany związane są wyraźnie oddzielone od stanów ciągłych

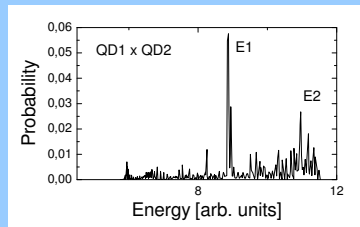


T. Nguyen, SM, *et al.*, PRB 2007

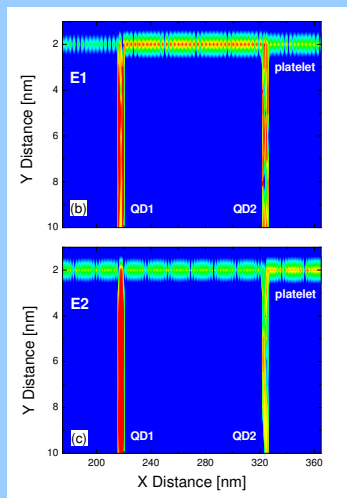
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Model układu



wzbudzenie placka umożliwia obsadzenie obu kropek kwantowych



T. Nguyen, SM, *et al.*, PRB 2007

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