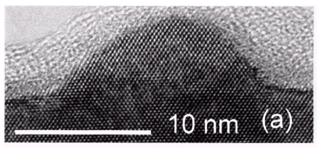
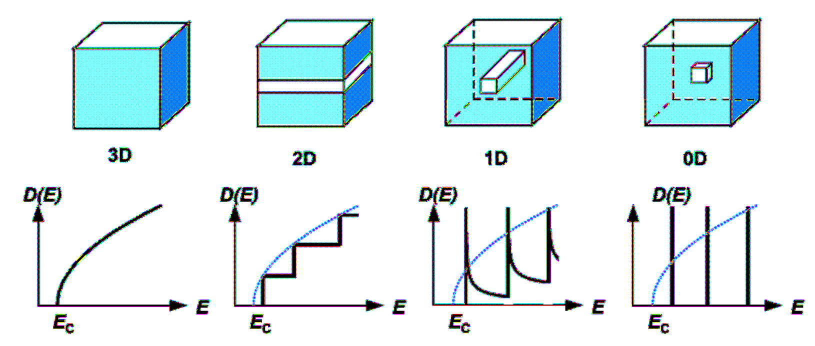
Kropki kwantowe - część I otrzymywanie

Sebastian Maćkowski

Instytut Fizyki
Uniwersytet Mikołaja Kopernika



Co to jest kropka kwantowa?

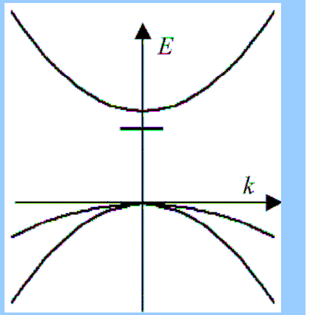


Co to jest ekscyton?

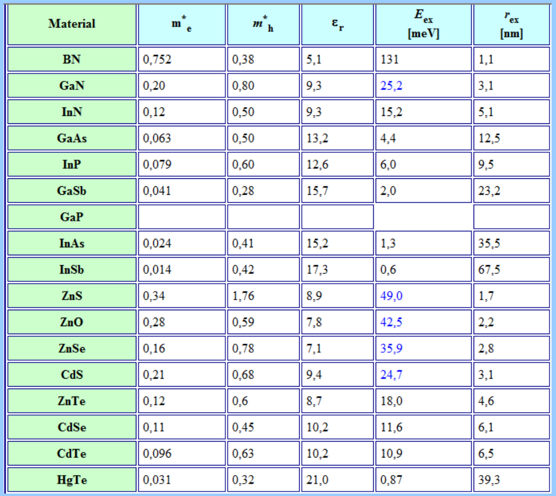
$$\left(-\frac{\hbar^2}{2\,m^*}\Delta-\frac{e^2}{4\pi\varepsilon_0\,\varepsilon_s\,r}\right)\Phi_n(\mathbf{r})=E\,\Phi_n(\mathbf{r})$$

$$E_n=-\frac{R^*}{n^2}\,;\qquad n=1,2,\ldots\,;$$

$$R^*=13.6eV\,\frac{m^*}{\varepsilon_s^{\,2}}\,;\qquad m^*=\frac{m_e m_h}{m_e+m_h}\,;$$

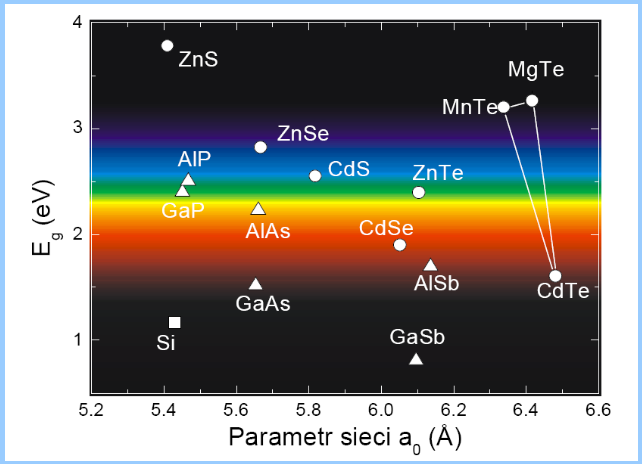


Co to jest ekscyton?

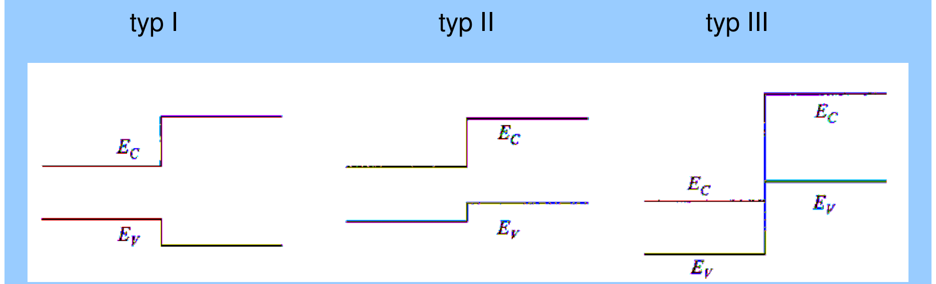


Material	m^*_e	m^*_h	ε_r	E_{ex} [meV]	r_{ex} [nm]
BN	0,752	0,38	5,1	131	1,1
GaN	0,20	0,80	9,3	25,2	3,1
InN	0,12	0,50	9,3	15,2	5,1
GaAs	0,063	0,50	13,2	4,4	12,5
InP	0,079	0,60	12,6	6,0	9,5
GaSb	0,041	0,28	15,7	2,0	23,2
GaP					
InAs	0,024	0,41	15,2	1,3	35,5
InSb	0,014	0,42	17,3	0,6	67,5
ZnS	0,34	1,76	8,9	49,0	1,7
ZnO	0,28	0,59	7,8	42,5	2,2
ZnSe	0,16	0,78	7,1	35,9	2,8
CdS	0,21	0,68	9,4	24,7	3,1
ZnTe	0,12	0,6	8,7	18,0	4,6
CdSe	0,11	0,45	10,2	11,6	6,1
CdTe	0,096	0,63	10,2	10,9	6,5
HgTe	0,031	0,32	21,0	0,87	39,3

Heterozłącze

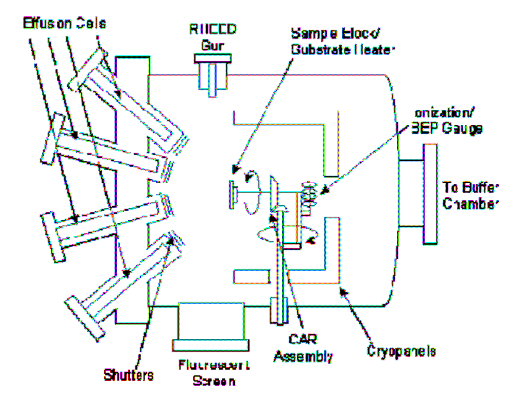


Heterozłącze

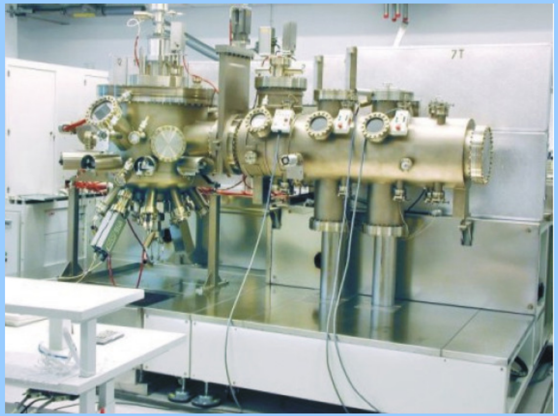


MBE

epitaksja z wiązek molekularnych (MBE)



MBE



Możliwości MBE

- wytwarzanie struktur wielowarstwowych złożonych ze związków o różnych strukturach elektronowych, np. GaAs – AlGaAs (band-gap engineering = inżynieria przerwy energetycznej)

- wysoki stopień czystości chemicznej osadzanych warstw

- dobra kontrola ostrości interfejsu (zmiana składu możliwa w jednej warstwie atomowej), możliwość otrzymywania pojedyńczej warstwy atomowej (1 ML = 1 monolayer)

- otrzymywanie supersieci (np. GaAs-AlGaAs-GaAs- itd.) o okresie od kilku Å.

- szerokie zakresy domieszkowania, np. dla (Al)GaAs, często w zakresie niedostępnym przy wykorzystaniu klasycznych metod wzrostu

Mody wzrostu

Frank van der Merwe

Stranski-Krastanov

Volmer-Weber

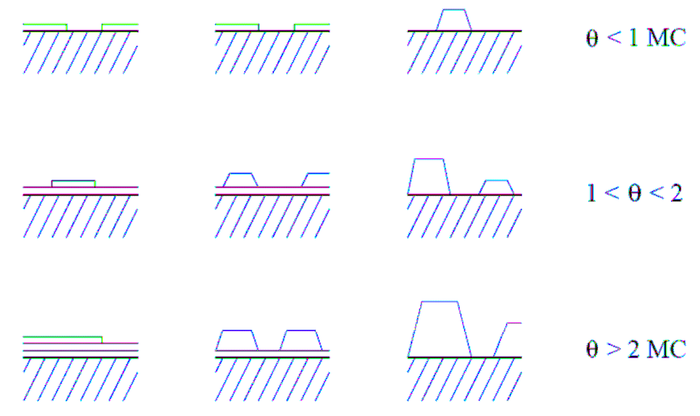
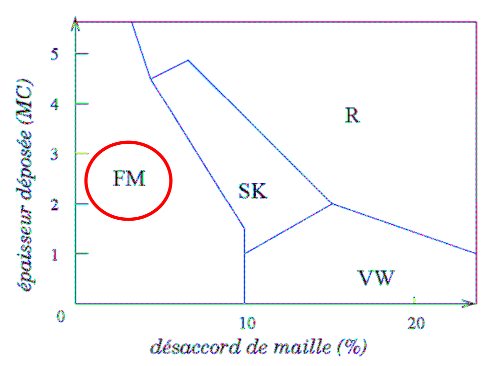


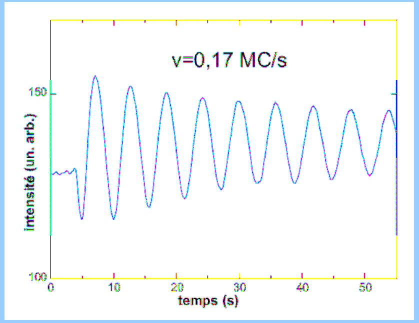
Diagram fazowy

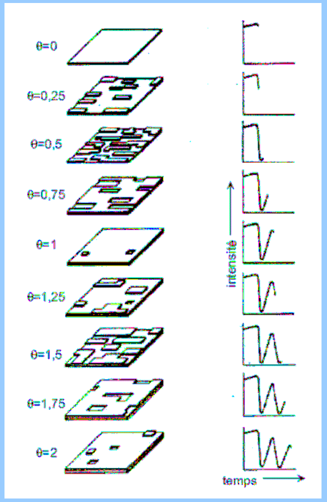


tak powstają studnie kwantowe

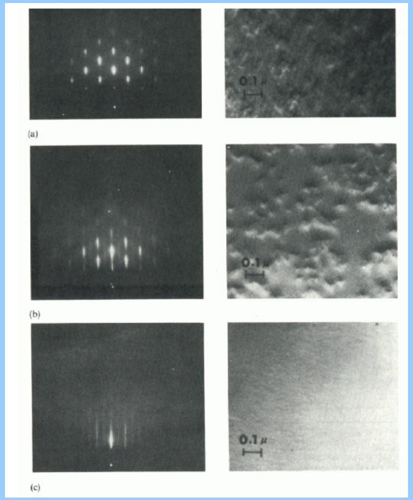
Oscylacje RHEED

oscylacje natężenia pozwalają określić szybkość wzrostu





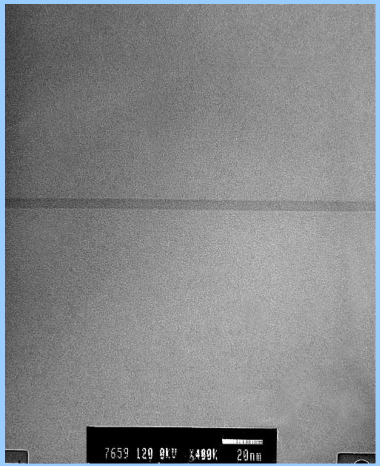
Obraz RHEED



wzrost
wyspowy

Frank van
der Merwe

Studnia kwantowa



GaAlAs

GaAs

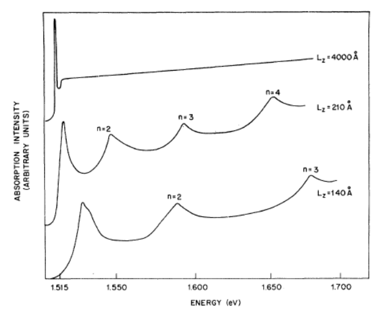
GaAlAs

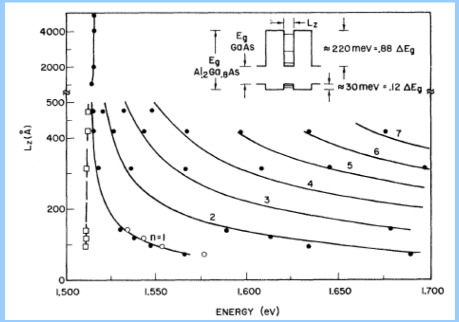
Pierwsze studnie

Quantum States of Confined Carriers in Very Thin
$Al_xGa_{1-x}As$-GaAs-$Al_xGa_{1-x}As$ Heterostructures

R. Dingle, W. Wiegmann, and C. H. Henry
Bell Laboratories, Murray Hill, New Jersey 07974

(Received 24 June 1974)



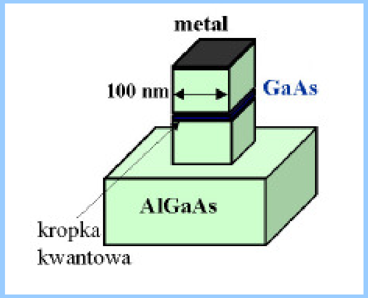


Studnia kwantowa

-) wpływ kwantowania przestrzennego na widmo absorpcji
i energię emisji ekscytonowej
-) tunelowanie nośników pomiędzy dwiema studniami o różnej
szerokości
-) tworzenie się ekscytonu skośnego – wzrost czasu rekombinacji
-) efekt Starka dla ekscytonu w studni kwantowej
-) efekty ekscytonowe: obserwacja biekscytonu i ekscytonów
naładowanych (trionów)
-) domieszkowanie modulacyjne – rekordowe ruchliwości
-) wytwarzanie studni profilowanych, w tym trójkątnych
i parabolicznych, metodą *digital alloy growth*

Wytwarzanie kropek

litografia przy użyciu wiązki elektronowej + trawienie chemiczne



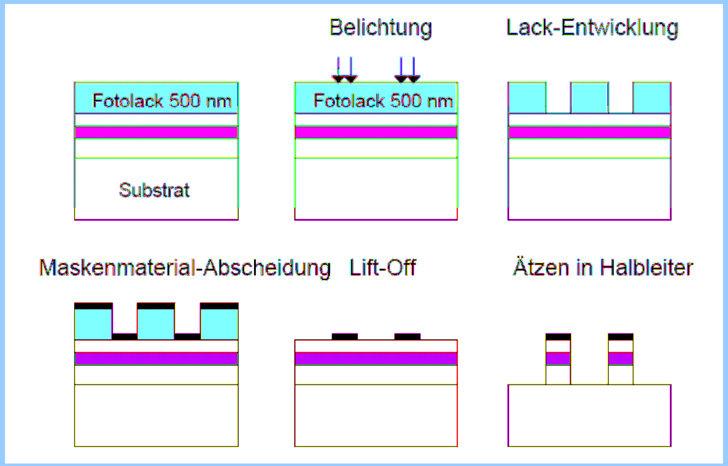
zaawansowana technologia

defekty na powierzchni –
niska jakość optyczna

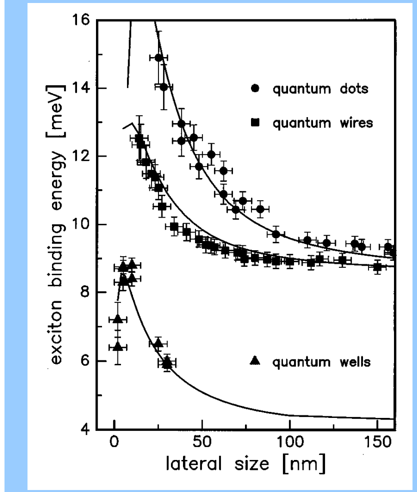
Litografia elektronowa

IFPAN

Litografia + trawienie



Energie wiązania ekscytonu



wzrost energii wiązania dla
struktur o obniżonej wymiarowości

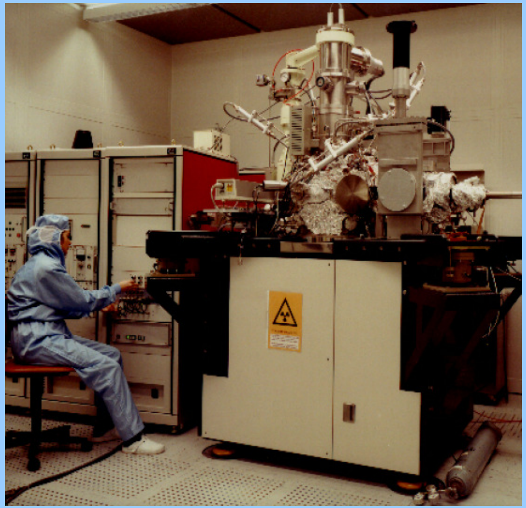
układy niskowymiarowe definiowane
przy pomocy litografii elektronowej
pozwalają na systematyczne pomiary
zależności wielkości fizycznych od
stopnia lokalizacji przestrzennej

Interdyfuzja

selektywna przestrzennie interdyfuzja
selektywność zapewniona przez odpowiednio przygotowaną maskę

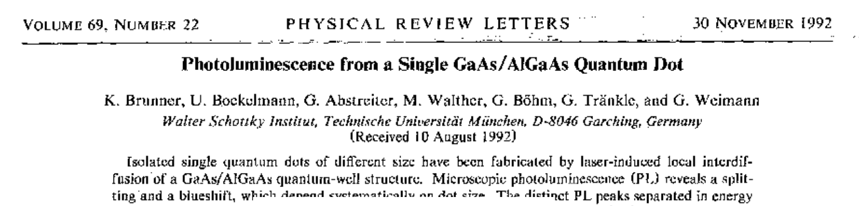
- zaawansowana technologia
- względnie dobra jakość optyczna
- rozmiary ~ kilkaset nm

Wiązka jonów



Uni Würzburg

Kropka kwantowa „dyfuzyjna”



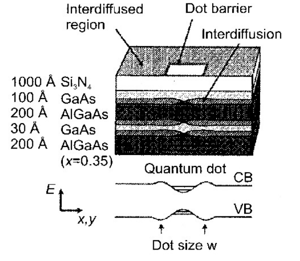
VOLUME 69, NUMBER 22 PHYSICAL REVIEW LETTERS 30 NOVEMBER 1992

Photoluminescence from a Single GaAs/AlGaAs Quantum Dot

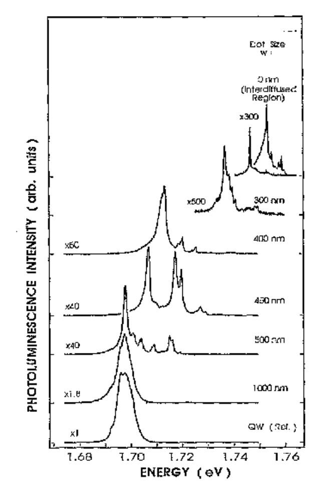
K. Brunner, U. Bockelmann, G. Abstreiter, M. Walther, G. Böhm, G. Tränkle, and G. Weimann
Walter Schottky Institut, Technische Universität München, D-8046 Garching, Germany

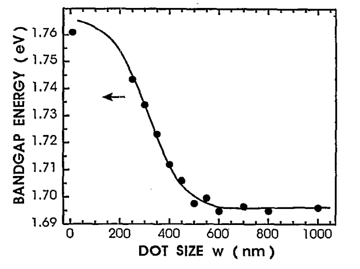
(Received 10 August 1992)

Isolated single quantum dots of different size have been fabricated by laser-induced local interdiffusion of a GaAs/AlGaAs quantum-well structure. Microscopic photoluminescence (PL) reveals a splitting and a blueshift, which depend systematically on dot size. The distinct PL peaks separated in energy
by up to 10 meV are ensional (0D) electron and hole
states. Complete qua ous broadening in a single dot
structure cause PL lin gher-energy transitions indicates
the slowed energy rela



Kropka kwantowa „dyfuzyjna”

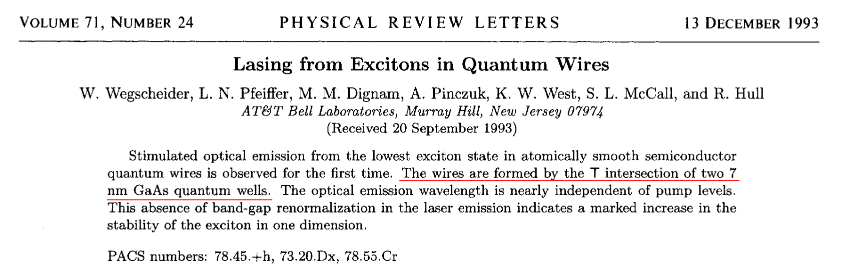




zależność energii emisji
od rozmiaru obszaru „kropki”

Wzrost na przełomie

cleaved edge overgrowth – początkowo metoda otrzymywania drutów kwantowych w kształcie litery T



VOLUME 71, NUMBER 24 PHYSICAL REVIEW LETTERS 13 DECEMBER 1993

Lasing from Excitons in Quantum Wires

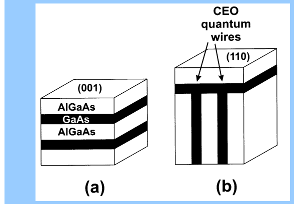
W. Wegscheider, L. N. Pfeiffer, M. M. Dignam, A. Pinczuk, K. W. West, S. L. McCall, and R. Hull
AT&T Bell Laboratories, Murray Hill, New Jersey 07974

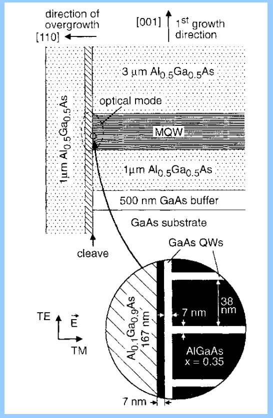
(Received 20 September 1993)

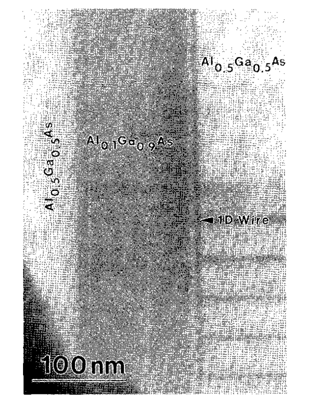
Stimulated optical emission from the lowest exciton state in atomically smooth semiconductor quantum wires is observed for the first time. The wires are formed by the T intersection of two 7 nm GaAs quantum wells. The optical emission wavelength is nearly independent of pump levels. This absence of band-gap renormalization in the laser emission indicates a marked increase in the stability of the exciton in one dimension.

PACS numbers: 78.45.+h, 73.20.Dx, 78.55.Cr

Wzrost na przełomie



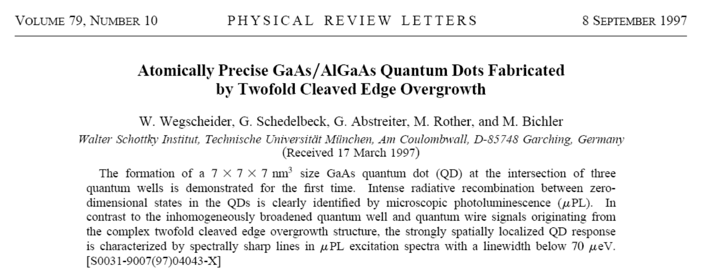




kontrola rozmiaru

trudność w dokładnym przełamaniu próbki w warunkach UHV

Kropka kwantowa na przełomie



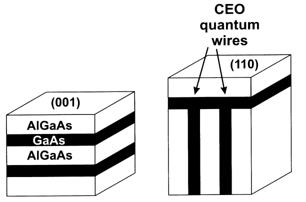
VOLUME 79, NUMBER 10 PHYSICAL REVIEW LETTERS 8 SEPTEMBER 1997

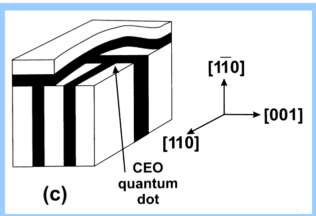
Atomically Precise GaAs/AlGaAs Quantum Dots Fabricated by Twofold Cleaved Edge Overgrowth

W. Wegscheider, G. Schedelbeck, G. Abstreiter, M. Rother, and M. Bichler
Walter Schottky Institut, Technische Universität München, Am Coulombwall, D-85748 Garching, Germany

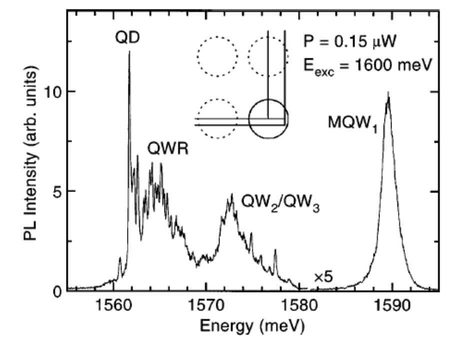
(Received 17 March 1997)

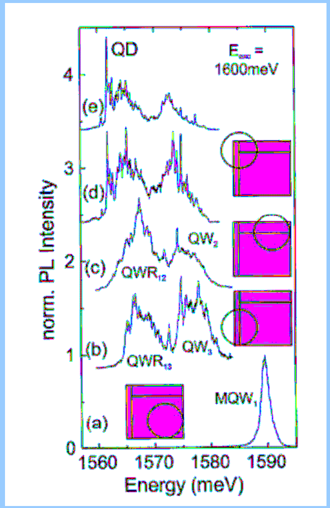
The formation of a $7 \times 7 \times 7$ nm^3 size GaAs quantum dot (QD) at the intersection of three quantum wells is demonstrated for the first time. Intense radiative recombination between zero-dimensional states in the QDs is clearly identified by microscopic photoluminescence (μPL). In contrast to the inhomogeneously broadened quantum well and quantum wire signals originating from the complex twofold cleaved edge overgrowth structure, the strongly spatially localized QD response is characterized by spectrally sharp lines in μPL excitation spectra with a linewidth below 70 μeV. [S0031-9007(97)04043-X]





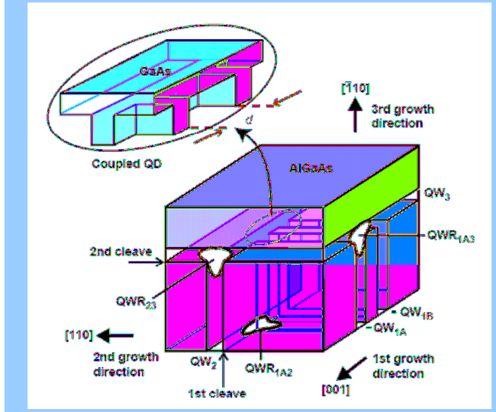
Ekscyton w kropce





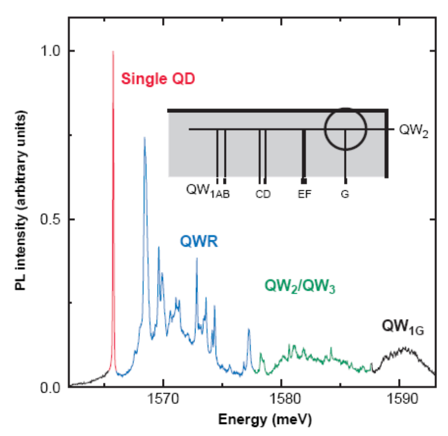
bardzo wąskie linie ekscytonowe Γ~70 µeV

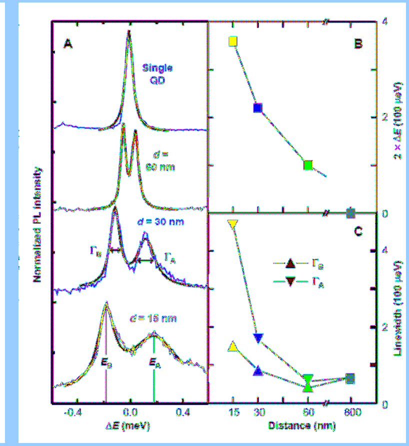
Układ dwóch kropek



zmiana odległości d między studniami prowadzi do wytworzenia układu podwójnych kropek kwantowych (*quantum dot molecule*)

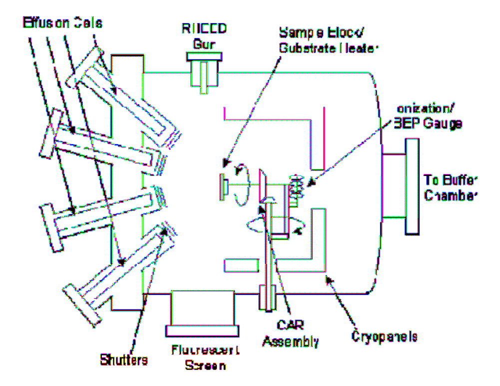
Układ dwóch kropek





Epitaksja z użyciem masek

epitaksja z wiązek molekularnych (MBE)



strumienie atomów padają na podłoże pod dobrze określonym kątem

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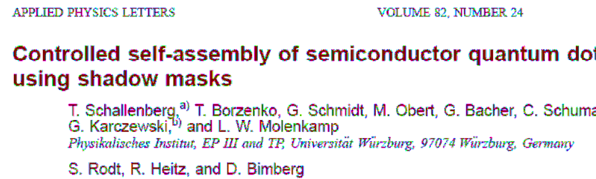
Epitaksja z użyciem masek

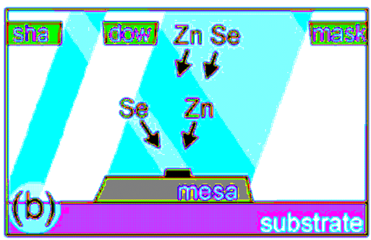

APPLIED PHYSICS LETTERS VOLUME 82, NUMBER 24 16 JUNE 2003

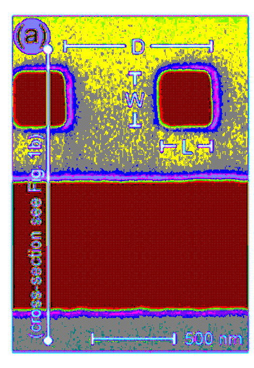
Controlled self-assembly of semiconductor quantum dots using shadow masks

T. Schallenberg,[a] T. Borzenko, G. Schmidt, M. Obert, G. Bacher, C. Schumacher,
G. Karczewski,[b] and L. W. Molenkamp
Physikalisches Institut, EP III and TP, Universität Würzburg, 97074 Würzburg, Germany

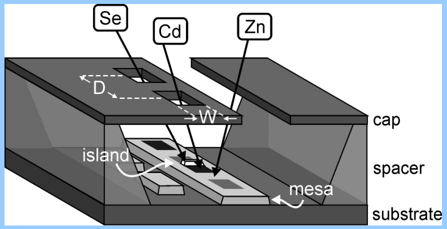
S. Rodt, R. Heitz, and D. Bimberg
Institut für Festkörperphysik, TU Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

(Received 27 December 2002; accepted 9 April 2003)



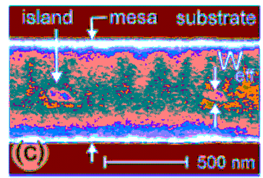


Epitaksja z użyciem masek

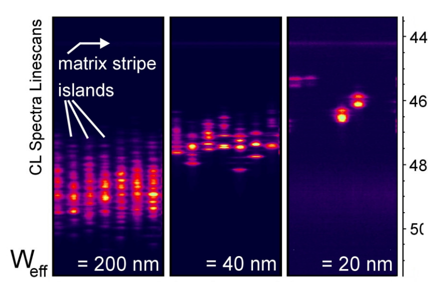


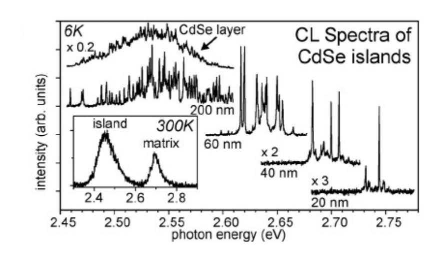
sekwencja:
Zn+Se = uformowanie bariery
Cd+Se = uformowanie kropek
Zn+Se = uformowanie bariery

dla niewielkich rozmiarów masek uzyskano niewielkie liczby kropek kwantowych
znaczna odległość (~900 nm) pomiędzy poszczególnymi wyspami z kropkami pozwala obserwować pojedyncze kropki



Epitaksja z użyciem masek





pojedyncze kropki kwantowe
o wąskich liniach emisyjnych

Mody wzrostu

Frank van der Merwe

Stranski-Krastanov

Volmer-Weber

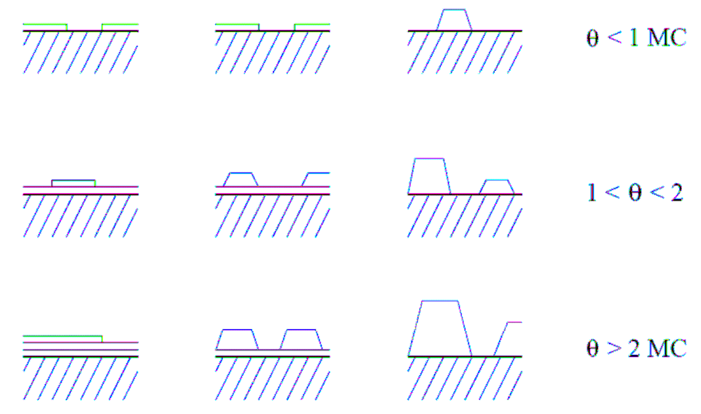
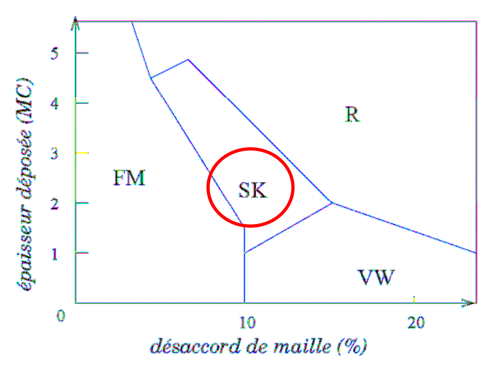


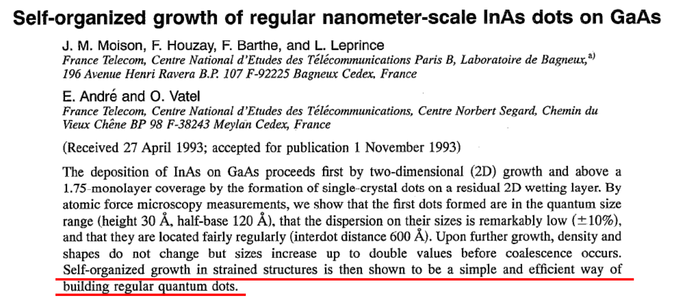
Diagram fazowy



Composés	Désaccord de maille (%)
$InAs/GaAs$	7,2
$CdSe/ZnSe$	6,8
GaN/AlN	2,4(c); 2,7(h)
$Si_{0,7}Ge_{0,3}/Si$	1,2
CdTe/ZnTe	6,2

tak powstają kropki kwantowe

Kropki samorosnące



Self-organized growth of regular nanometer-scale InAs dots on GaAs

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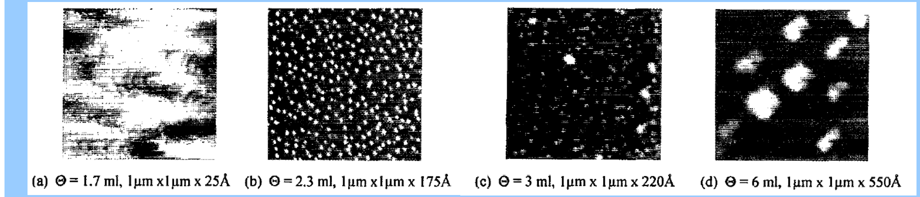
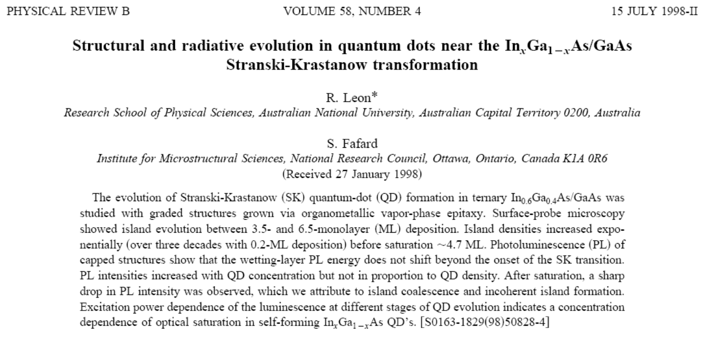
(Received 27 April 1993; accepted for publication 1 November 1993)

The deposition of InAs on GaAs proceeds first by two-dimensional (2D) growth and above a 1.75-monolayer coverage by the formation of single-crystal dots on a residual 2D wetting layer. By atomic force microscopy measurements, we show that the first dots formed are in the quantum size range (height 30 Å, half-base 120 Å), that the dispersion on their sizes is remarkably low (±10%), and that they are located fairly regularly (interdot distance 600 Å). Upon further growth, density and shapes do not change but sizes increase up to double values before coalescence occurs. Self-organized growth in strained structures is then shown to be a simple and efficient way of building regular quantum dots.



(a) Θ = 1.7 ml, 1μm x 1μm x 25Å (b) Θ = 2.3 ml, 1μm x 1μm x 175Å (c) Θ = 3 ml, 1μm x 1μm x 220Å (d) Θ = 6 ml, 1μm x 1μm x 550Å

Kropki samorosnące



PHYSICAL REVIEW B VOLUME 58, NUMBER 4 15 JULY 1998-II

Structural and radiative evolution in quantum dots near the $In_xGa_{1-x}As/GaAs$ Stranski-Krastanow transformation

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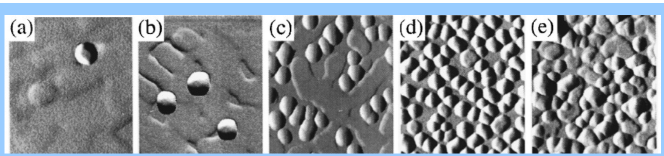
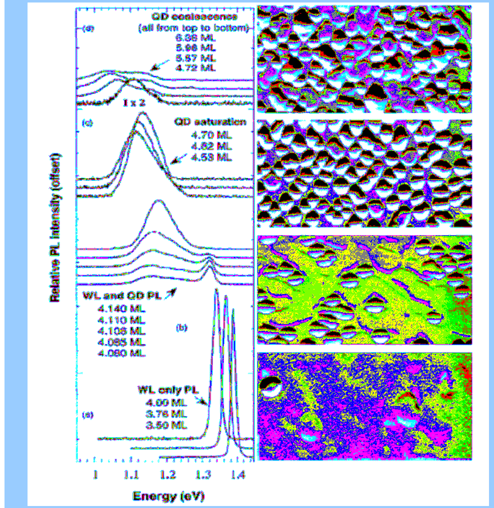
(Received 27 January 1998)

The evolution of Stranski-Krastanow (SK) quantum-dot (QD) formation in ternary $In_{0.6}Ga_{0.4}As/GaAs$ was studied with graded structures grown via organometallic vapor-phase epitaxy. Surface-probe microscopy showed island evolution between 3.5- and 6.5-monolayer (ML) deposition. Island densities increased exponentially (over three decades with 0.2-ML deposition) before saturation ~4.7 ML. Photoluminescence (PL) of capped structures show that the wetting-layer PL energy does not shift beyond the onset of the SK transition. PL intensities increased with QD concentration but not in proportion to QD density. After saturation, a sharp drop in PL intensity was observed, which we attribute to island coalescence and incoherent island formation. Excitation power dependence of the luminescence at different stages of QD evolution indicates a concentration dependence of optical saturation in self-forming $In_xGa_{1-x}As$ QD's. [S0163-1829(98)50828-4]



Morfologia a luminescencja

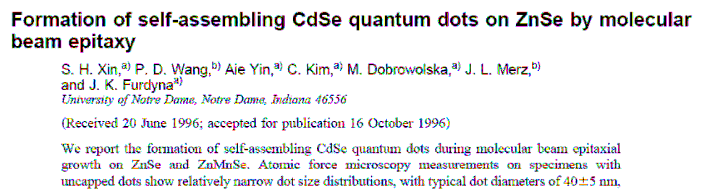


brak emisji z WL
słaba intensywność emisji
z kropek kwantowych

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

energia przesuwa się ze
wzrostem grubości warstwy
InGaAs

Kropki kwantowe CdSe/ZnSe



Formation of self-assembling CdSe quantum dots on ZnSe by molecular beam epitaxy

S. H. Xin,[a] P. D. Wang,[b] Aie Yin,[a] C. Kim,[a] M. Dobrowolska,[a] J. L. Merz,[b]
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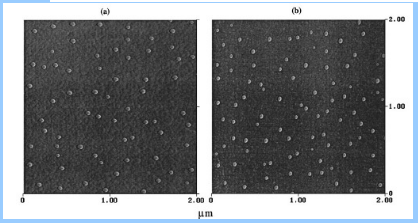
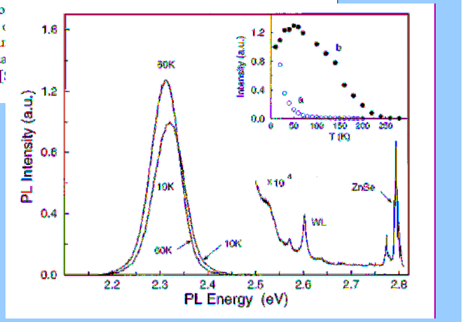
(Received 20 June 1996; accepted for publication 16 October 1996)

We report the formation of self-assembling CdSe quantum dots during molecular beam epitaxial growth on ZnSe and ZnMnSe. Atomic force microscopy measurements on specimens with uncapped dots show relatively narrow dot size distributions, with typical dot diameters of 40±5 nm, and with a diameter-to-height ratio consistently very clo
with time: their density was observed to drop by an
evidence of ripening observed for some dots. Photolumin
localization much stronger than in ZnCdSe/ZnSe qua
confinement. © *1996 American Institute of Physics.*





Kropki kwantowe CdTe/ZnTe

APPLIED PHYSICS LETTERS VOLUME 73, NUMBER 25 21 DECEMBER 1998

Zero-dimensional excitonic properties of self-organized quantum dots of CdTe grown by molecular beam epitaxy

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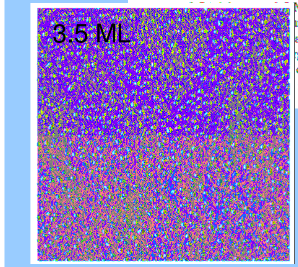
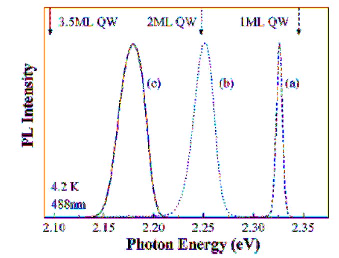
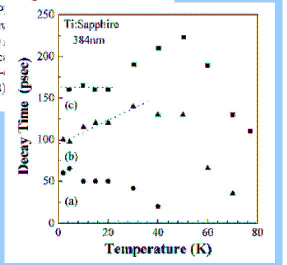
(Received 22 June 1998; accepted for publication 18 October 1998)

The successful growth of self-organized quantum dots (QDs) of CdTe on ZnTe (100) surface by molecular beam epitaxy is reported. Atomic force microscope measurements on the uncapped samples revealed the formation of CdTe QDs with typical dot diameters of 20±2 nm and heights of


3.5 ML





Kropki kwantowe CdTe/ZnTe

APPLIED PHYSICS LETTERS VOLUME 74, NUMBER 20 17 MAY 1999

Photoluminescence study of CdTe/ZnTe self-assembled quantum dots

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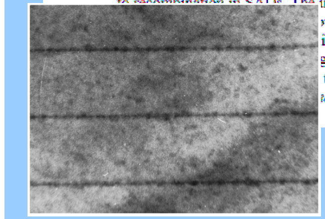
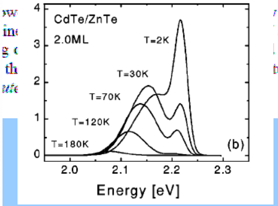
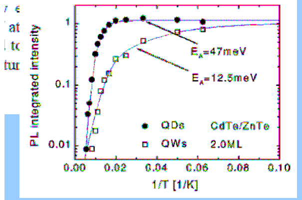
(Received 19 August 1998; accepted for publication 26 March 1999)

We report on optical properties of CdTe self-assembled quantum dots (SADs) grown by molecular beam epitaxy on ZnTe. Formation of SADs was achieved by deposition of 1.5–2.5 monolayers of CdTe at a substrate temperature of 420 °C and by applying growth interrupts for few seconds in Cd flux. The resulting dots have a typical diameter of 2 nm and a sheet density of 10^{12} cm^{-2}. At T=2 K the photoluminescence (PL) spectra consist of two emission lines. The high-energy line originates from excitonic recombination in a wetting layer while the low-energy emission PL band is assigned







Korelacje przestrzenne

VOLUME 75, NUMBER 13 PHYSICAL REVIEW LETTERS 25 SEPTEMBER 1995

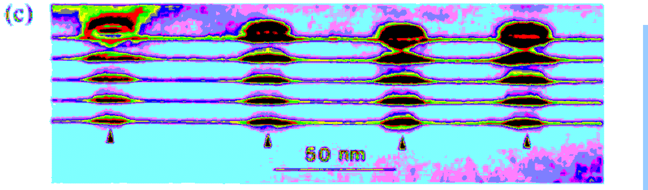
Vertically Self-Organized InAs Quantum Box Islands on GaAs(100)

Qianghua Xie, Anupam Madhukar, Ping Chen, and Nobuhiko P. Kobayashi
Photonic Materials and Devices Laboratory, Departments of Materials Science and Physics, University of Southern California, Los Angeles, California 90089-0241

(Received 6 April 1995)

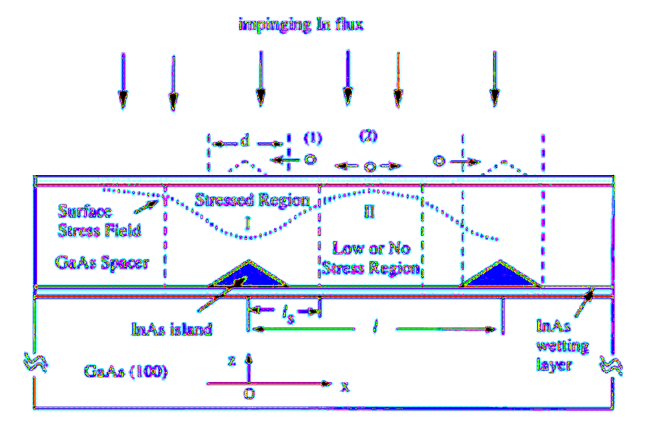
Coherent InAs islands separated by GaAs spacer layers are shown to exhibit self-organized growth along the vertical (i.e., growth) direction. The driving force for such vertically self-organized growth is shown to be the interacting strain fields induced by the islands which give rise to a preferred direction for In migration. A model analysis accounting for the mechanochemical surface diffusion gives an island average size and average separation dependent characteristic spacer layer thickness z_0 below which a vertically self-organized growth occurs.

(c)



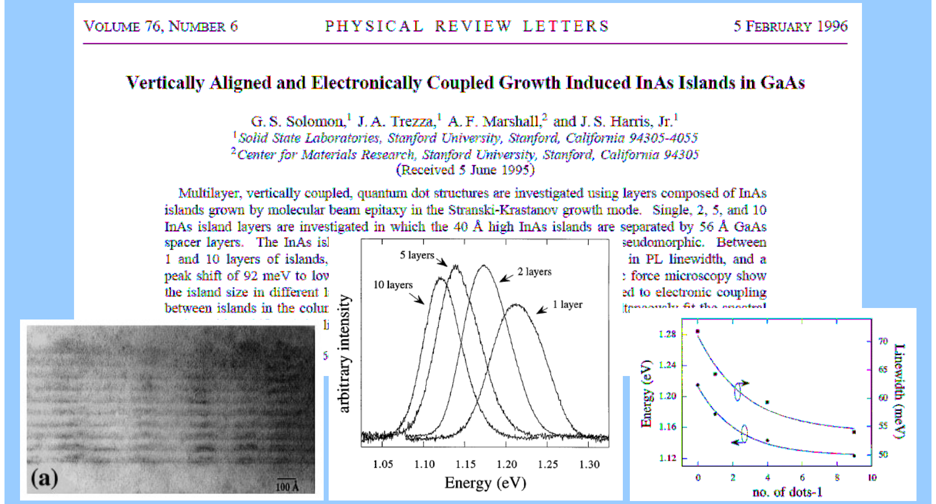
Δ=36ML

Korelacje przestrzenne



brak informacji optycznej

Korelacje przestrzenne



VOLUME 76, NUMBER 6 PHYSICAL REVIEW LETTERS 5 FEBRUARY 1996

Vertically Aligned and Electronically Coupled Growth Induced InAs Islands in GaAs

G. S. Solomon,[1] J. A. Trezza,[1] A. F. Marshall,[2] and J. S. Harris, Jr.[1]
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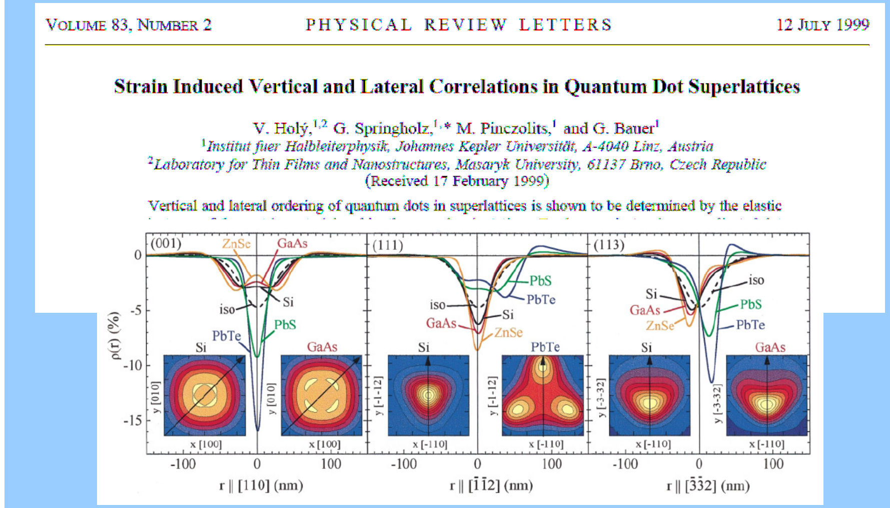
[2] *Center for Materials Research, Stanford University, Stanford, California 94305*
(Received 5 June 1995)

Multilayer, vertically coupled, quantum dot structures are investigated using layers composed of InAs islands grown by molecular beam epitaxy in the Stranski-Krastanov growth mode. Single, 2, 5, and 10 InAs island layers are investigated in which the 40 Å high InAs islands are separated by 56 Å GaAs
spacer layers. The InAs isl … seudomorphic. Between
1 and 10 layers of islands, … in PL linewidth, and a
peak shift of 92 meV to low … force microscopy show
the island size in different l … ed to electronic coupling
between islands in the colur

Kryształ z kropek



VOLUME 83, NUMBER 2 PHYSICAL REVIEW LETTERS 12 JULY 1999

Strain Induced Vertical and Lateral Correlations in Quantum Dot Superlattices

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[2] *Laboratory for Thin Films and Nanostructures, Masaryk University, 61137 Brno, Czech Republic*
(Received 17 February 1999)

Vertical and lateral ordering of quantum dots in superlattices is shown to be determined by the elastic

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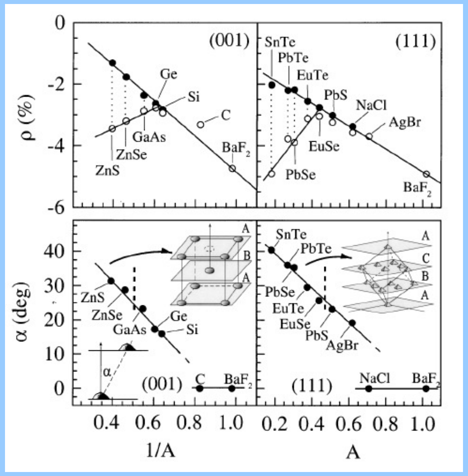
Kryształ z kropek



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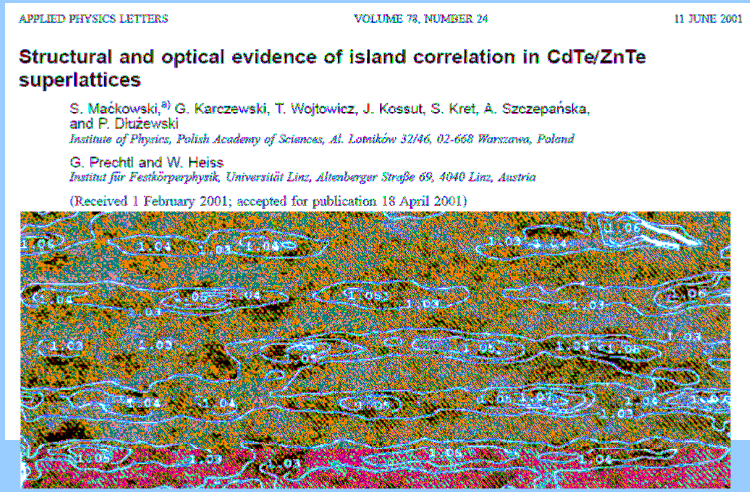

APPLIED PHYSICS LETTERS VOLUME 78, NUMBER 24 11 JUNE 2001

Structural and optical evidence of island correlation in CdTe/ZnTe superlattices

S. Maćkowski,[a)] G. Karczewski, T. Wojtowicz, J. Kossut, S. Kret, A. Szczepańska, and P. Dłużewski
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