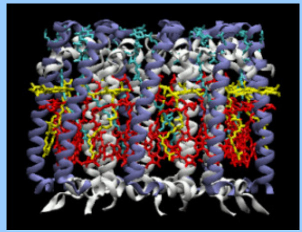
Optyka nanostruktur



Sebastian Maćkowski

Instytut Fizyki
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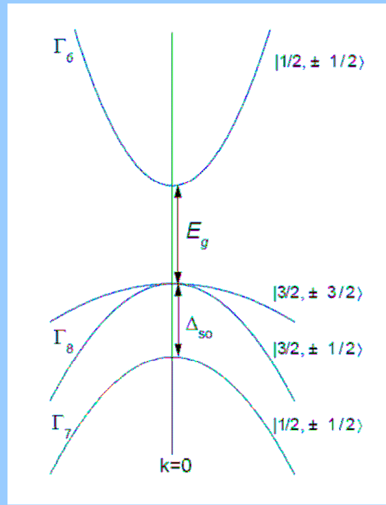
Biuro: **365**, telefon: **611-3250**

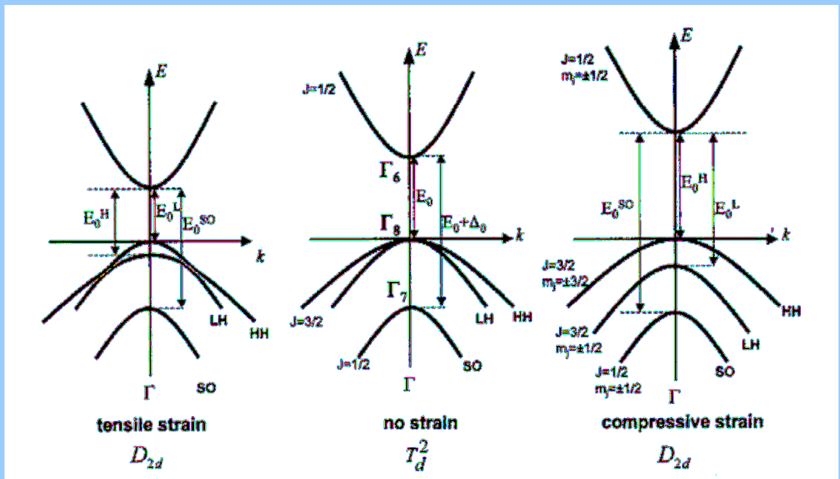
Struktura pasmowa



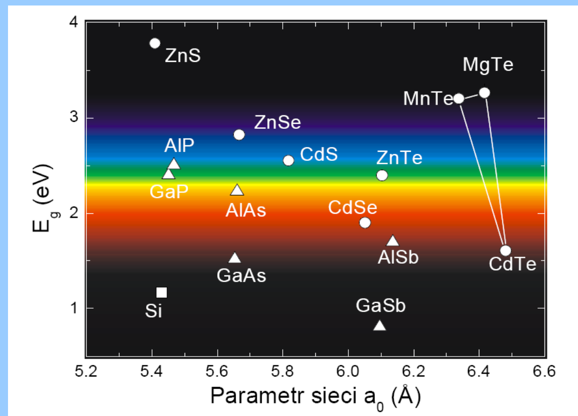
przejścia optycznie dozwolone:
Δs=±1 – bright exciton

przejścia wzbronione
Δs=±2 – dark exciton

Wpływ naprężeń



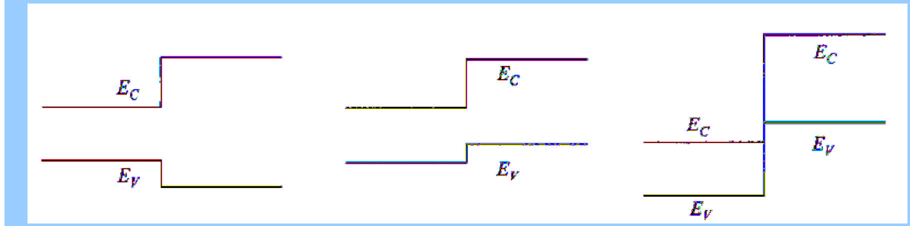
Stała sieci vs. energia przerwy



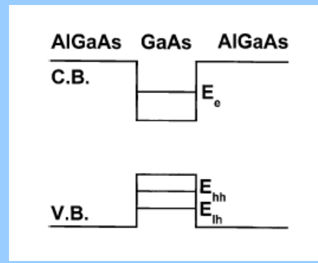
dla większości układów występuje
niedopasowanie sieciowe!

Heterozłącze

typ I | typ II | typ III



Studnia kwantowa



dla nieskończonych barier

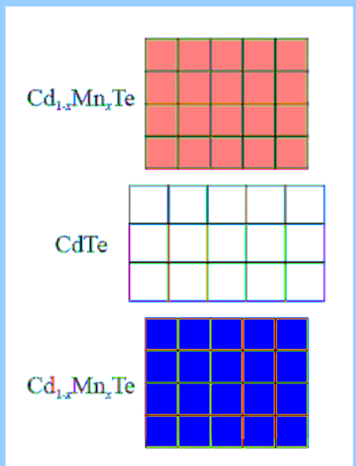
$$E_n = \frac{\hbar^2 \pi^2 n^2}{mL^2}$$

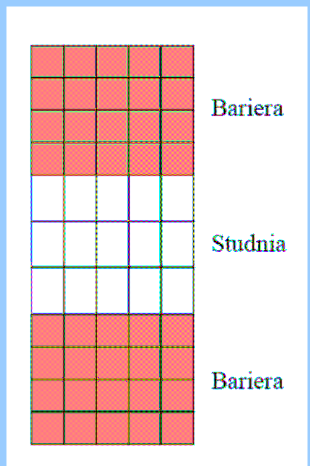
dla skończonych barier

$$V_h(z_h) = \begin{cases} 0, & |z_h| < \frac{1}{2}L \\ V_h, & |z_h| > \frac{1}{2}L \end{cases}$$

$$V_e(z_e) = \begin{cases} 0, & |z_e| < \frac{1}{2}L \\ V_e, & |z_e| > \frac{1}{2}L \end{cases}$$

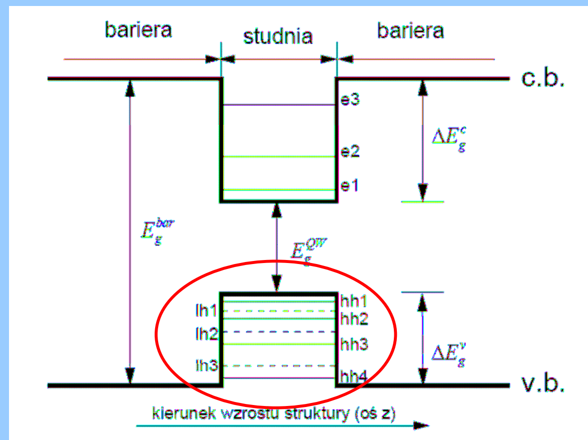
Wzrost pseudomorficzny





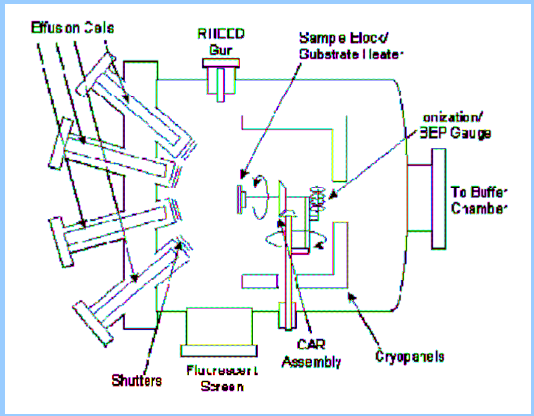
naprężenie ściskające

Zniesienie degeneracji pasm



Epitaksja

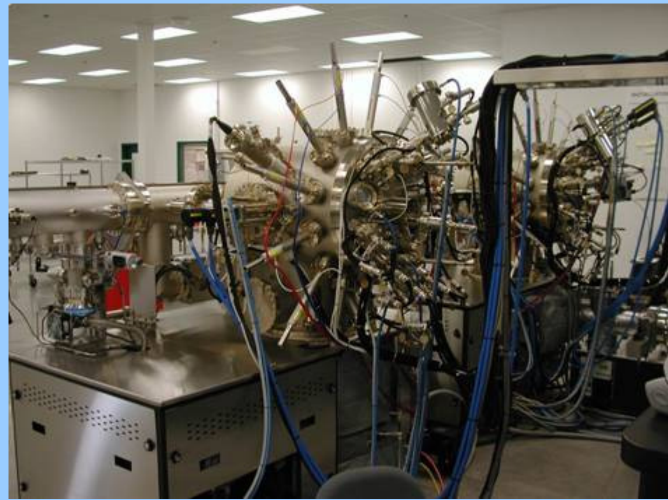
epitaksja z wiązek molekularnych (MBE)



p~10^{-9}-10^{-10} Torr
1Torr – 133 Pa

charakteryzacja
in-situ

Urządzenie MBE



Możliwości MBE

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

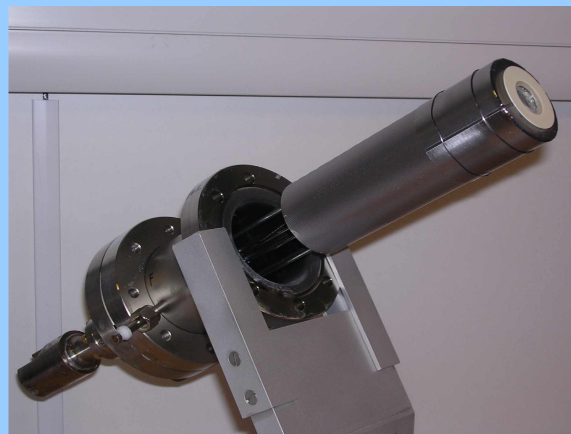
- wysoki stopień czystości chemicznej osadzanych warstw

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

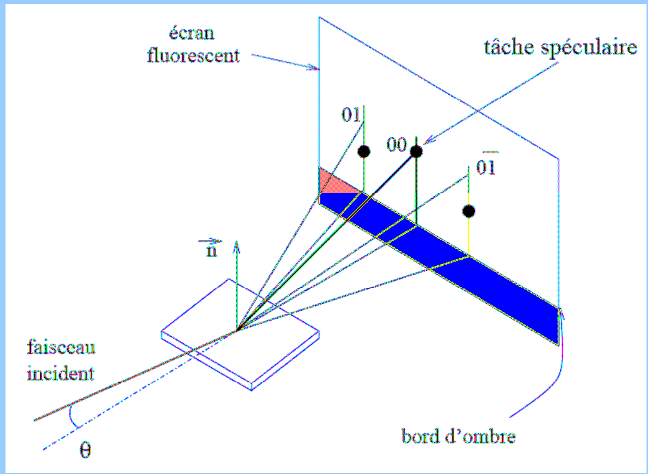
- otrzymywanie supersieci (np. GaAs-AlGaAs-GaAs- itd.) o okresie od kilku Å.

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

Komórka efuzyjna

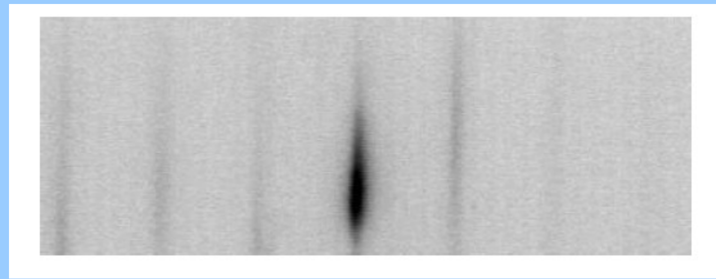


RHEED



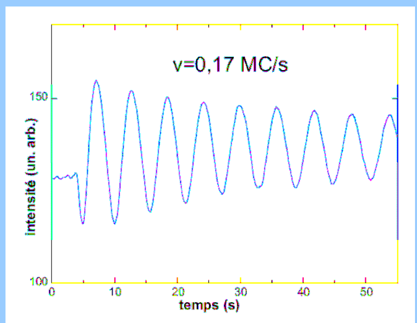
RHEED

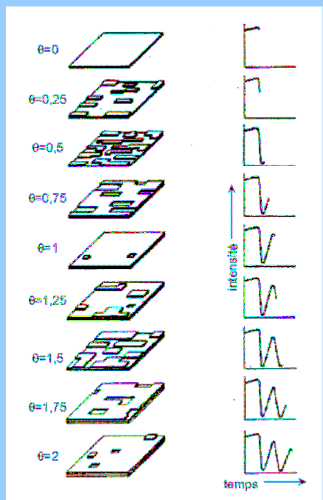
warstwa CdTe na podłożu ZnTe



Oscylacje RHEED

oscylacje natężenia pozwalają określić szybkość wzrostu





Mody wzrostu

Frank van der Merwe | Stranski-Krastanov | Volmer-Weber

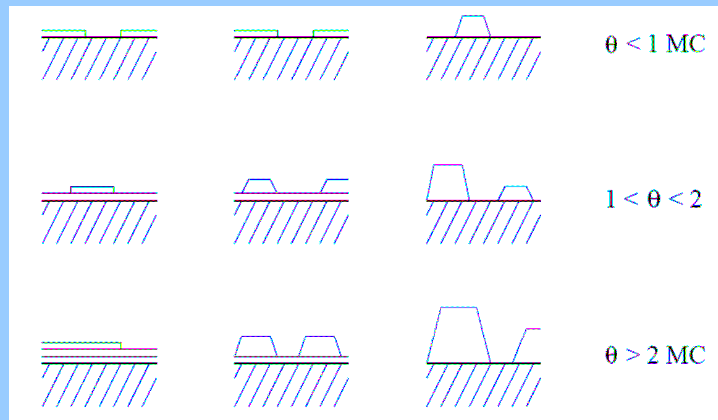
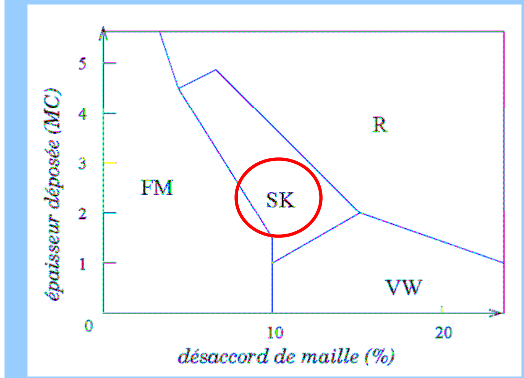


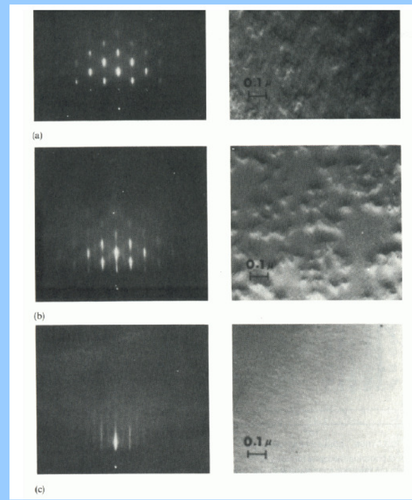
Diagram fazowy



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

Obraz RHEED

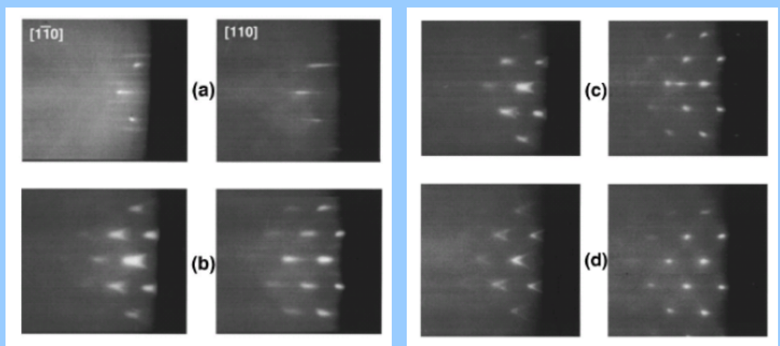


wzrost wyspowy

Frank van der Merwe

Obraz RHEED

RHEED w przypadku wzrostu warstw niedopasowanych sieciowo

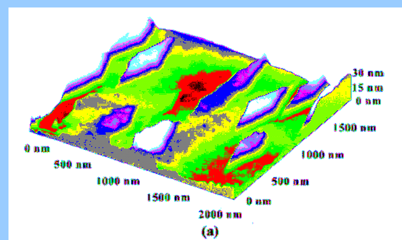


wzrost InAs na GaAs(001)
przy ok. 2 ML wzrost przechodzi w mod Stransky-Krastanov'a

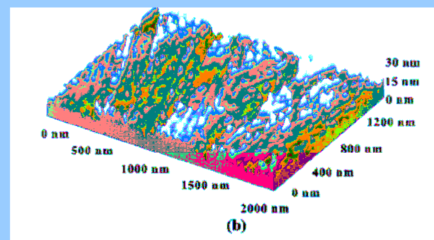
AFM

AFM – mikroskopia sił atomowych jako metoda charakteryzacji powierzchni w ultra wysokiej próżni

3 ML CdTe na ZnTe

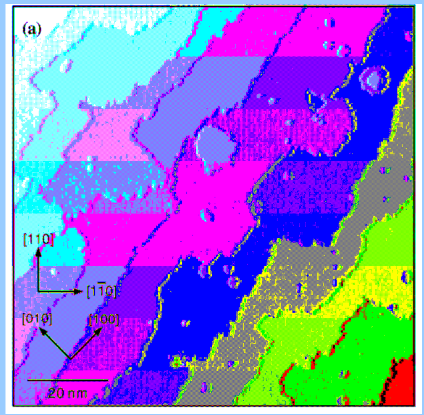


6 ML CdTe na ZnTe

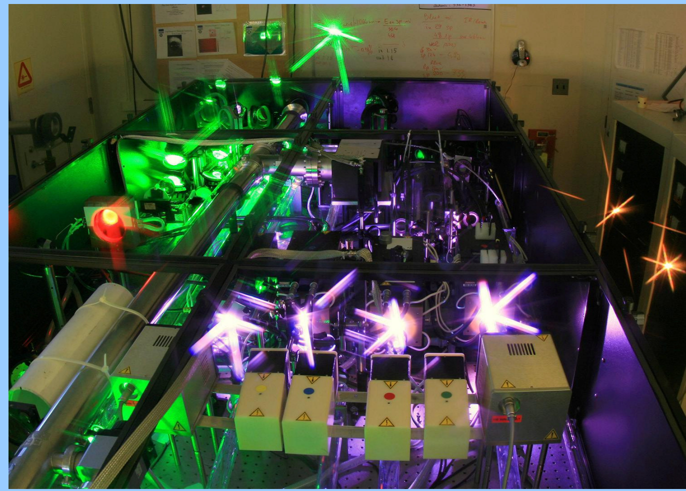


STM

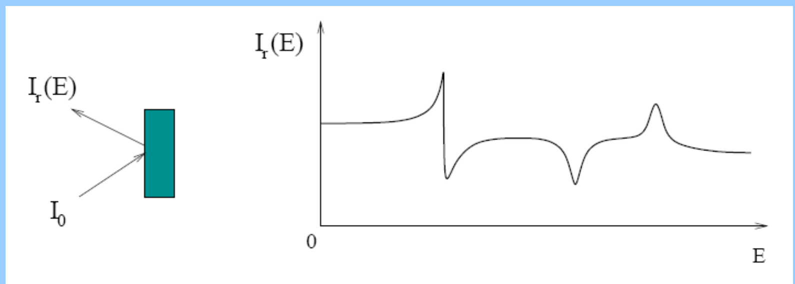
STM – skaningowa mikroskopia tunelowa jako metoda charakteryzacji powierzchni w ultra wysokiej próżni



Spektroskopia optyczna

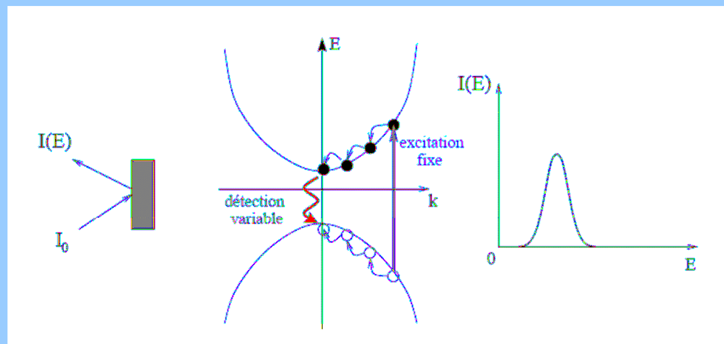


Odbicie



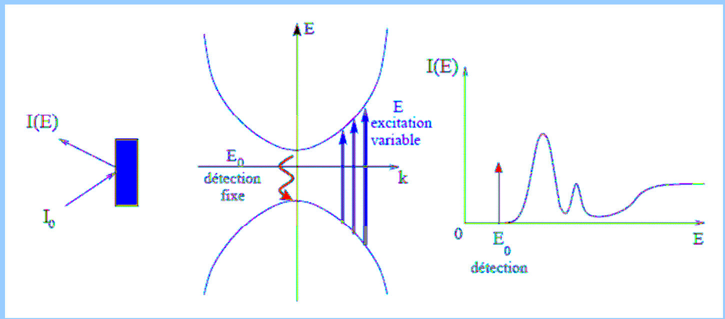
energie ekscytonów – pomiar prostszy niż absorpcja

Luminescencja



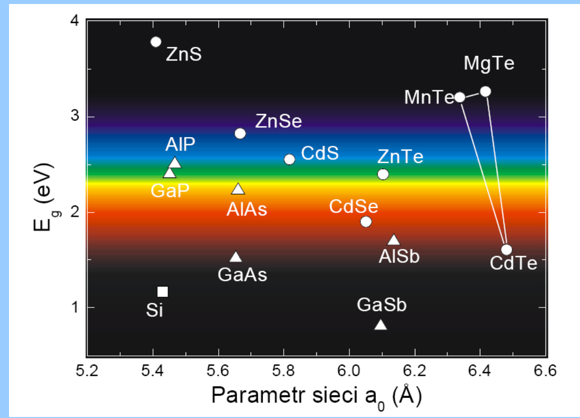
dynamika ekscytonów,
mechanizmy poszerzenia

Wzbudzenie luminescencji



wzbudzenie ekscytonów,
mechanizmy relaksacji

Pierwsze studnie



GaAs-AlGaAs – dla 30% Al brak niedopasowania sieciowego

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)

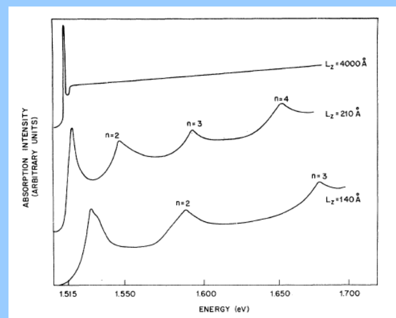
Quantum levels associated with the confinement of carriers in very thin, molecular-beam–grown $Al_xGa_{1-x}As$-GaAs-$Al_xGa_{1-x}As$ heterostructures result in pronounced structure in the GaAs optical absorption spectrum. Up to eight resolved exciton transitions, associated with different bound-electron and bound-hole states, have been observed. The heterostructure behaves as a simple rectangular potential well with a depth of $\approx 0.88\Delta E_g$ for confining electrons and $\approx 0.12\Delta E_g$ for confining holes, where ΔE_g is the difference in the semiconductor energy gaps.

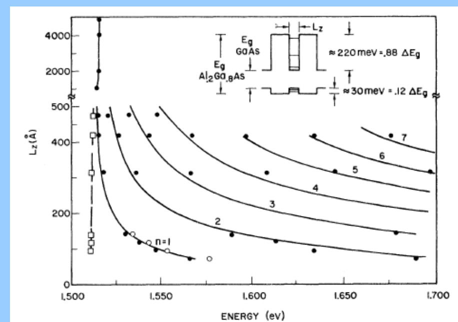
testowanie mechaniki kwantowej!

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)





Luminescencja

PHYSICAL REVIEW B VOLUME 22, NUMBER 2 15 JULY 1980

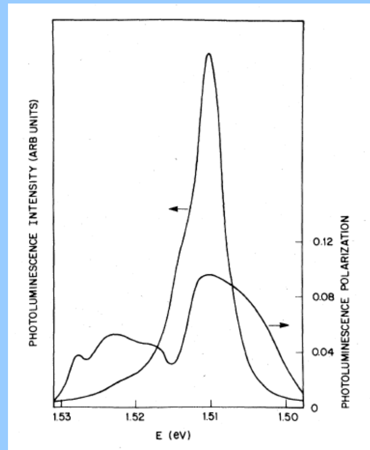
Luminescence studies of optically pumped quantum wells in GaAs-$Al_xGa_{1-x}As$ multilayer structures

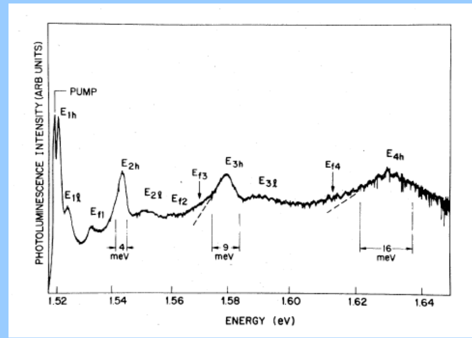
R. C. Miller, D. A. Kleinman, W. A. Nordland, Jr., and A. C. Gossard
Bell Laboratories, Murray Hill, New Jersey 07974

(Received 9 January 1980)

Various properties derivable from the photoluminescence of a multilayer structure consisting of many thin GaAs layers (wells) separated by thin $Al_xGa_{1-x}As$ layers (barriers) have been determined as a function of temperature from 7 K to greater than 150 K. These measurements, which were made utilizing both fixed- and tunable-frequency laser sources, include the following: the circular photoluminescence polarization ρ generated by circularly polarized optical excitation, the magnetic field dependence of ρ in the Voigt geometry (Hanle effect) to determine the electron lifetime τ and spin-relaxation time τ_s, the excitation spectrum for the peak of the photoluminescence which shows thirteen exciton quantum transitions characteristic of multilayer samples, the photoluminescence spectra which exhibit five transitions in emission, the excitation intensity I_p dependence of the integrated photoluminescence intensity, and τ and τ_s as a function of I_p. The temperature dependence of τ_s suggests that there is a center with a binding energy of about 5 meV that relaxes the electron spins at low temperatures. In the high-temperature region, $T \gtrsim 100$ K, τ_s is close to that observed by others for lightly doped p-type bulk GaAs and is close to estimates of τ_s for the D'yakonov-Perel' spin-relaxation mechanism. The absence of optical alignment with linearly polarized pumping and the characteristics of the magnetic field dependence of ρ both argue against significant hole polarization. The linear dependence of the integrated photoluminescence intensity on I_p leads to a simple model for the radiative lifetime whose temperature dependence is found to be consistent with expectations. Also, these data are used to estimate the nonradiative lifetime $\tau_n = 5\times10^{-9}$ sec which varies little with T and the radiative lifetime $\tau_r(T) = 3\times10^{-10}$ sec at 7 K, which varies $\sim T^{3/2}$.

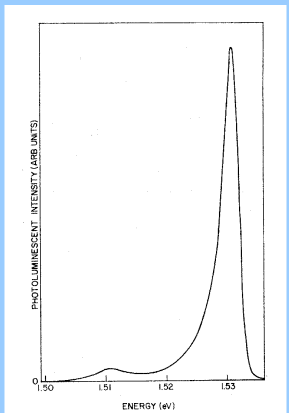
Luminescencja

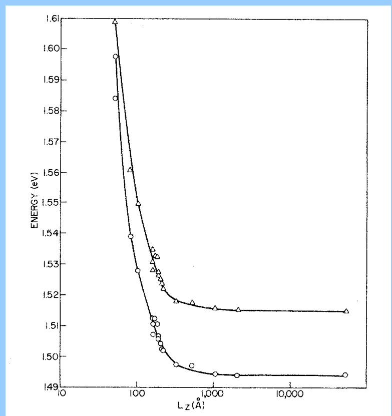




szerokość linii rezonansowych

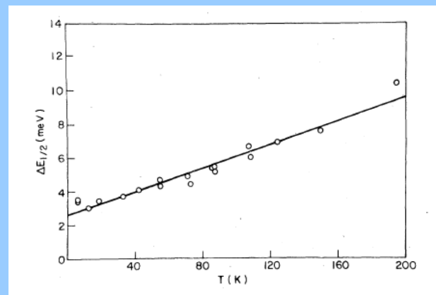
Luminescencja





zależność energii emisji ekscytonu od szerokości studni kwantowej

Luminescencja



poszerzenie linii luminescencyjnej
związane z rozpraszaniem na
fononach akustycznych i optycznych

Biekscyton

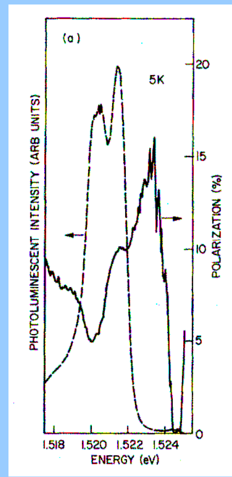
PHYSICAL REVIEW B VOLUME 25, NUMBER 10 15 MAY 1982

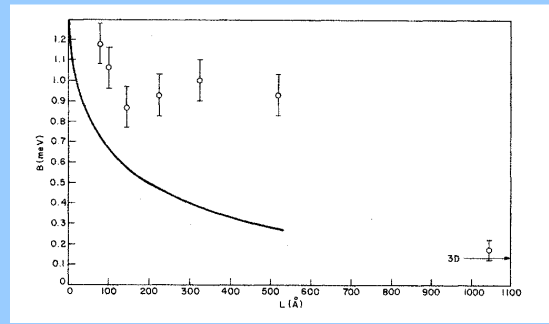
Biexcitons in GaAs quantum wells

R. C. Miller, D. A. Kleinman, A. C. Gossard, and O. Munteanu
Bell Laboratories, Murray Hill, New Jersey 07974
(Received 24 March 1982)

Careful examination of the exciton edge of the photoluminescence from a number of high-quality multiple-GaAs-quantum-well samples grown by molecular-beam epitaxy reveals at low temperatures a double peak whose splitting of approximately 1 meV decreases somewhat with increasing GaAs well width L. The higher-energy peak is due to the $n=1$ free-heavy-hole-exciton transition while the excitation intensity, temperature, and polarization dependences of the lower-energy peak suggest that it is due to biexcitons with a binding energy B of about 1 meV. In support of the biexciton interpretation a theoretical calculation of $B(L)$ is presented. This calculation gives two-dimensional biexciton binding energies more than an order of magnitude larger than the three-dimensional calculated values.

Biekscyton





zależność energii wiązania biekscytonu od szerokości studni kwantowej

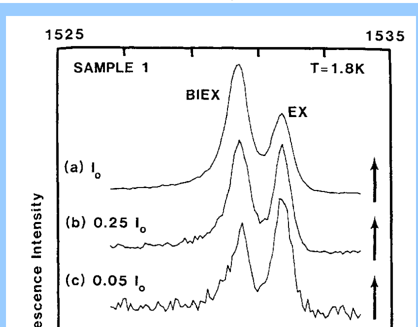
Biekscyton

PHYSICAL REVIEW B VOLUME 38, NUMBER 5 15 AUGUST 1988-I

Optical investigation of biexcitons and bound excitons in GaAs quantum wells

S. Charbonneau, T. Steiner, and M. L. W. Thewalt
Department of Physics, Simon Fraser University, Burnaby, British Columbia, Canada V5A 1S6

Emil S. Koteles, J. Y. Chi, and B. Elman
General Telephone and Electronics Laboratories Incorporated, 40 Sylvan Road, Waltham, Massachusetts 02254
(Received 26 February 1988)



Tunelowanie

PHYSICAL REVIEW B VOLUME 41, NUMBER 17 15 JUNE 1990-I

Resonant-tunneling transfer times between asymmetric GaAs/$Al_{0.35}Ga_{0.65}As$ double quantum wells

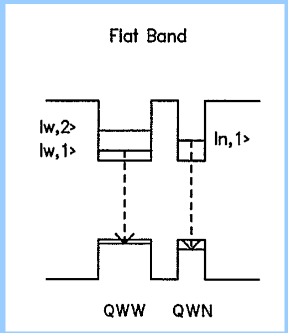
M. G. W. Alexander, M. Nido,* and W. W. Rühle
Max-Planck-Institut für Festkörperforschung, D7000 Stuttgart 80, Federal Republic of Germany

K. Köhler
Fraunhofer-Institut für Angewandte Festkörperphysik, D7800 Freiburg, Federal Republic of Germany
(Received 26 January 1990; revised manuscript received 23 March 1990)

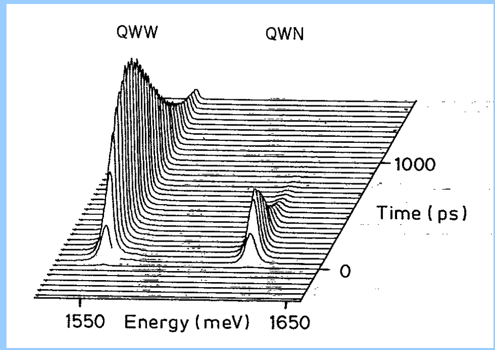
Electron tunneling through the barrier in asymmetric double-quantum-well structures is investigated by time-resolved picosecond luminescence spectroscopy. Change from nonresonant to resonant tunneling is achieved with a perpendicular electric field. Energetic alignment of electron subbands in the two wells strongly enhances tunneling transfer rates. The resonant transfer times decrease strongly with barrier thickness. The wells are coupled at resonance by energy-conserving scattering processes between states localized in a single well. The buildup of delocalized coherent states at resonance would lead to much shorter transfer times.

Podwójna studnia kwantowa

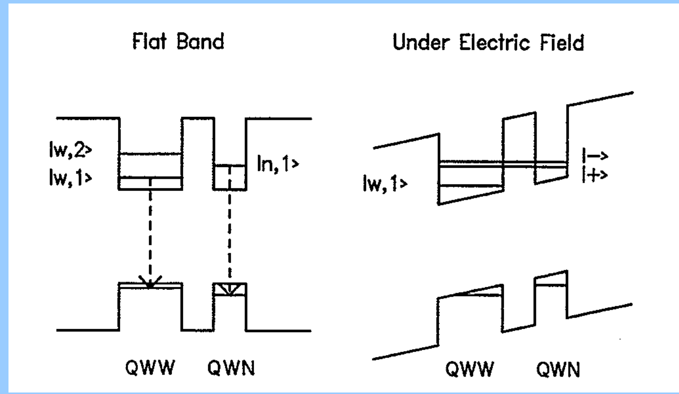
struktura pasmowa



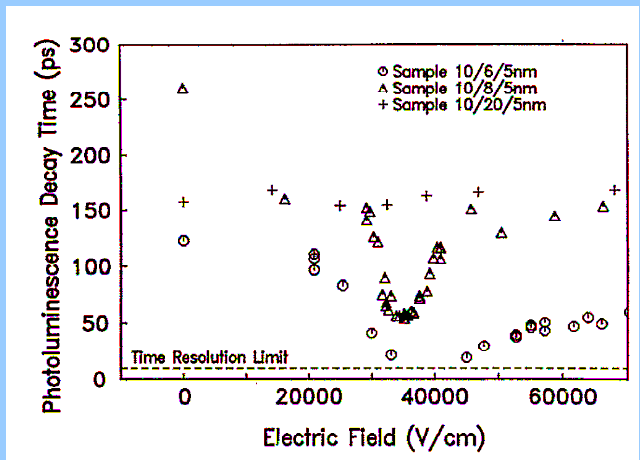
dynamika luminescencji



Podwójna studnia kwantowa



Tunelowanie rezonansowe



Ekscyton skośny

PHYSICAL REVIEW B VOLUME 38, NUMBER 9 15 SEPTEMBER 1988-II

Brief Reports

Brief Reports are short papers which report on completed research which, while meeting the usual **Physical Review** *standards of scientific quality, does not warrant a regular article. (Addenda to papers previously published in the* **Physical Review** *by the same authors are included in Brief Reports.) A Brief Report may be no longer than 3½ printed pages and must be accompanied by an abstract. The same publication schedule as for regular articles is followed, and page proofs are sent to authors.*

Transformation of spatially direct to spatially indirect excitons in coupled double quantum wells

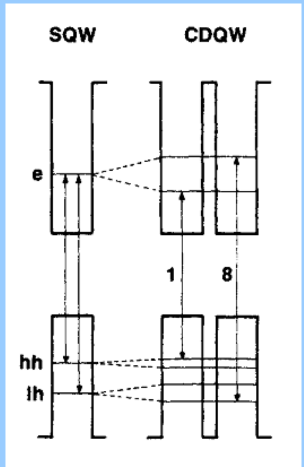
S. Charbonneau and M. L. W. Thewalt
Department of Physics, Simon Fraser University, Burnaby, British Columbia, Canada V5A 1S6

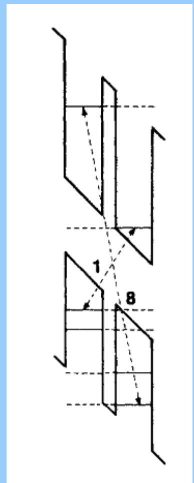
Emil S. Koteles and B. Elman
GTE Laboratories Incorporated, 40 Sylvan Road, Waltham, Massachusetts 02254

(Received 12 April 1988)

We report a detailed experimental study of the influence of electric fields on exciton lifetimes in a GaAs/Al_xGa_{1-x}As coupled-double-quantum-well structure. The energy of the lowest-lying photoluminescent exciton peak was observed to decrease and its decay time was found to increase by over an order of magnitude as the internal electric field was increased. The increase in the decay time is attributed to the change of the exciton transition from spatially direct (i.e., taking place within a single well) to spatially indirect (connecting an electron level in one well with a hole level in the adjacent well).

Ekscyton skośny





Ekscyton skośny

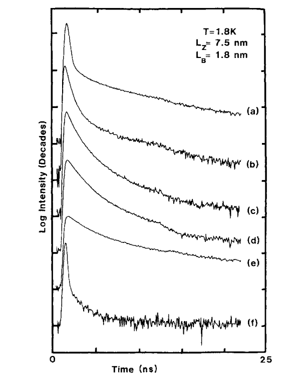
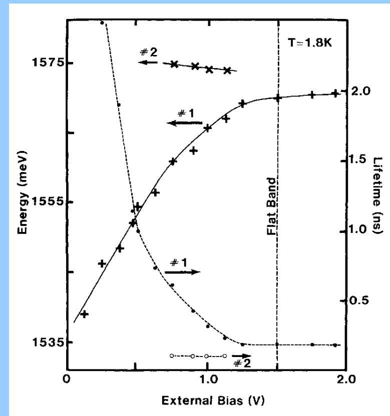


FIG. 3. The luminescence decay of exciton peaks PL [curves (a)–(e) correspond to transition 1 and curve (f) corresponds to transition 2] under various bias voltages. Each of the tick marks on the vertical scale represents one decade of intensity. The transient curves represent decays having time constants of (a) $V=1.5$ V, $\tau=0.19$ ns; (b) $V=1.0$ V, $\tau=0.31$ ns; (c) $V=0.75$ V, $\tau=0.61$ ns; (d) $V=0.50$ V, $\tau=1.0$ ns; (e) $V=0.375$ V, $\tau=1.91$ ns; (f) $V=1.0$ V, $\tau=0.10$ ns (transition no. 2).



Efekt Starka

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Lifetime Enhancement of Two-Dimensional Excitons by the Quantum-Confined Stark Effect

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We report on picosecond luminescence studies of GaAs/AlGaAs quantum wells in the regime of the quantum-confined Stark effect. A drastic increase of the recombination lifetime is accompanied by a Stark shift of the photoluminescence of the lowest free exciton for electric fields perpendicular to the quantum-well layers. A consistent picture of the quantum-confined Stark effect is presented.

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