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Research Workshop on Condensed Matter Physics
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AND SELF-ORGANIZING NANOSTRUCTURES
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"Quantum Islands by Submonolayer Insertions in wide bandgap matrices: New Concepts for Optoelectronics"

PART II

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These are preliminary lecture notes, intended only for distribution to participants.

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QUANTUM ISLANDS BY SUBMONOLAYER INSERTIONS IN WIDE BANDGAP MATRICES: NEW CONCEPTS FOR OPTOELECTRONICS

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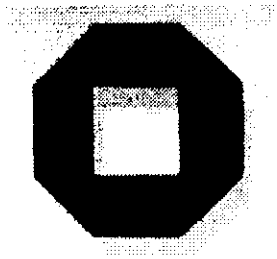

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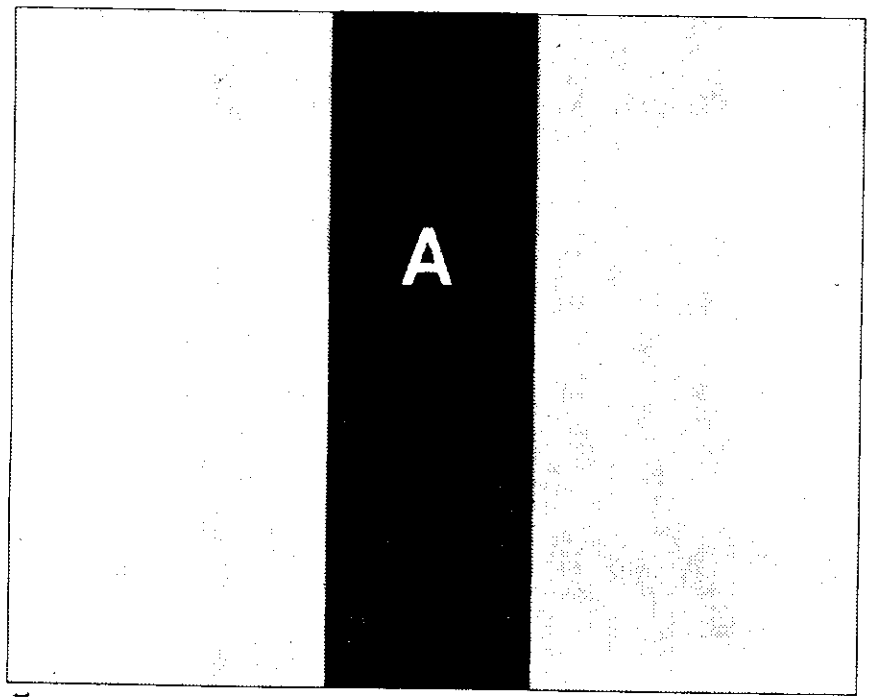
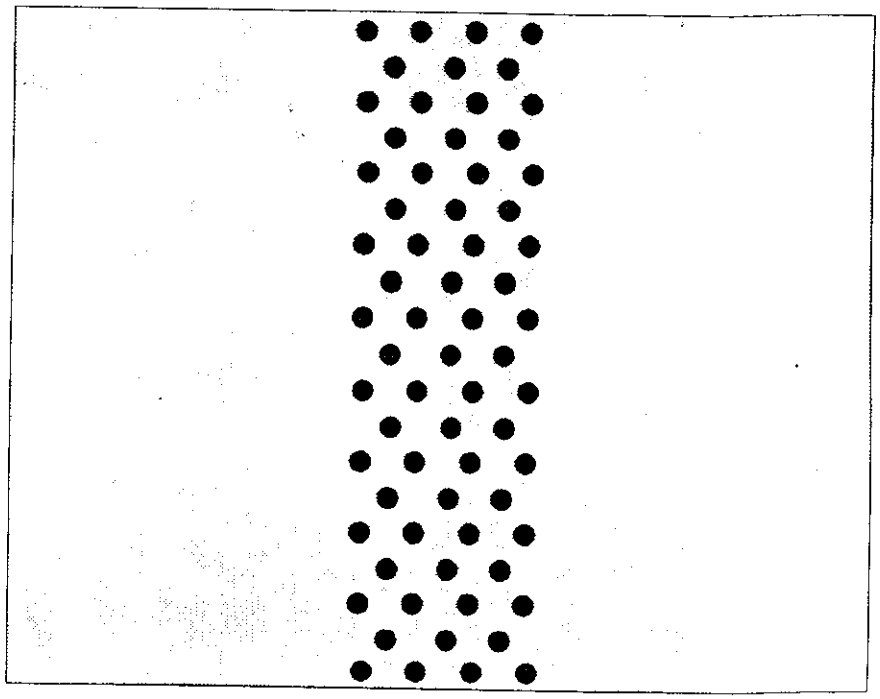
Contents:

- Motivation for "Homojunction" Laser
- Concept of Waveguiding using Resonant Absorber in a Bulk Matrix
- Quantum Dots as an Active Media
- Selforganization of Nanoscale Islands by Submonolayer and Monolayer Deposition
- HRTEM Characterization of ML and SML CdSe Insertions in a ZnSe Matrix
- Optical Properties: Giant Exciton Oscillator Strength and Lifting of the k-selection Rule
- PLE Spectra: Evidence of QD Energy Spectrum
- Gain Studies
- Exciton-Induced Waveguiding and Lasing up to 300K

Double Heterostructure vs Excitonic Waveguide

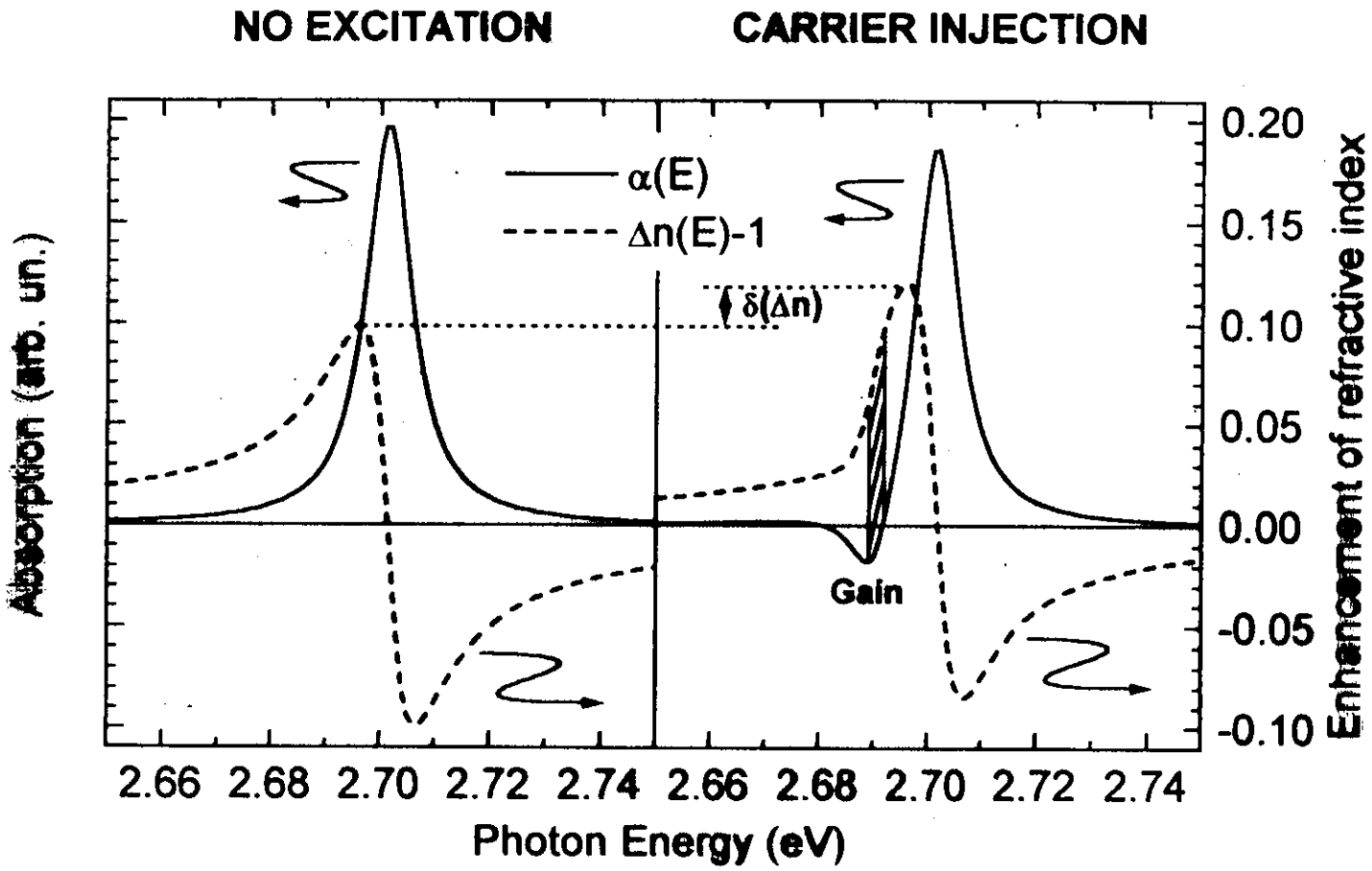




- Large Δn between A and B
- A and B must be lattice matched
- Large Δn is usually related to large ΔE_g

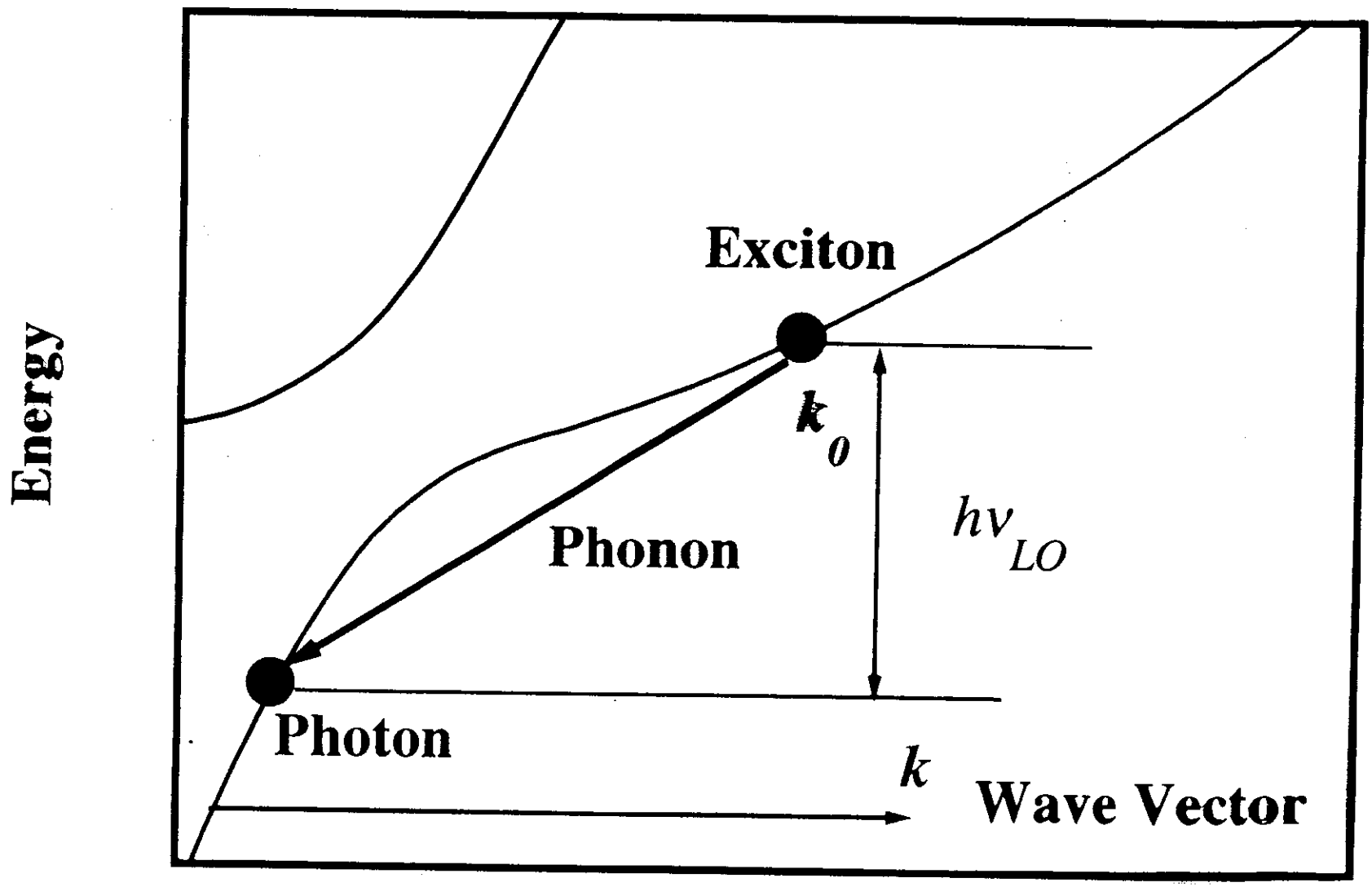
- Diluted array of islands, no need for lattice match
- Large Δn can be realized for small ΔE_g

Modulation of Exciton-Induced Waveguiding Effect under Carrier Injection



- **For appropriate excitation level (or structure geometry) carrier injection can cause ENHANCEMENT of the waveguiding effect**

Indirect in k-space Excitons in a Direct Gap Crystal



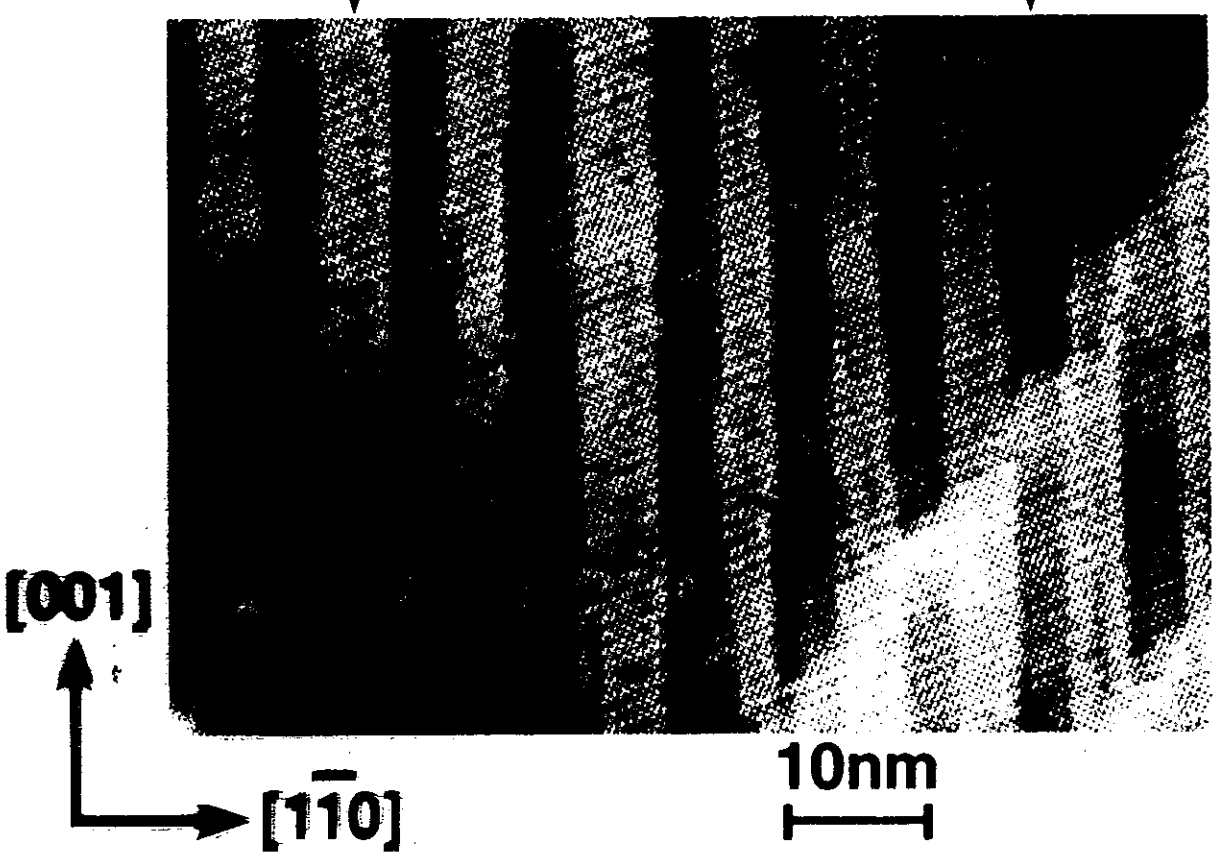
Periodic Arrays of Monolayer-Height Islands

O/Cu(110)

K.Kern et.al. (1991)

Clean Cu(110)

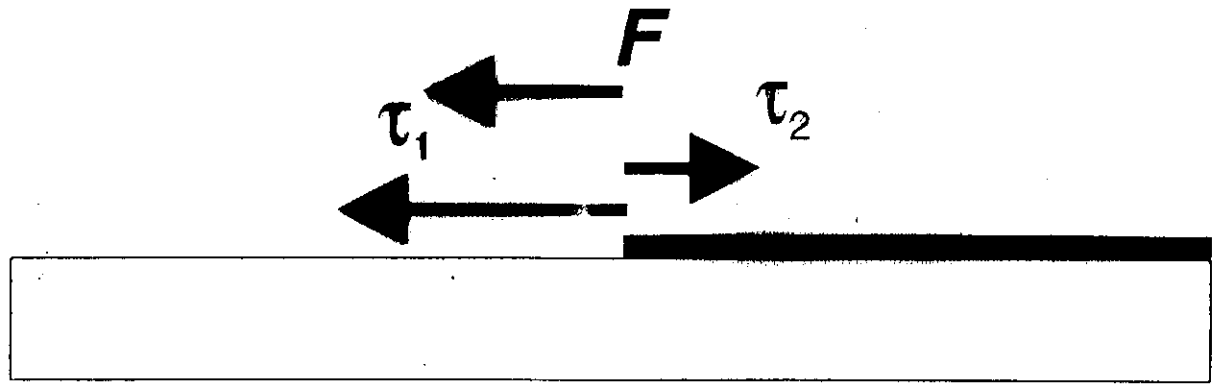
1 monolayer
of Oxygen on Cu



STM image
for Oxygen coverage
Θ=0.26 monolayer

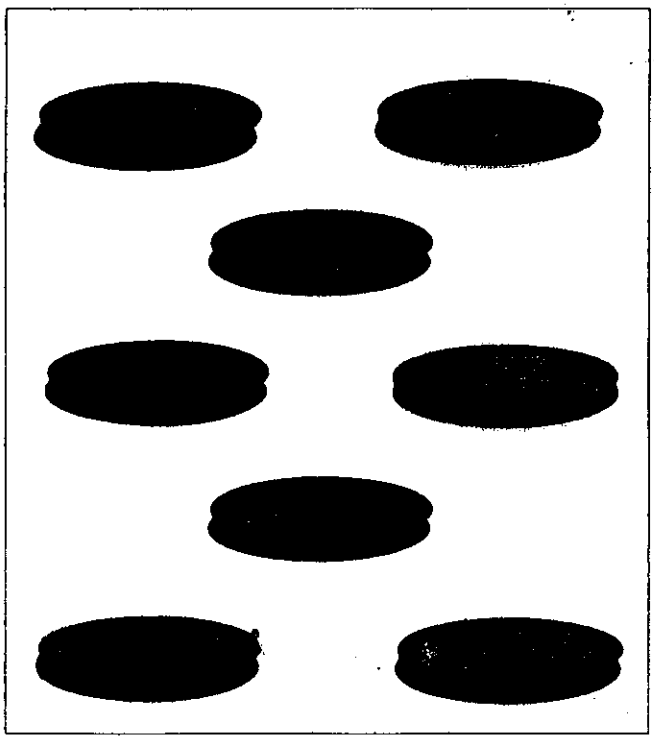
annealing at T=550 K

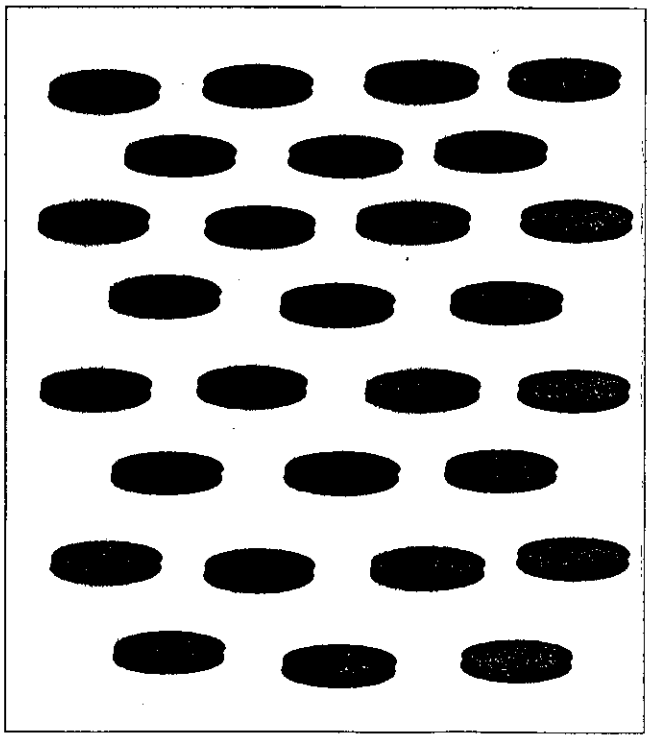
Surface Stress Relaxation at Domain Boundaries



$-\Delta E_s$ (long range surface stress relaxation)

$+\Delta E_s$ short range forces (additional dangling bonds)



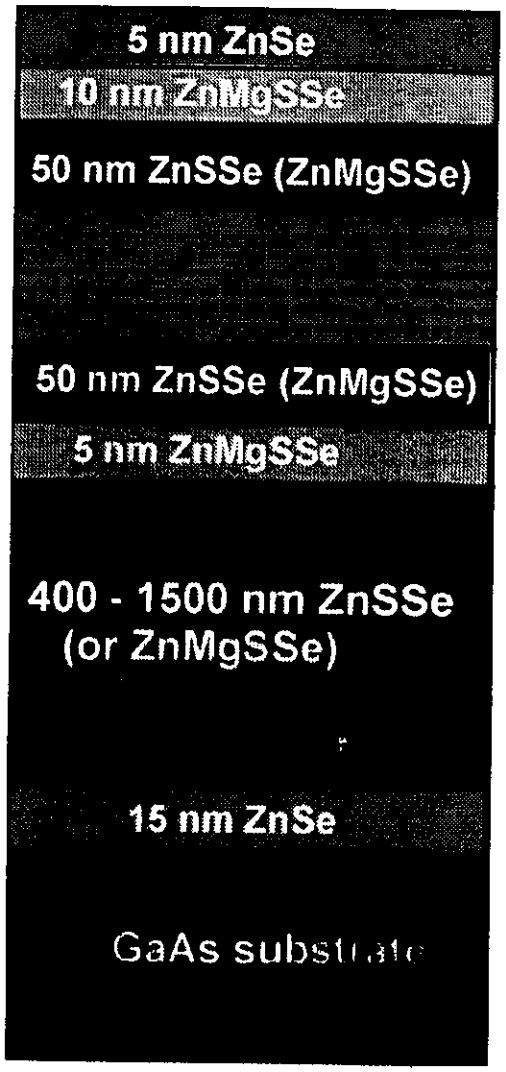


LARGE ISLANDS DO NOT PROVIDE EFFICIENT SURFACE STRESS RELAXATION

FOR VERY SMALL ISLANDS SHORT RANGE ENERY TERM DOMINATES

→ **OPTIMUM SIZE**

Scheme of the Structure



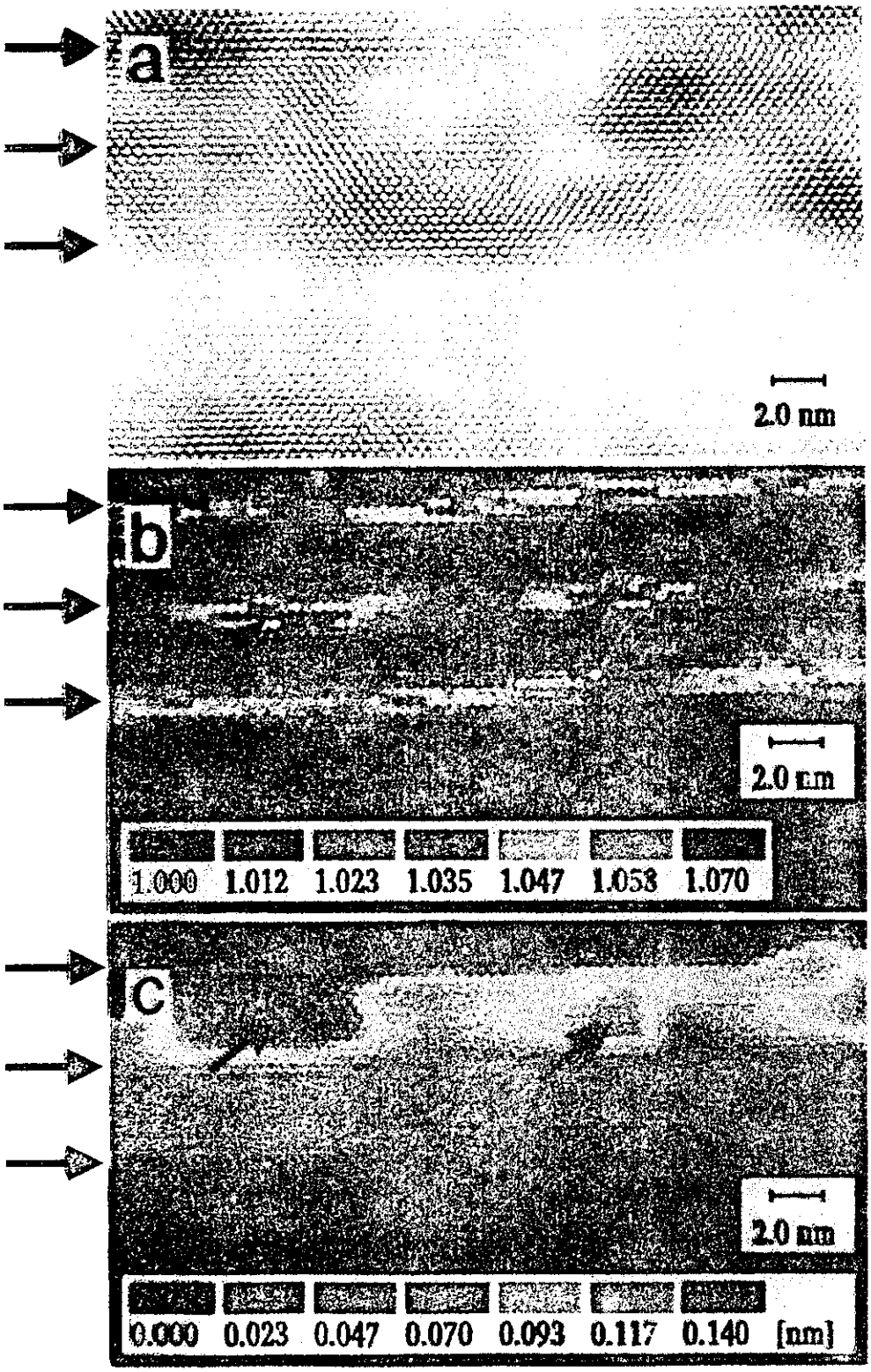
Submonolayer Superlattice
(total thickness 60 nm)

1/3-1 monolayer CdSe insertions

- ***3 - 8 nm-thick separating ZnSe (or ZnMgSSe) layers.***
- ***0.4 - 1.5 μm-thick ZnSSe (or ZnMgSSe) buffer layer***

NO THICK CLADDING LAYERS HAVING LOWER RERFRACTIVE INDEX ARE USED

HREM of CdSe Insertions in a ZnSe Matrix



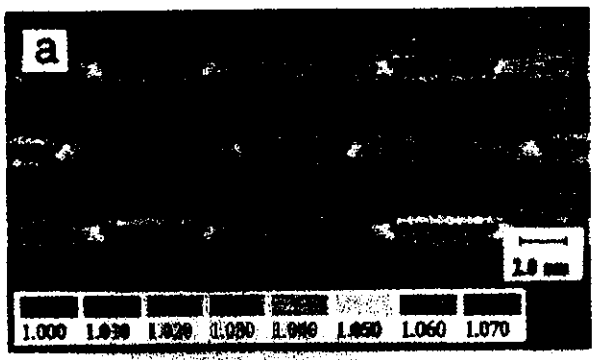
1 ML *CdSe* in a *ZnSe* matrix

Cross Section High Resolution Transmission Electron Microscopy Image

Local Lattice Parameter Map (in growth direction)

Total Atom Displacement Map

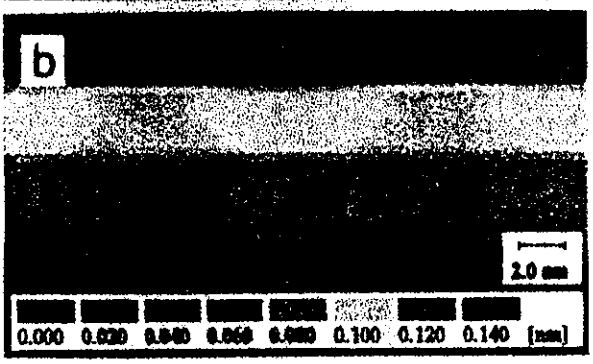
Modeling of Monolayer Insertions



4 ML $Cd_xZn_{1-x}Se$

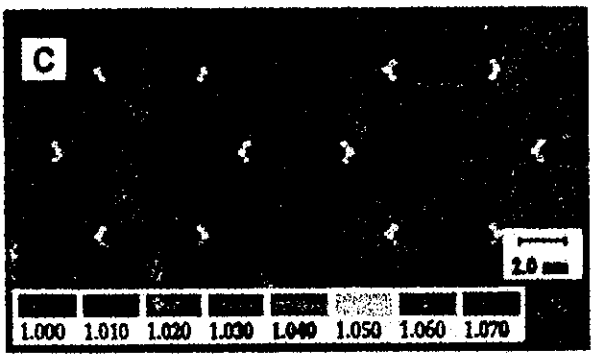
$x_{ind} = 0.4$

$x_{sep} = 0.2$



Local Lattice Parameter Map (in growth direction)

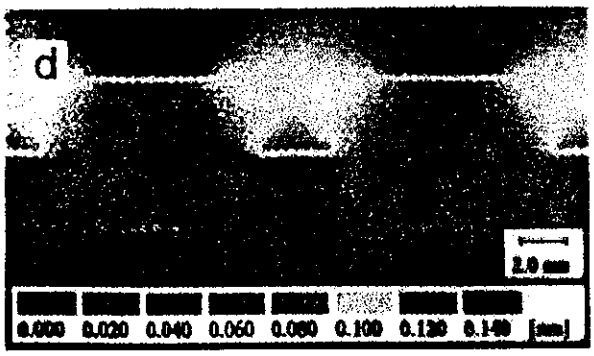
Total Atom Displacement Map



3 ML $CdSe$

$x_{ind} = 1$

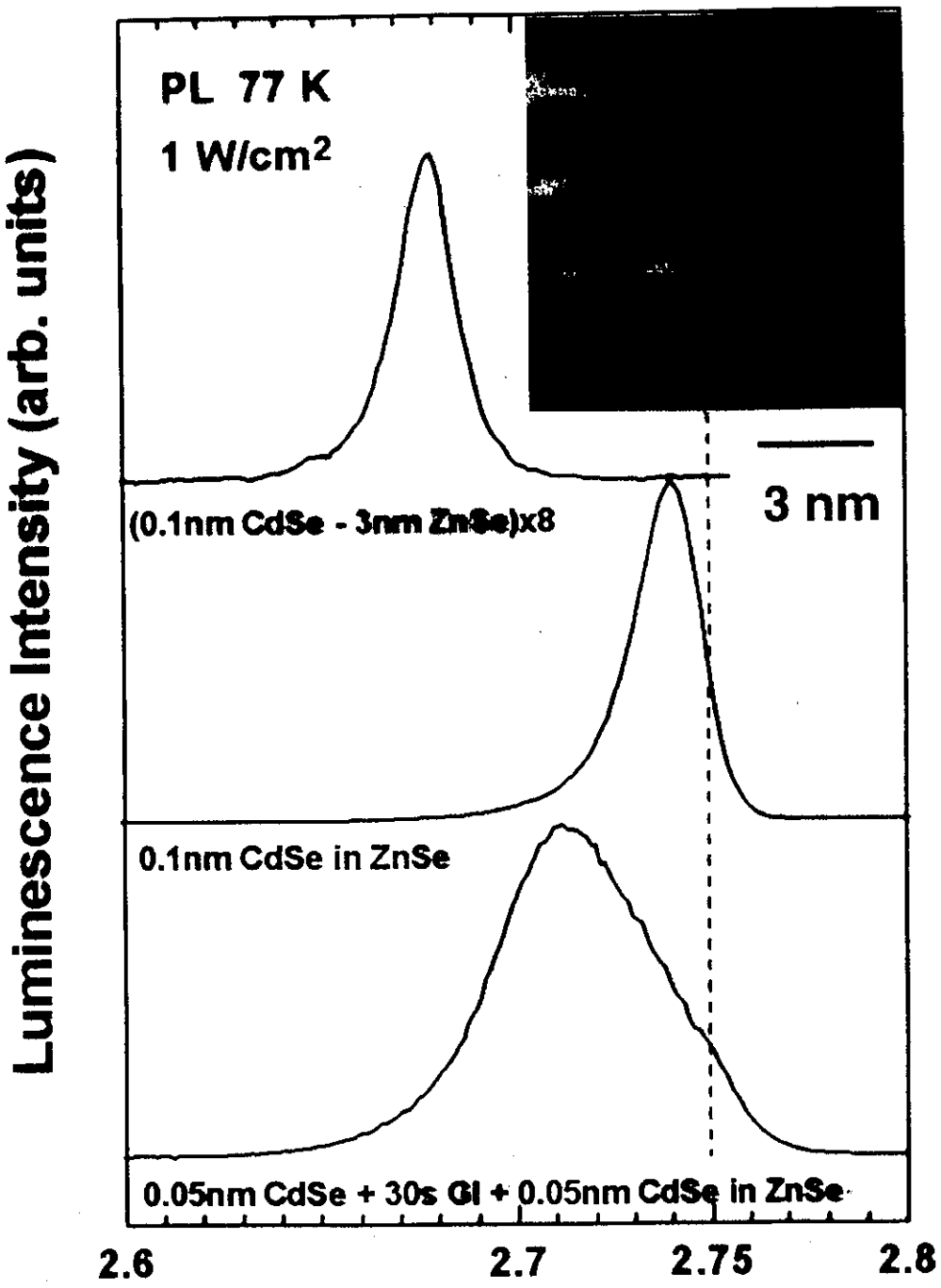
$x_{sep} = 0$



Local Lattice Parameter Map

Total Atom Displacement Map

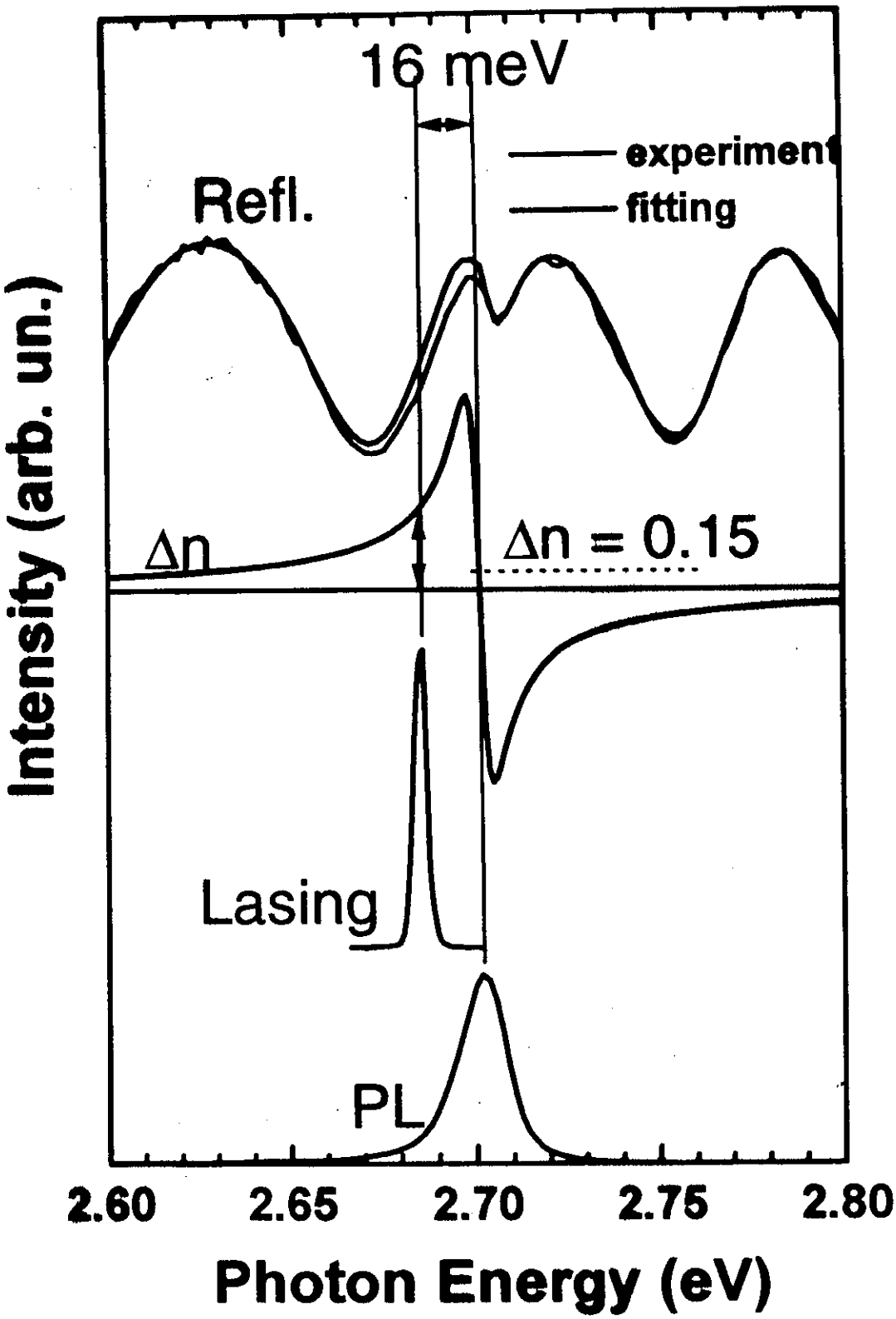
PL Spectra and HREM (LEP) of Submonolayer CdSe inserions in a ZnSe matrix



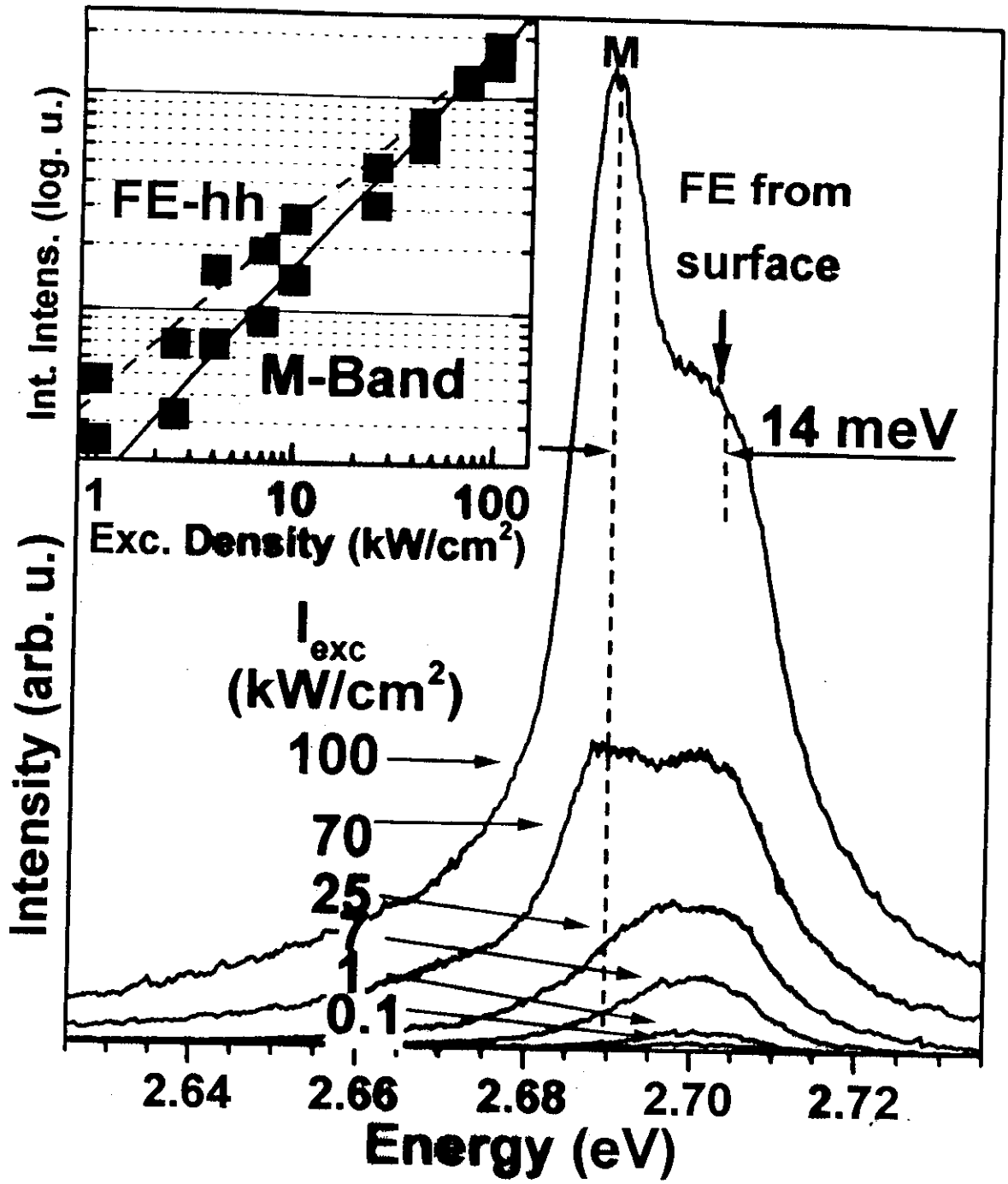
1. 2D Islands with a lateral size of 4 nm

2. Vertically-correlated growth

Resonant Modulation of the Refractive Index



Edge Luminescence and Stimulated Emission in SML SL at 1.8 K



- 90^0 emission is Stokes shifted by -3 meV compared to 180^0 emission
- M-band grows superlinearly and dominates at high $I_{exc.}$

Gain to Absorption Convertion in Excitonic Waveguides

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OFFENDING COMMAND: timeout
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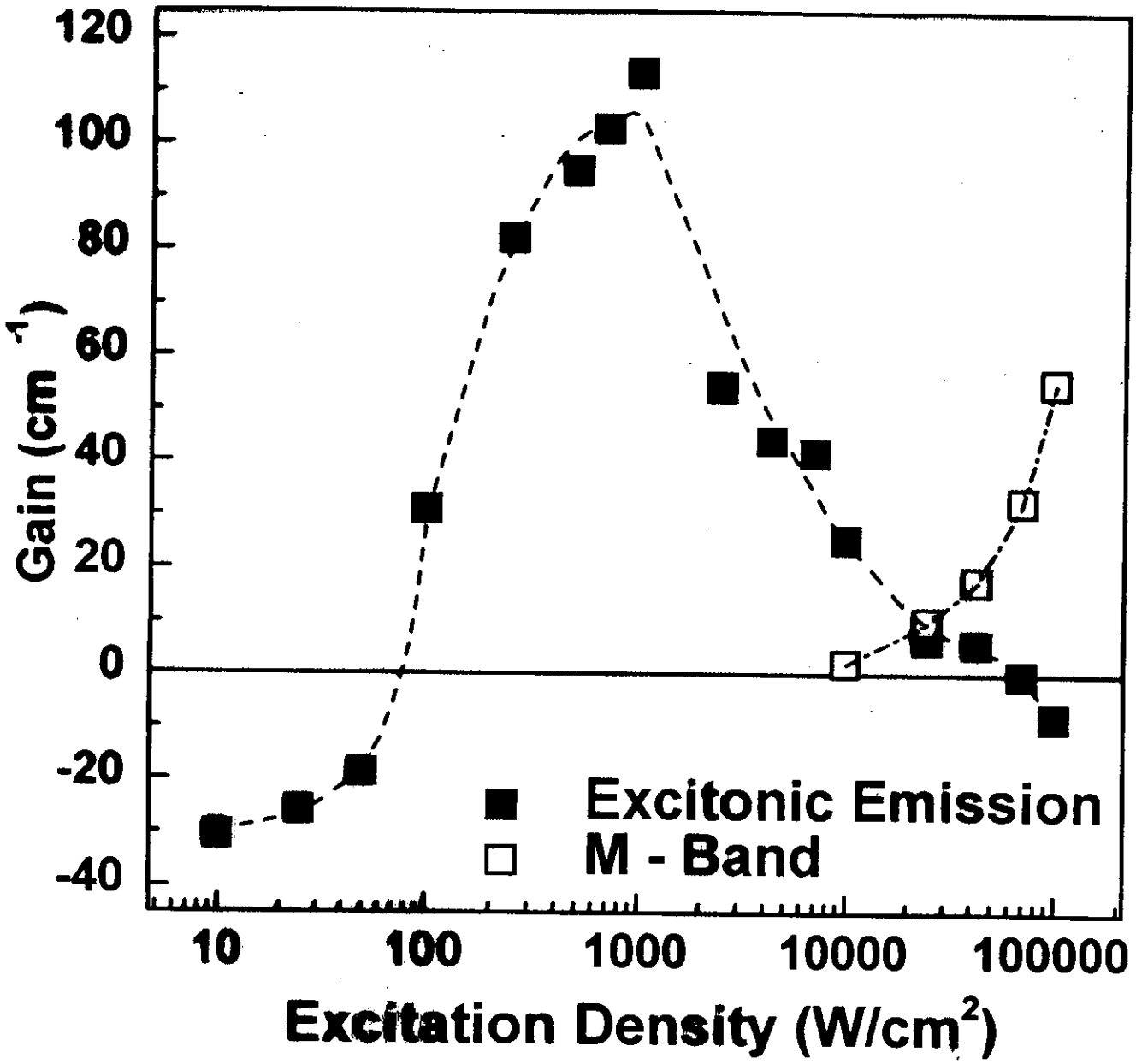
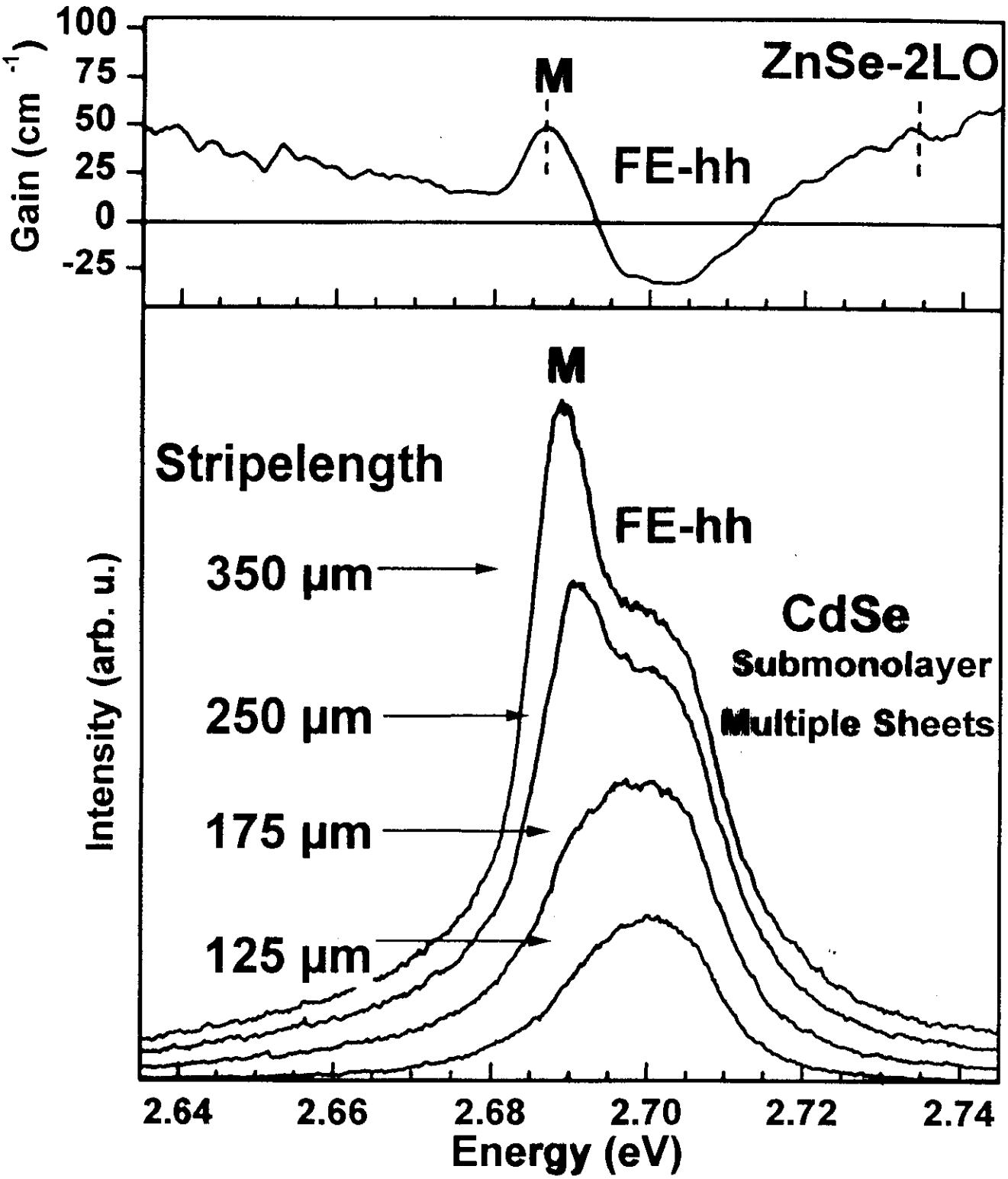


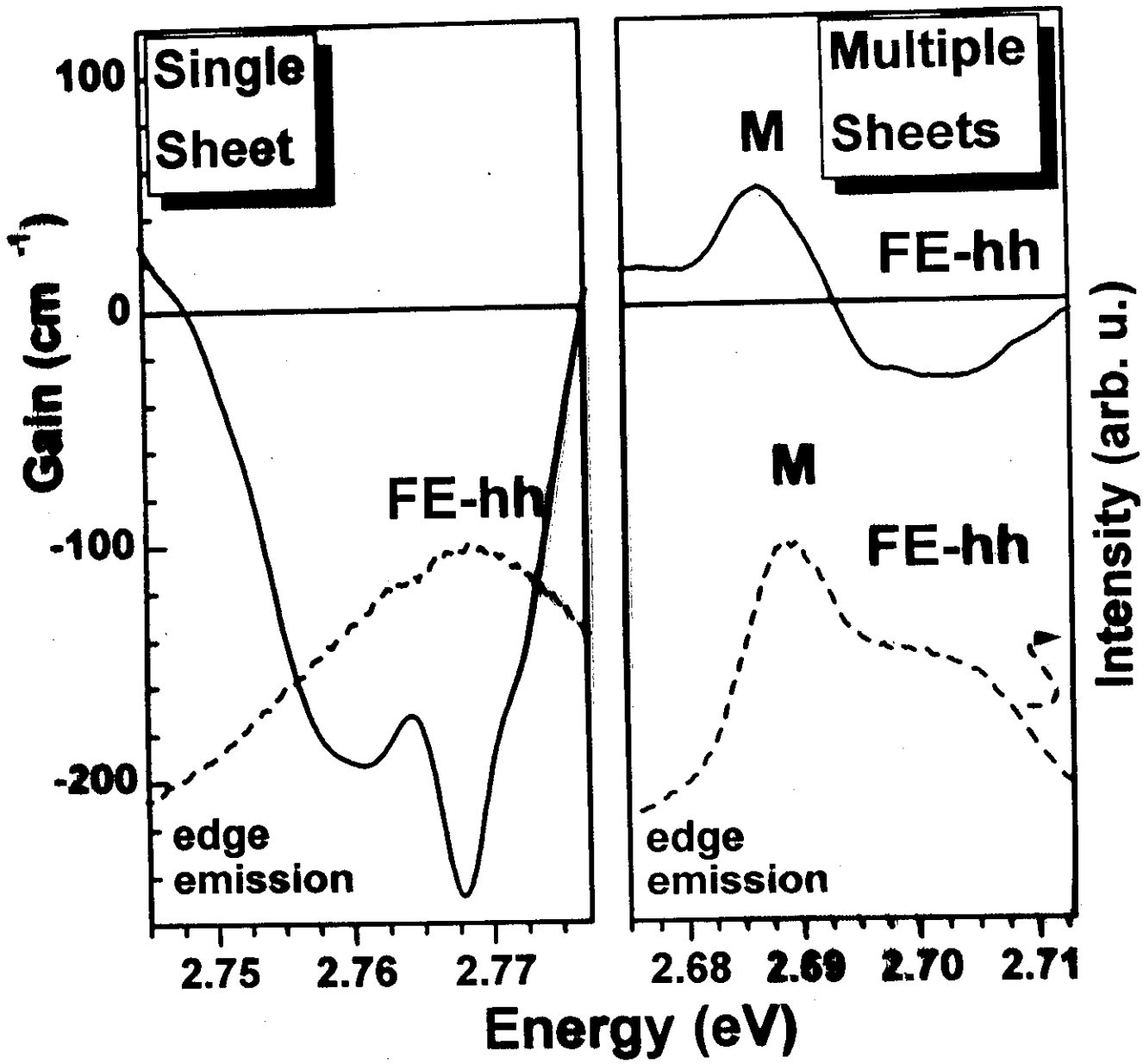
- *Gain peak is Stokes shifted from the PL maximum in surface geometry by only 3 meV*
- *A second gain peak appeares at high excitation densities*

Gain Mechanisms in CdSe-ZnSe Submonolayer Superlattice



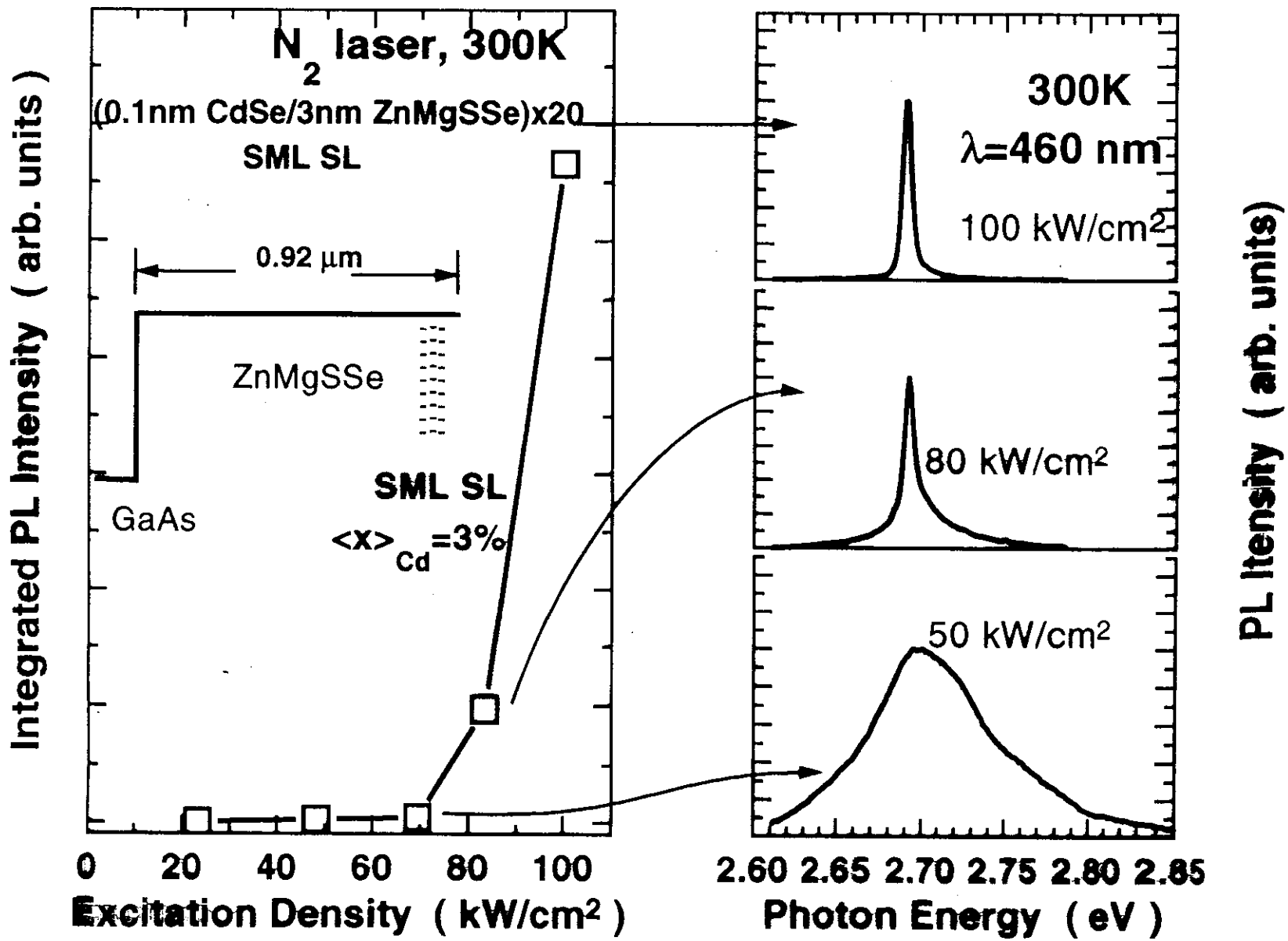
- *Saturation and supression of Gain resonant to FE-hh transitions at high densities*

Gain of Submonolayer Single and Multiple Sheet

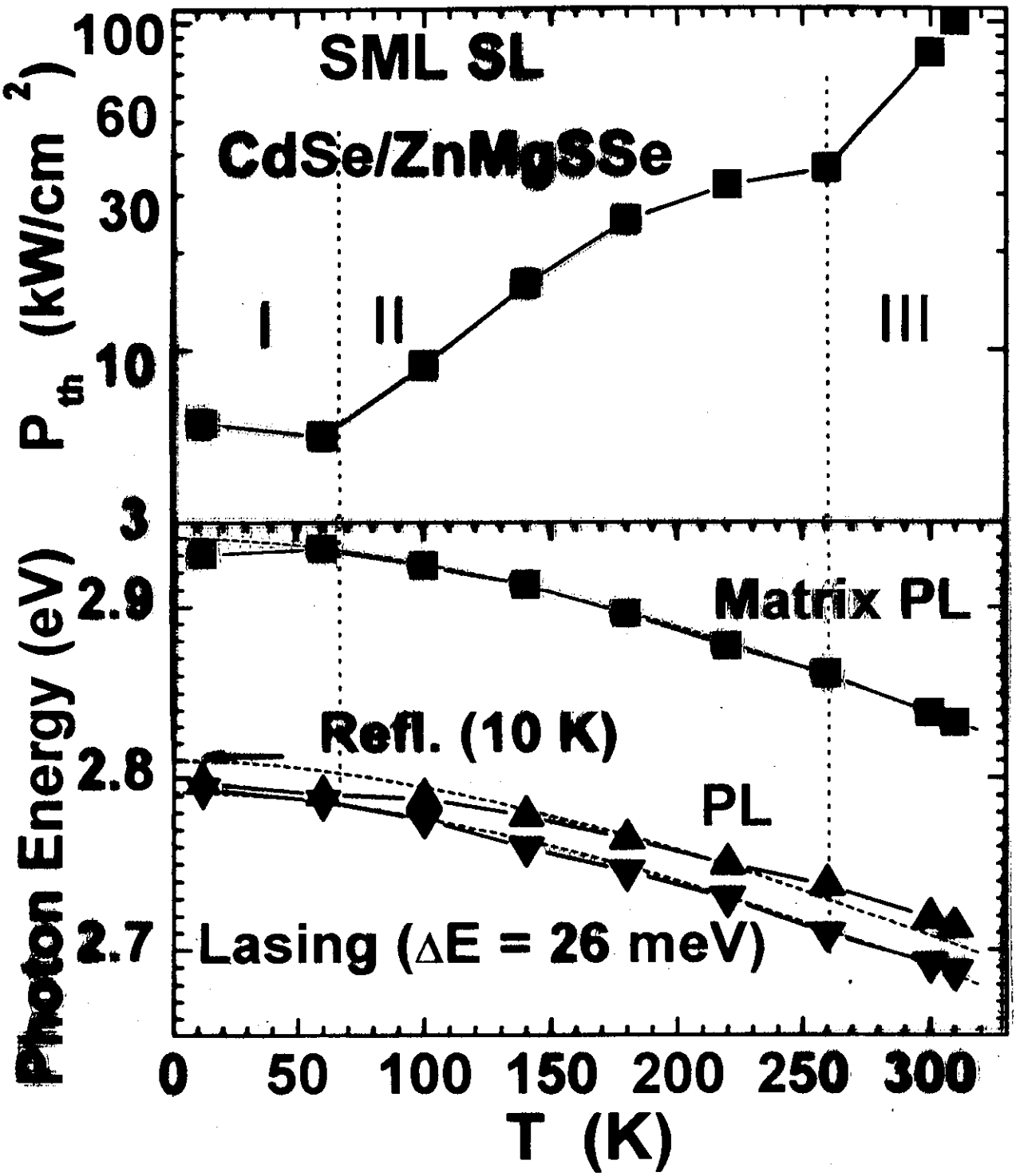


- ***Strong absorption in the GaAs-substrate for a single sheet***
- ***Zero-phonon-gain for multiple sheet structure***

RT Entirely Exciton Induced Waveguiding and Lasing in stacked CdSe submonolayers in a ZnMgSSe Matrix



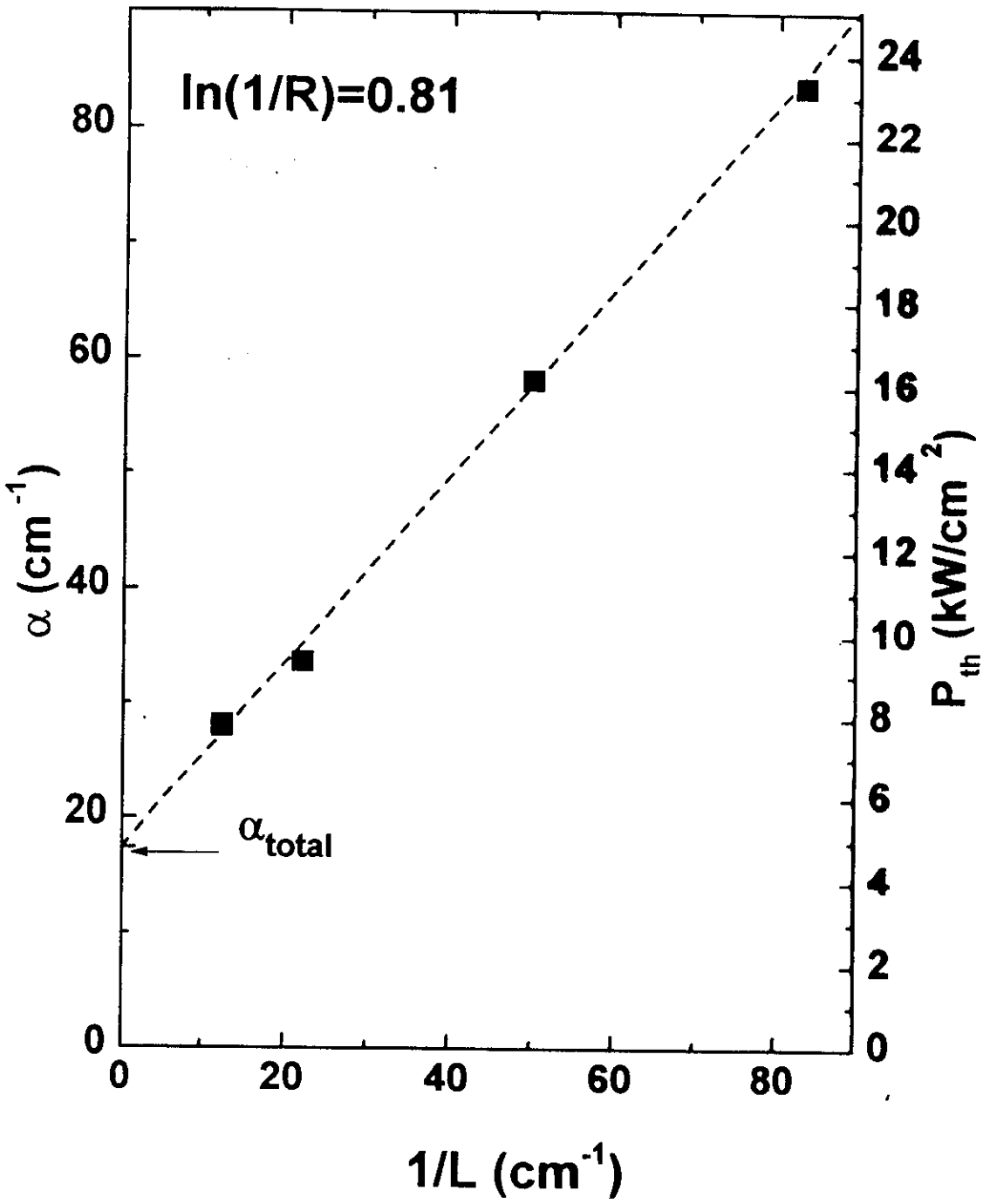
Lasing up to 300 K (λ=4.33 nm)
in Excitonic Waveguide



Lasing mechanism)

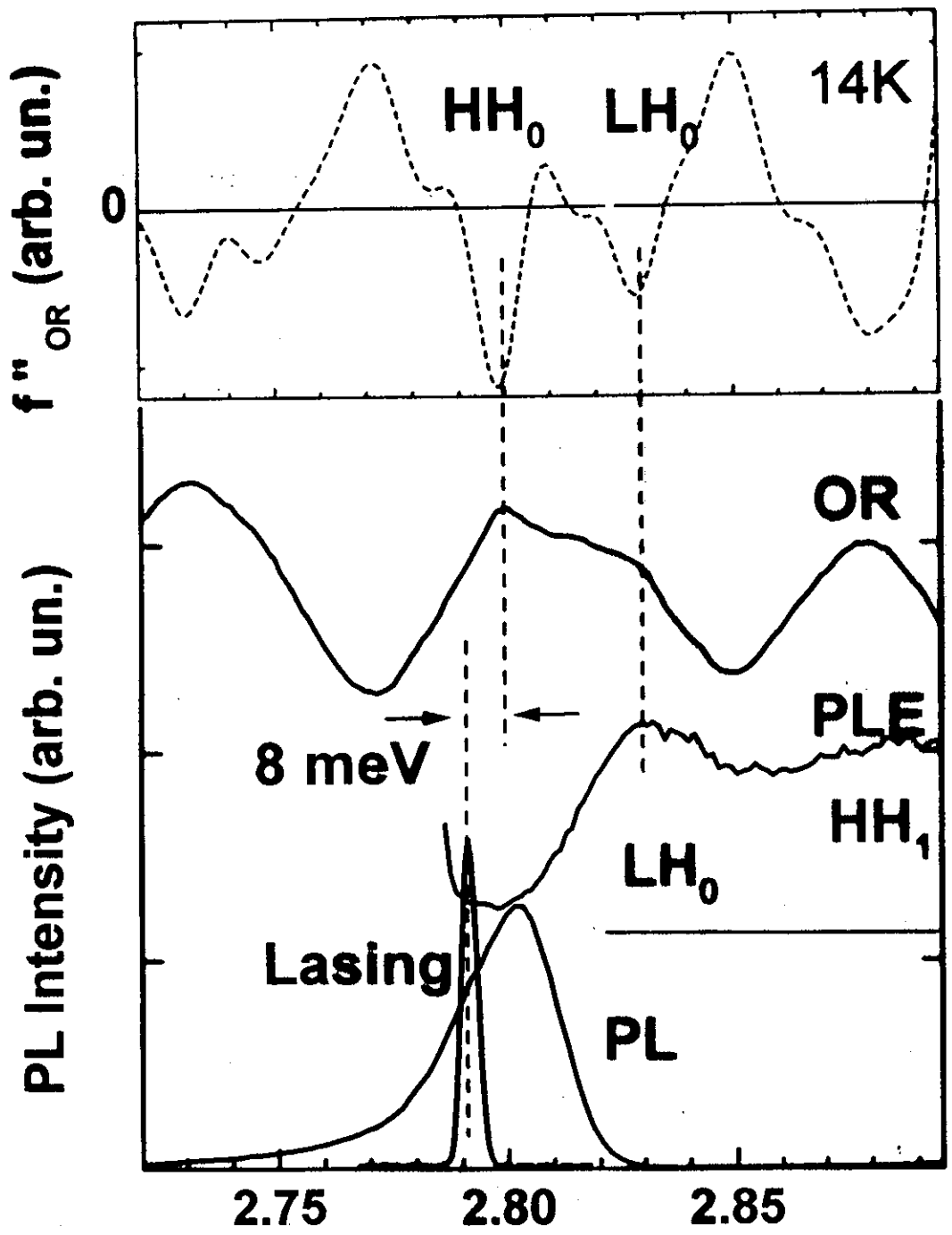
does not change up to 320K

Low Total Internal Losses in Excitonic Waveguides



Internal losses are comparable to those in DHS SCH Lasers

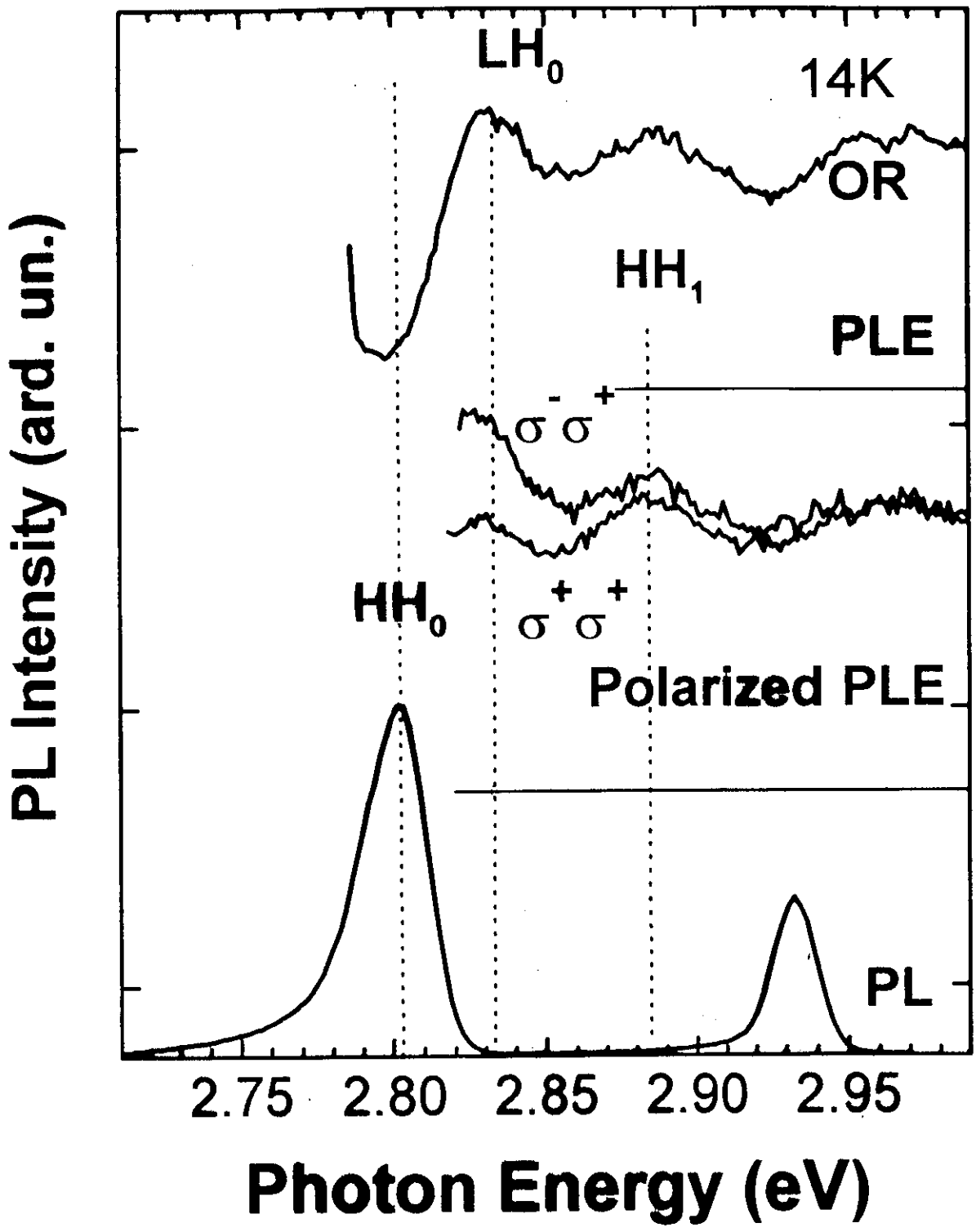
PLE and OR Spectra of the CdSe-ZnMgSSe SML SL



No Ground State is Revealed in PLE)

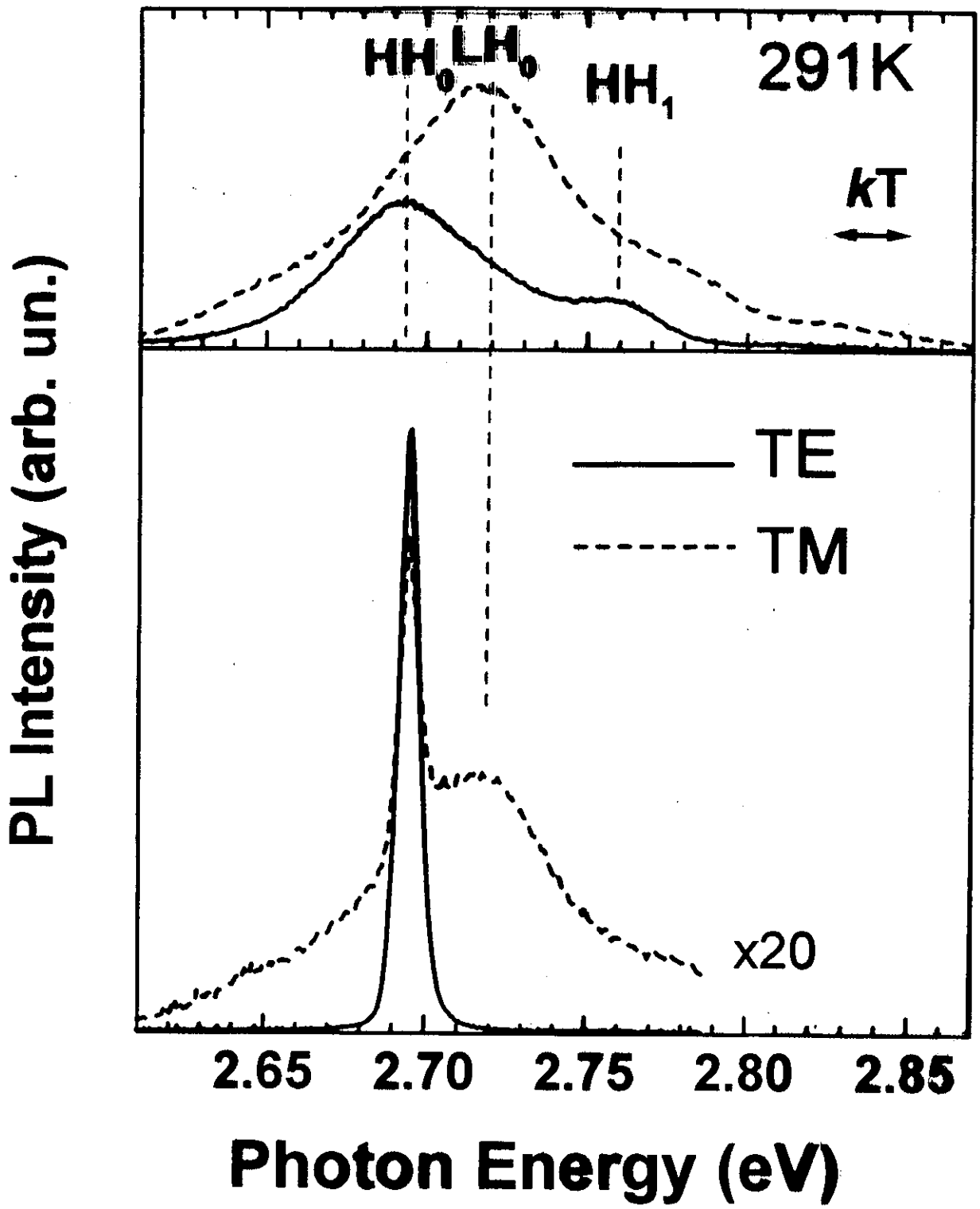
(Quantum Dot Behavior)

Circular Polarized PLE Spectra of Excited States



First Peak in PLE Has Light Hole Origin

Polarization of Edge Luminescence and Lasing



First Excited State Has Light Hole Origin

in Agreement with Circular Polarized PLE Specta

Conclusion

- *Submonolayer and monolayer deposition of CdSe in (ZnMg)(SSe) leads to quantum islands*
- *These quantum islands have a large oscillator strength and cause an excitonic waveguide*
- *QD behaviour in PLE*
- *Gain does not destroy waveguiding*
- *Lasing for for diluted arrays and thin ZnSSe/GaAs buffer layers*
- *460 nm lasing at RT*
- *Nitrides?*