Semiconductors alloys (electron and optical properties)

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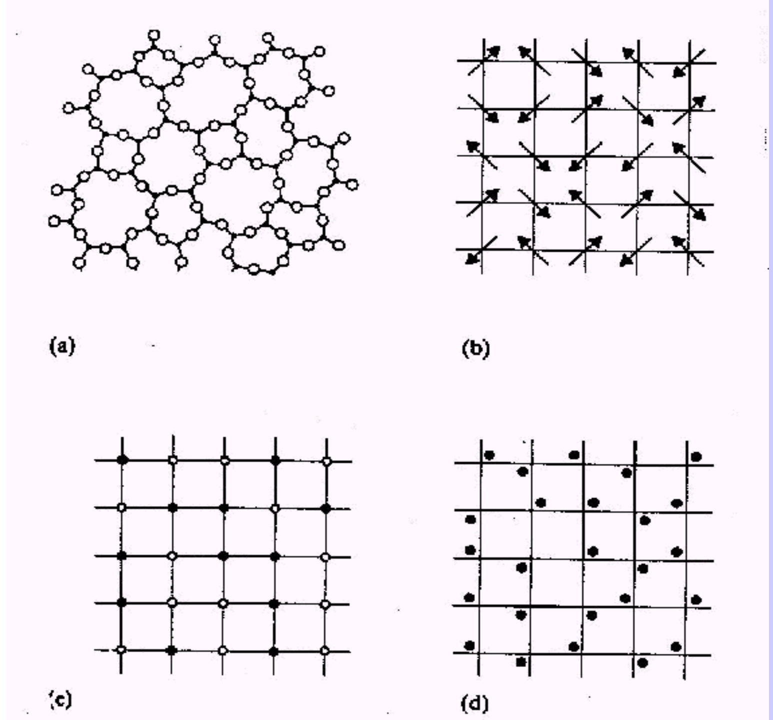
Disordered Systems

- Types of disorder



(a) structural, (b) orientational (spin),
(c) compositional and (d) vibrational

I. Solid solutions (basic ideas, energy spectra)

Semiconductor alloys.

A_xB_{1-x}

x – concentration

A solid solution has a crystal lattice and randomly distributed atoms of the components over crystal sites.

Intrinsic potential:

$$\varphi = \varphi_{periodic} + \varphi_{random}$$

I. Solid solutions (basic ideas, energy spectra)

Virtual crystal:

Atom potential:

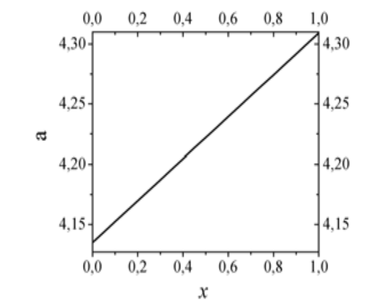
$$\varphi = x\varphi_A + (1-x)\varphi_B$$

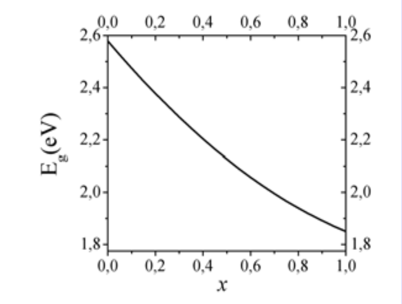
Vegard law (lattice constant):

$$a_x = x\, a_A + (1-x)a_B$$

Energy gap:

$$E_g(x) = xE_g^{\,A} + (1-x)E_g^{\,B} - bx(1-x)$$





I. Solid solutions (basic ideas, energy spectra)

Short range perturbations:

The compositional fluctuations result in the random potential, deviations of the position of the bottom of the conduction and the top of the valence band, which can split energy levels from conduction and valence bands.

$E_{cr} = \hbar^2/ma^2$

m- effective mass

a – spatial size of the well

I. Solid solutions (basic ideas, energy spectra)

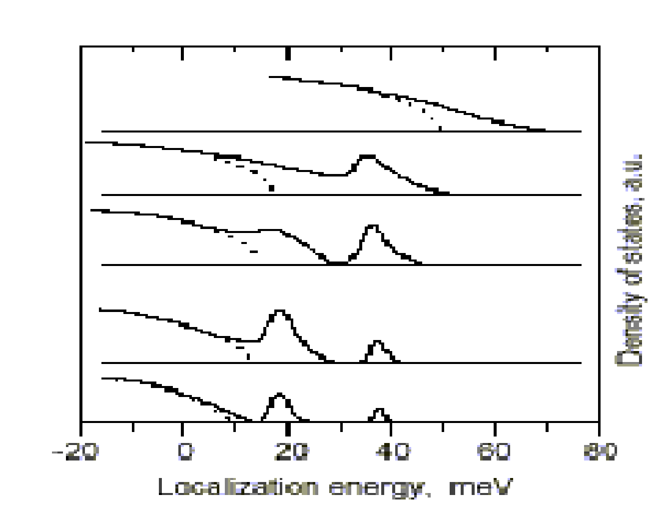
Three cases for forming the energy spectrum and DOS (density of the states) function:

1) $E_{pert} > E_{cr}$ (isoelectronic traps)

2) $E_{pert} < E_{cr}$

3) $E_{cr} \geq E_{pert}$ (statistical cluster)

E_{pert} – perturbation energy introduced by one impurity atom.



x_{cr} - critical concentration corresponding to the formation of the percolation cluster of macroscopic size, which leads to the disappearance of isolated clusters.

I. Solid solutions (basic ideas, energy spectra)

Classification of exciton states in semiconductor alloys

R_{int} - a characteristic length determining the distance, over which the tunneling transfer of energy to the deeper states is possible.

Isolated clusters – energy transfer is impossible,
Superclusters – partial energy transfer,
percolation cluster – free excitons,

E_{ME} - mobility edge

II. Solid solutions (optical properties, exciton spectroscopy)

Interaction of light with the medium

$\mathbf{P} = \chi\mathbf{E}$

P – medium polarization;

E – external electric field; χ - susceptibility tensor

D – electric displacement vector;

$\mathbf{D} = \varepsilon\mathbf{E}$

ε - dielectric tensor.

On the other hand:

$\mathbf{D} = \mathbf{E} + 4\pi\,\mathbf{P}$, $\varepsilon = 1 + 4\pi\chi$.

$$\varepsilon^{1/2} = n = n' + in''$$

n' – refractive index (n=v/c)

n'' – extinction index.

II. Solid solutions (optical properties, exciton spectroscopy)

reflection

$$R = I_{ref} / I_{inc}$$

$$R = ((n' - 1)^2 + n''^2) / ((n' + 1)^2 + n''^2)$$

absorption

$$dI / I = -\alpha dz$$

$$I(z) = I_{inc} \exp(-\alpha z)$$

$\alpha = 4\pi n'' / \lambda_0$ - absorption

II. Solid solutions (optical properties, exciton spectroscopy)

Motion of charged particles under external electric field:

$$d^2r + 2\gamma dr + \omega_0^2 r = -e\,\mathbf{E}(t)\,/m$$

Since $\mathbf{E}(t) = \mathbf{E}\exp(-i\omega t)$, r must have the same behavior. Thus:

$$r(t) = -e\,\mathbf{E}(t)/m\,(-\omega^2 - 2i\gamma\omega + \omega_0^2)$$

and

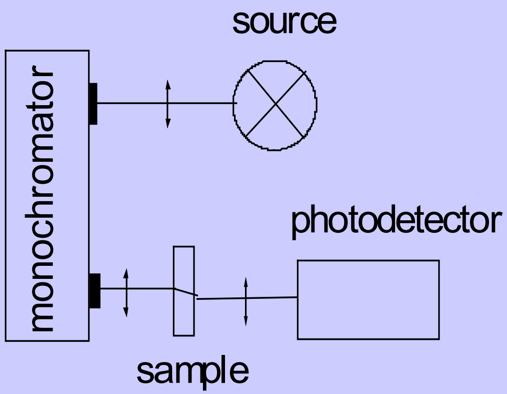
$$P = Np = Ne\,r(t) = -e^2 N\,\mathbf{E}(t)/m\,(-\omega^2 - 2i\gamma\omega + \omega_0^2),$$

$$\varepsilon = 1 + \Sigma 4\pi N\,e^2/m(\omega_0^2 - \omega^2 - 2i\gamma\omega)$$

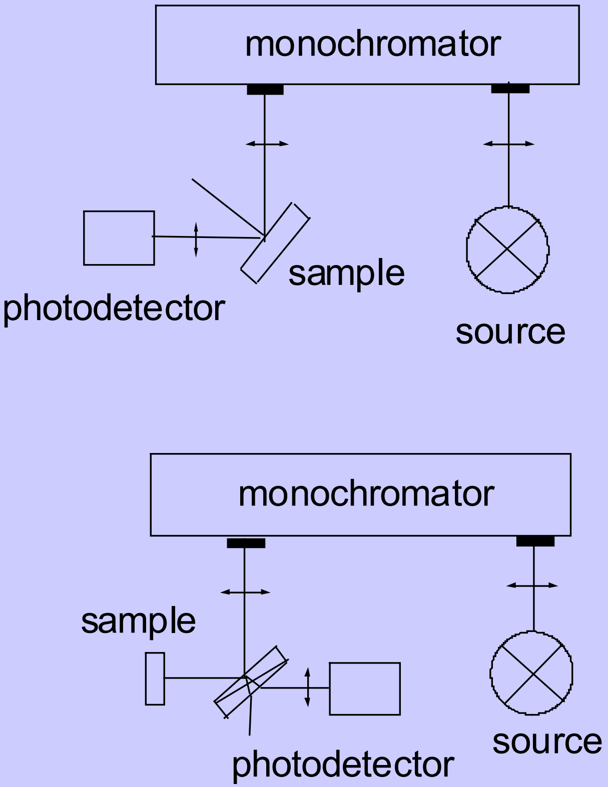
II. Solid solutions (optical properties, exciton spectroscopy)

- Optical schemes

Transmission



Reflection



II. Solid solutions (optical properties, exciton spectroscopy)

Exciton.

Hydrogen-like system

$$E = E_g - R/n^2 + \hbar^2K^2/M$$

where $R = 13.6(\mu/m\varepsilon_0^2)$eV is exciton Rydberg or binding energy of exciton.

It can be considered as a wave of polarization. The interaction between polarization and electromagnetic waves gives a new polariton wave.

In order the absorption to occur (that is, the energy to be dissipated from the phonon field) polaritons have to be scattered inelastically.

II. Solid solutions (optical properties, exciton spectroscopy)

If scattered processes are effective after conversion of photon into exciton, it loses its energy completely inside the medium. And in this case we can separate photons and excitons.

$$\left[\frac{\hbar\omega}{M}\nabla_{\mathbf{R}}^{2} - \omega_{T}^{2} + \omega^{2} - i\omega_{T}\Gamma_{0}\right]\mathbf{P}(\mathbf{R},\omega) = \beta_{0}\omega_{T}^{2}\mathbf{E}(\mathbf{R},\omega)$$

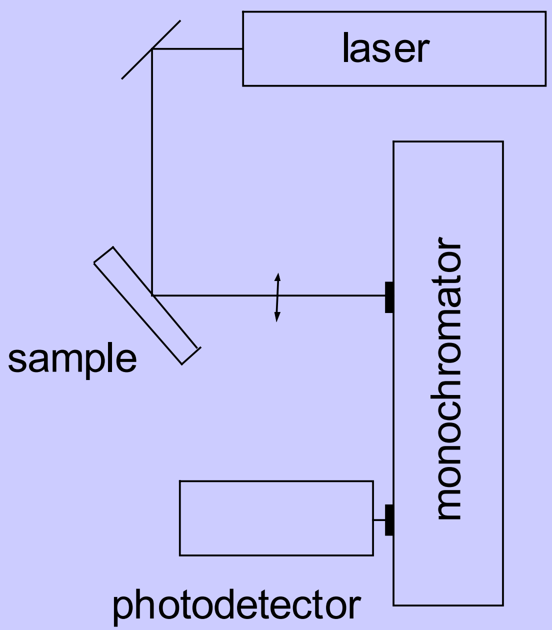
Γ - damping constant describing scattering processes.

II. Solid solutions (optical properties, exciton spectroscopy)

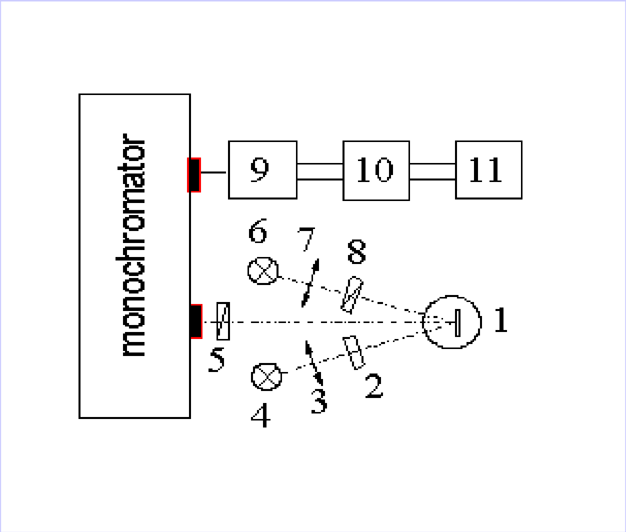
Exciton states associated to percolation cluster, can be observed in reflection excitonic spectra.

Localized exciton states manifest themselves in transmission and photoluminescence exciton spectra.

Photoluminescence (PL)

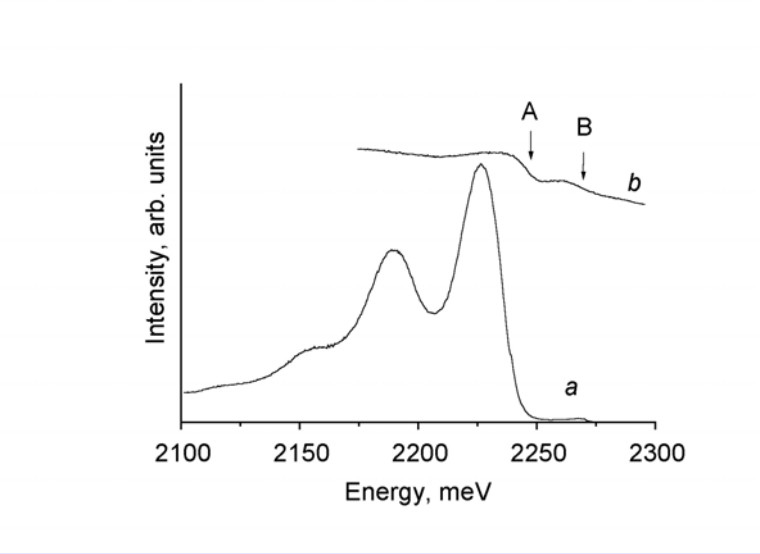


Typical setup



II. Solid solutions (optical properties, exciton spectroscopy)

Optical spectra of solid solution

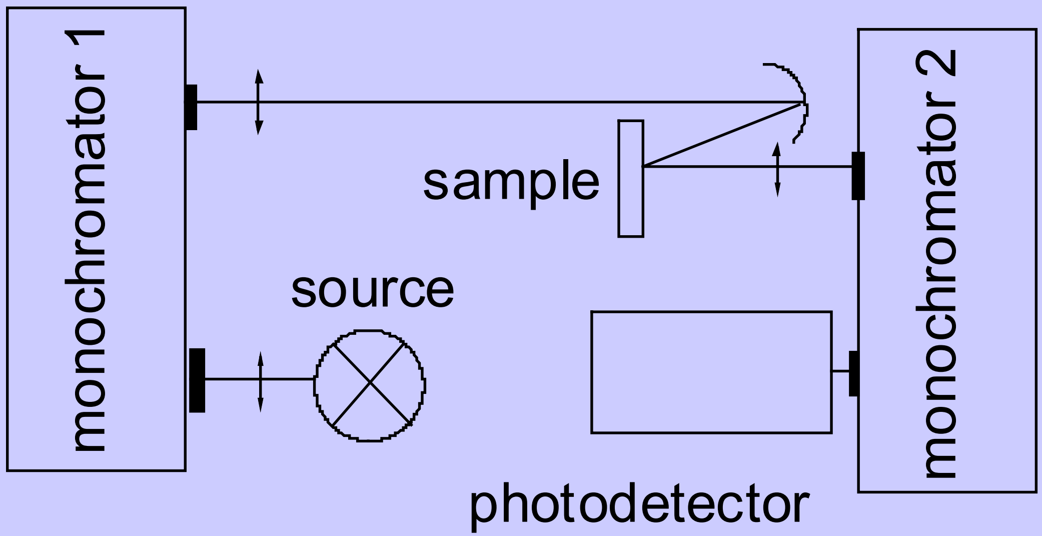


PL (*a*) Reflection (*b*) - spectra of the $CdS_{0.7}Se_{0.3}$ at T = 4.2 K

II. Solid solutions (optical properties, exciton spectroscopy)

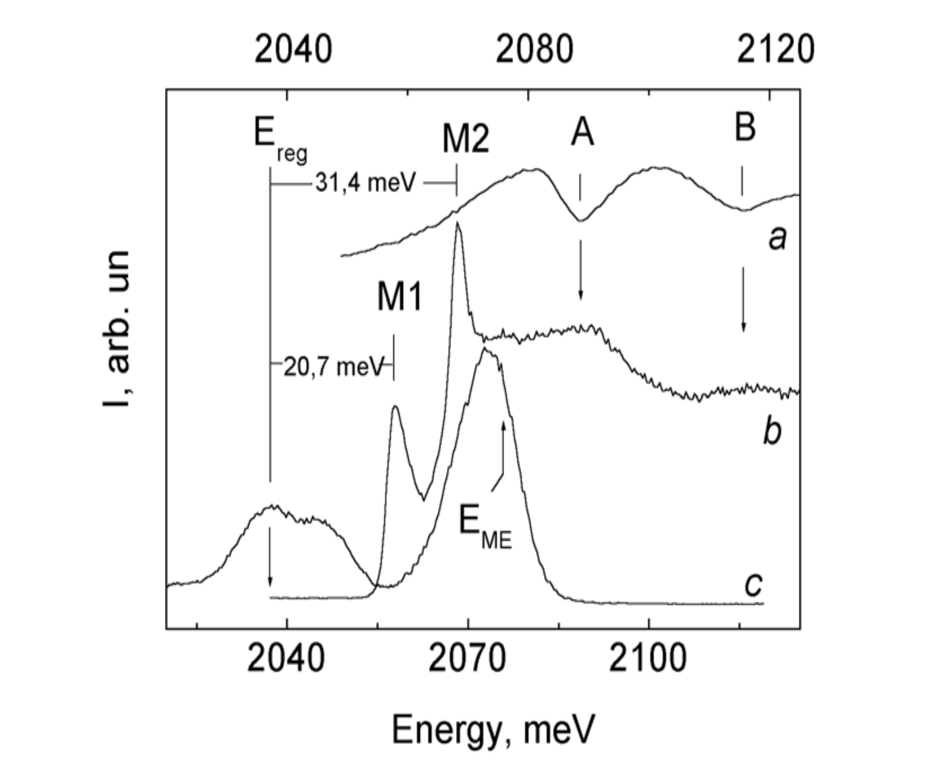
Manifestation of isolated exciton states associated with spatially separate clusters

Excitation PL



II. Solid solutions (optical properties, exciton spectroscopy)

•Optical spectra of solid solution

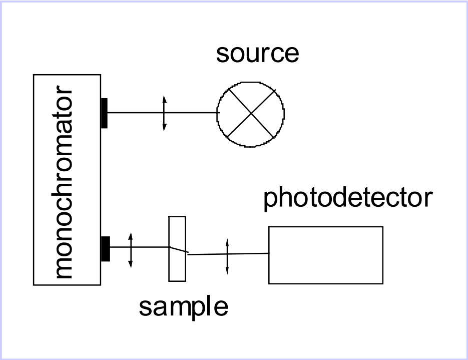


Reflection (*a*) PLE (*b*) and PL (*c*) -spectra of the $CdS_{0.5}Se_{0.5}$ at T = 4.2 K

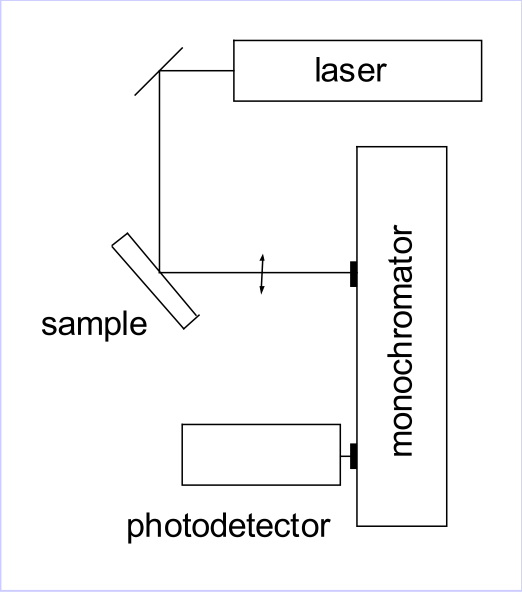
Optical properties

Optical schemes

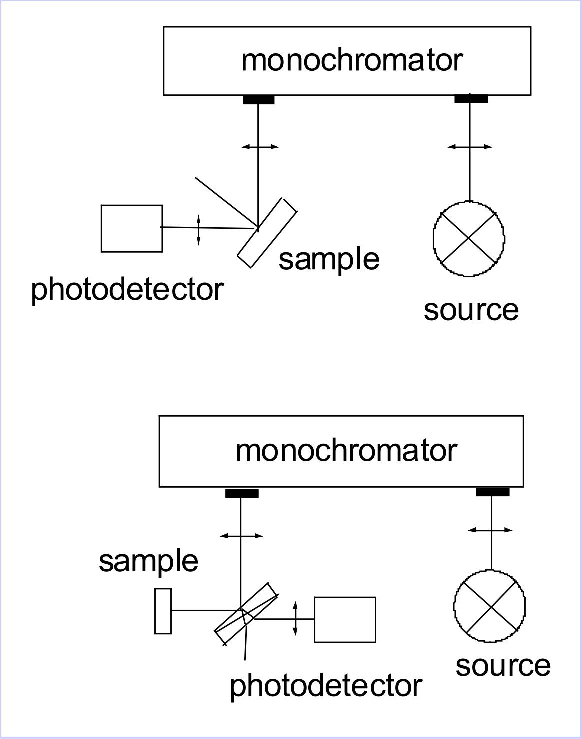
Transmission



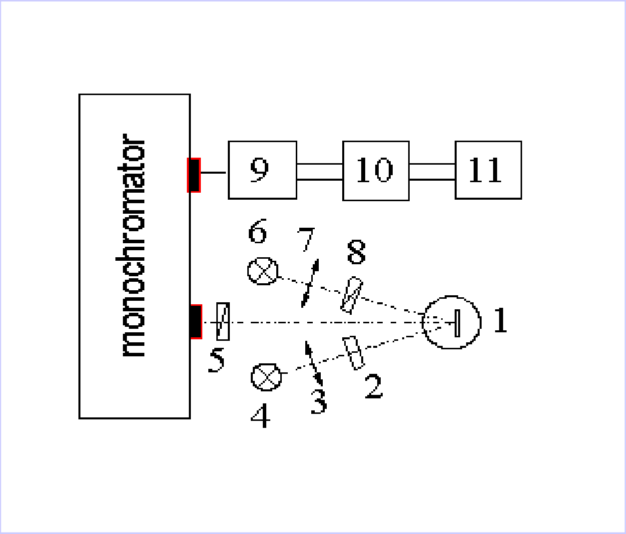
Photoluminescence (PL)



Reflection



Typical setup



Excitation PL