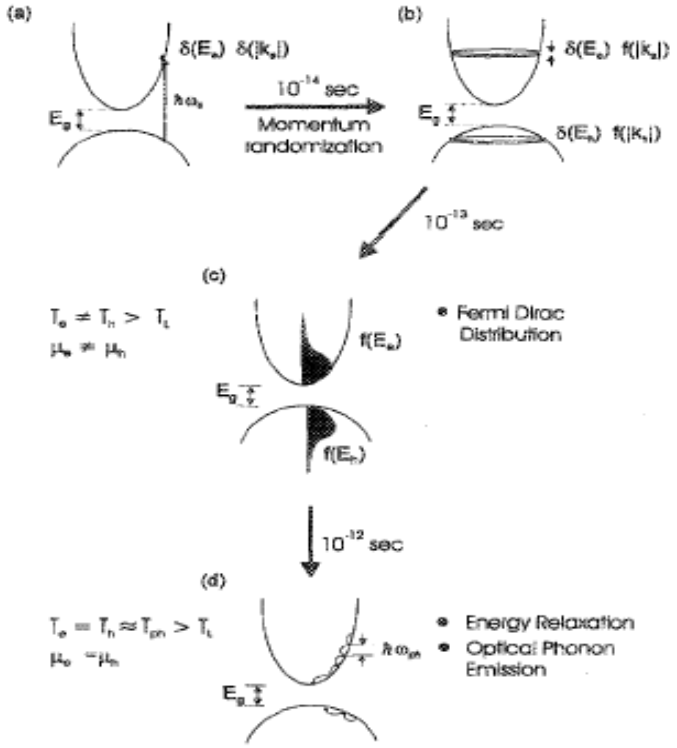
# Фемтосекундная спектроскопия - методика экспериментального исследования сверхбыстрых процессов в полупроводниках

# Semiconductor dynamics probing

Fundamental processes in semiconductor

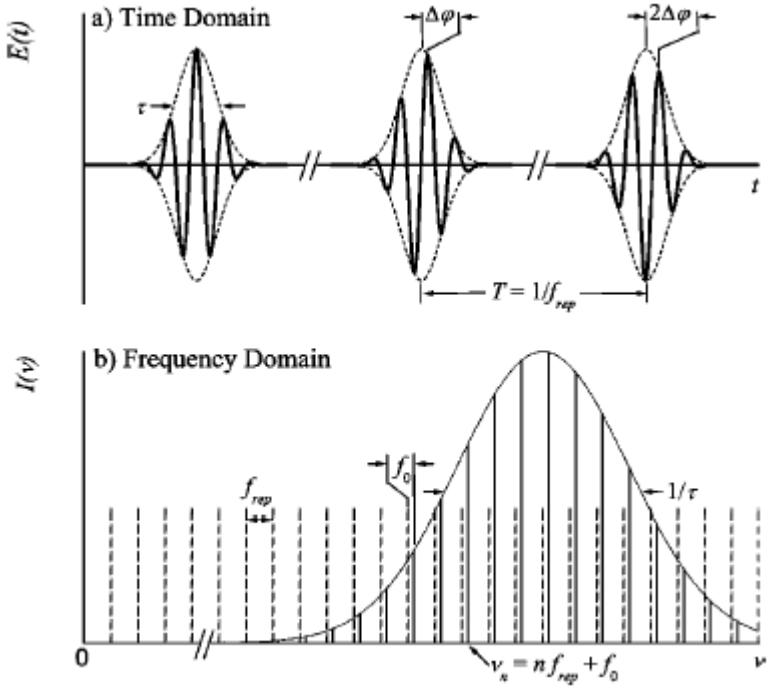
| | |
|---|---|
| Carrier-carrier scattering | 10e-15-10e-12 s |
| Intervalley scattering | ≥ 10e-14 s |
| Intravalley scattering | ~ 10e-13 s |
| Carrier-optical phonon thermalization | ≥ 10e-12 s |
| Optical phonon-acoustic phonon interaction | ~ 10e-11 s |
| Carrier diffusion (0,1 μm) | ~ 10e-11 s |
| Auger recombination (carrier density ~ 10e20 cm-3) | ~ 10e-10 s |
| Radiative recombination | ≥10e-9 s |
| Lattice heat diffusion (1 μm) | ~10e-8 s |

A schematic diagram of photoexitation and subsequent energy relaxation

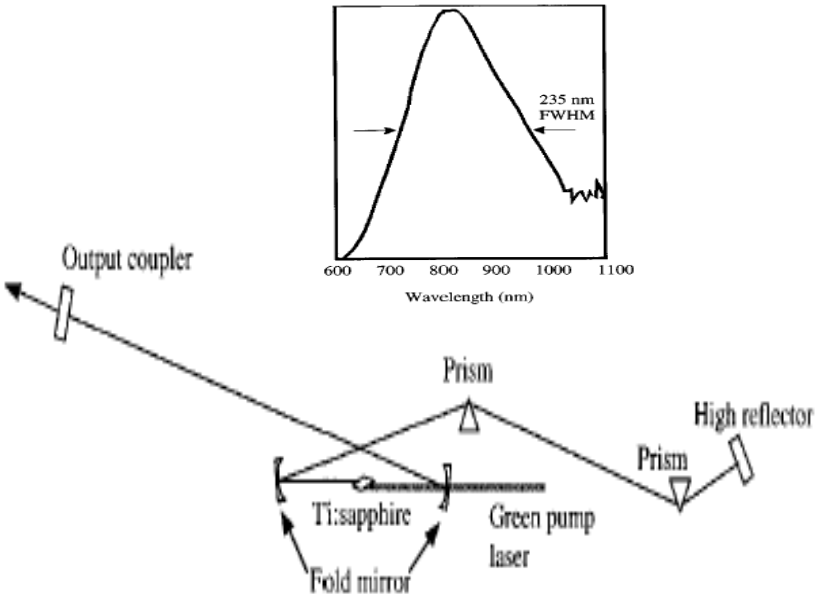


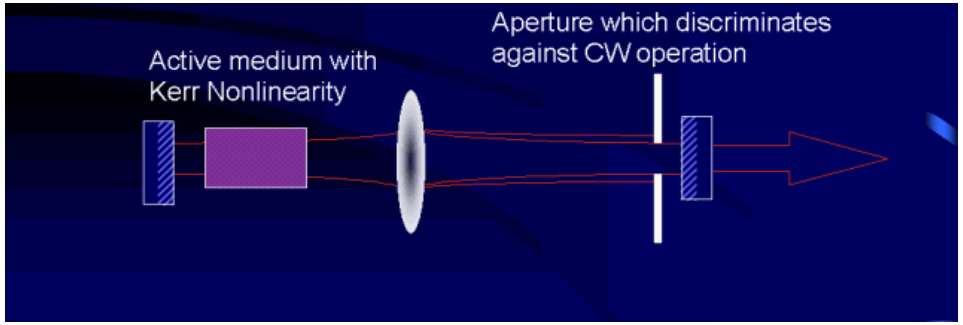
# Generation of ultrashort laser pulses

## Mode-locked lasers



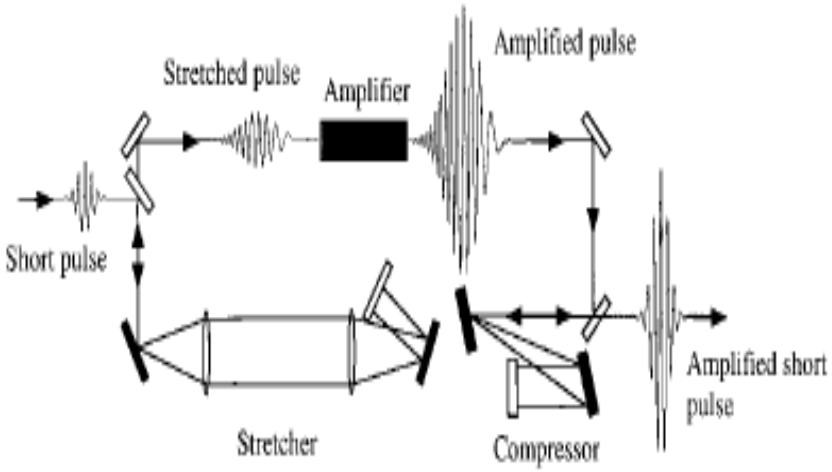

## Ti:Sapphire laser



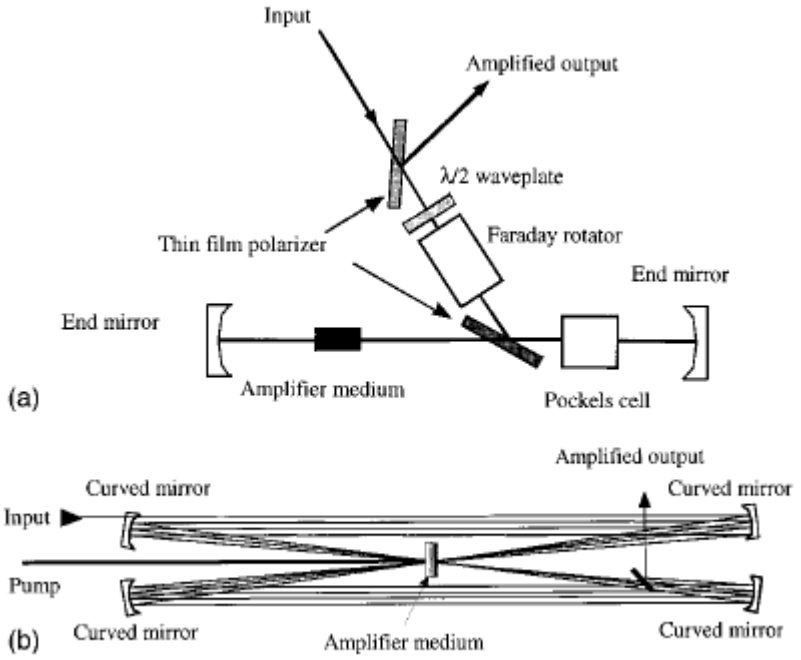



# Ultrashort pulse amplification

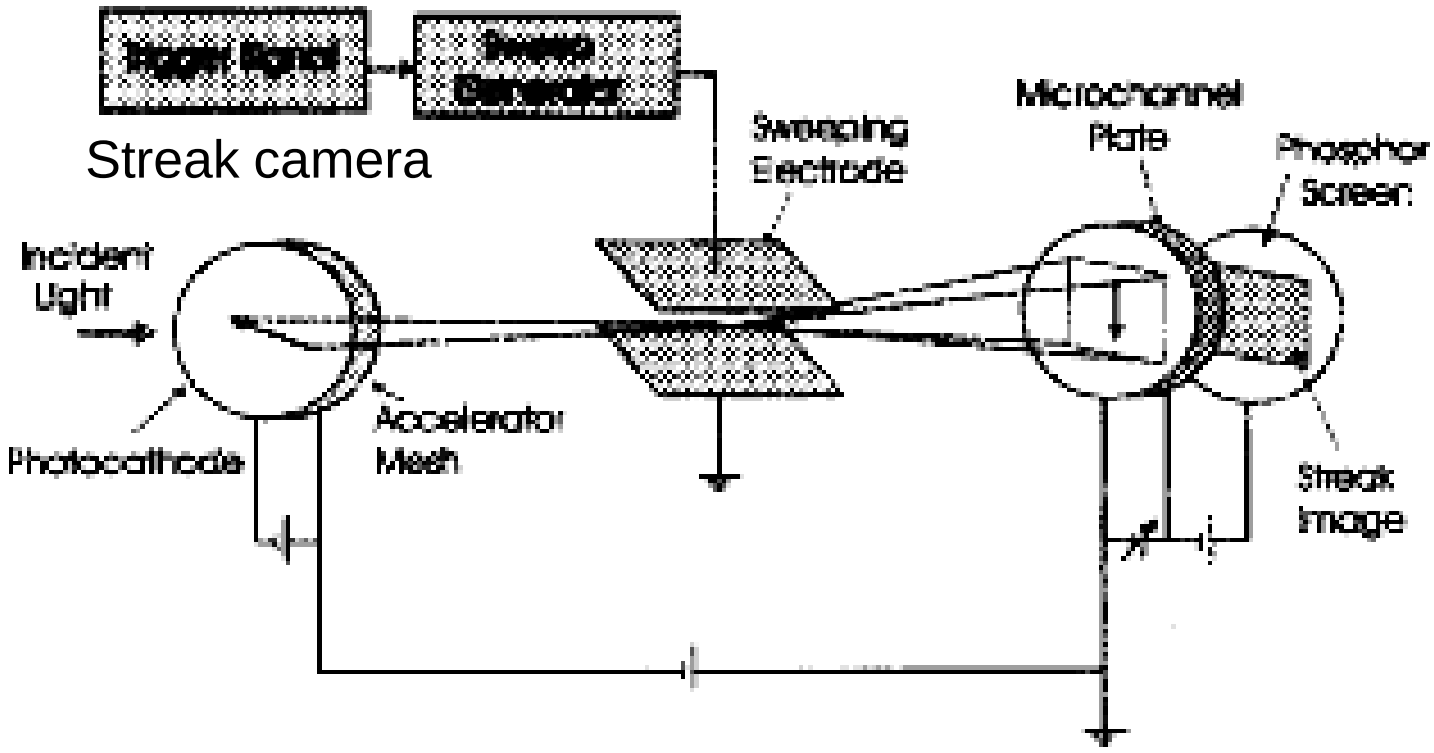
Chirped-pulse amplification (CPA)



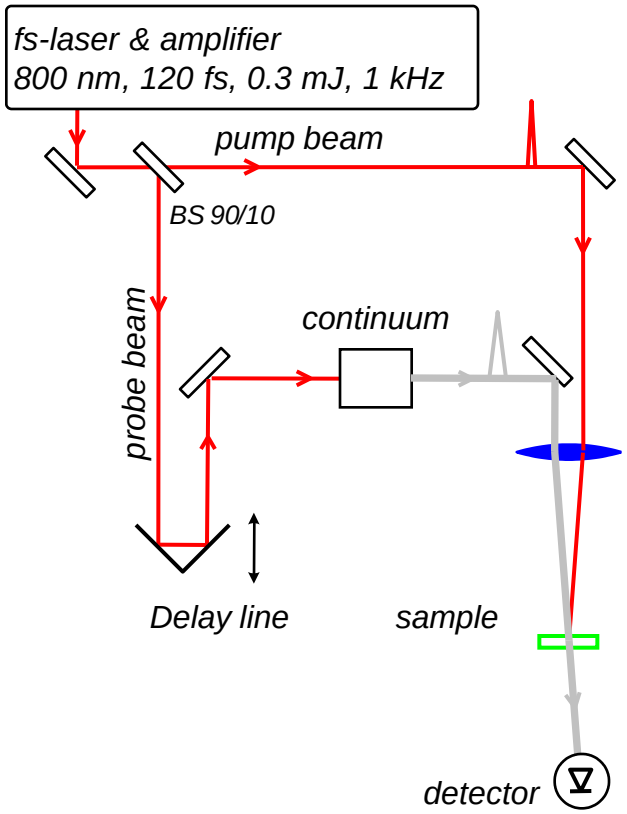

Regenerative (a) and multipass (b) preamplifier

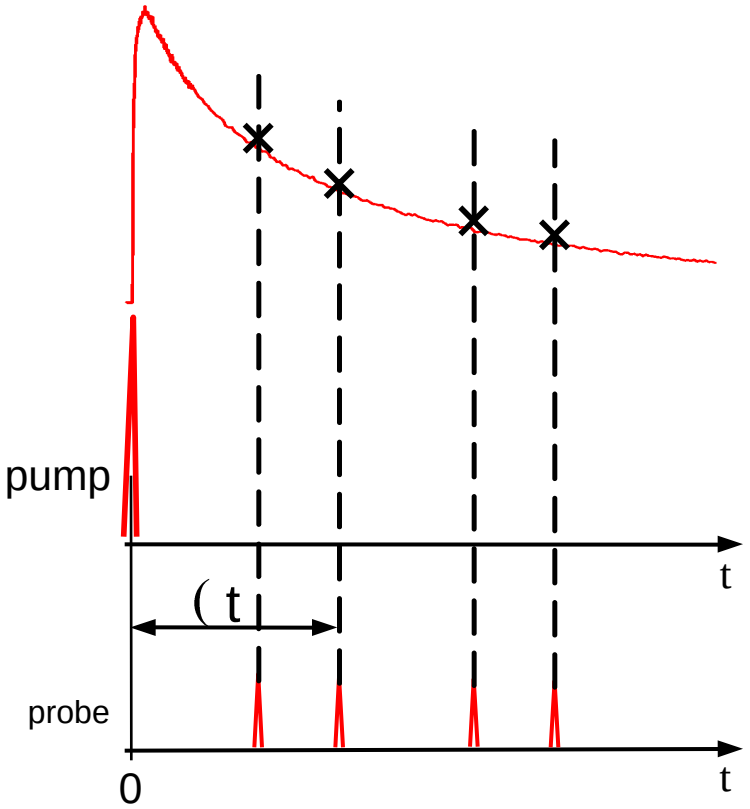


# Techniques for probing ultrafast dynamics (~1 ps)

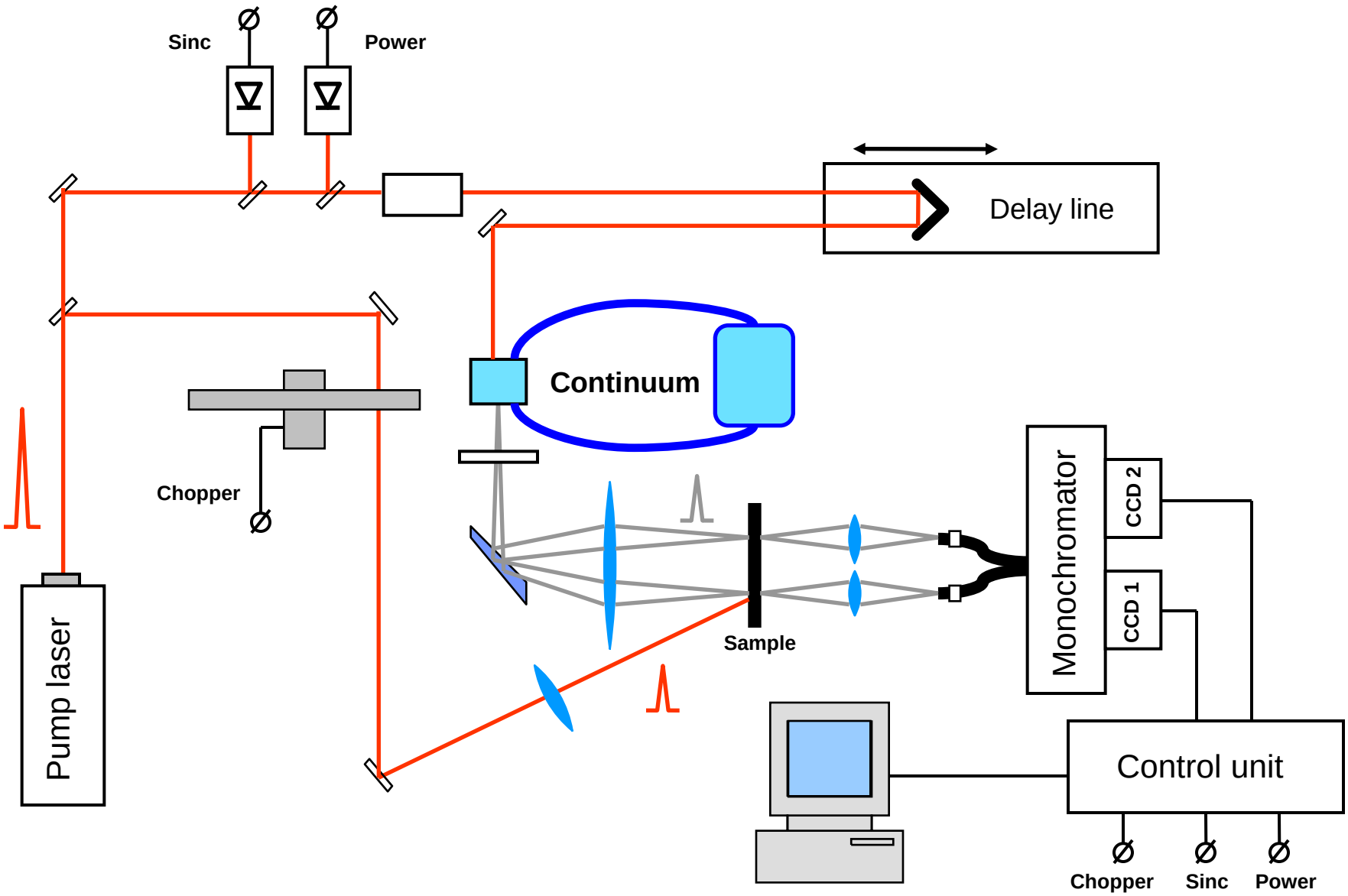


# Метод pump-probe



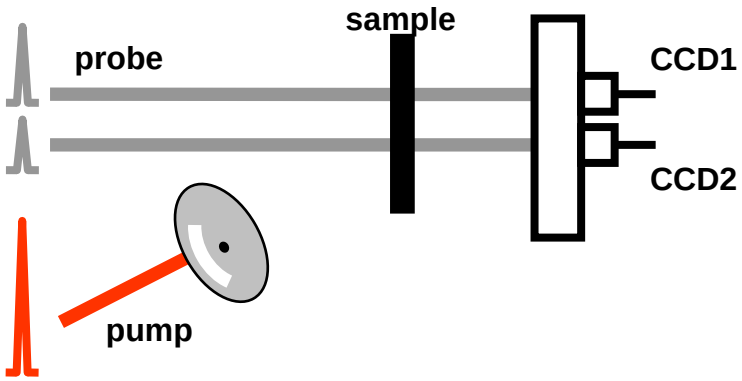
# Схема установки pump-probe



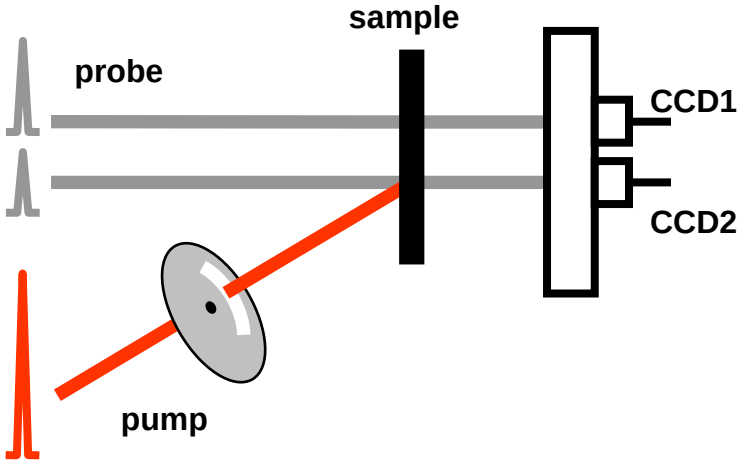
**Измерение относительного пропускания**

## Возможности установки pump-probe.

**Определение баланса каналов**




**Измерение относительного пропускания**




Измерение спектров пропускания и отражения:

- в интервале длинн волн 350 – 1000 нм;

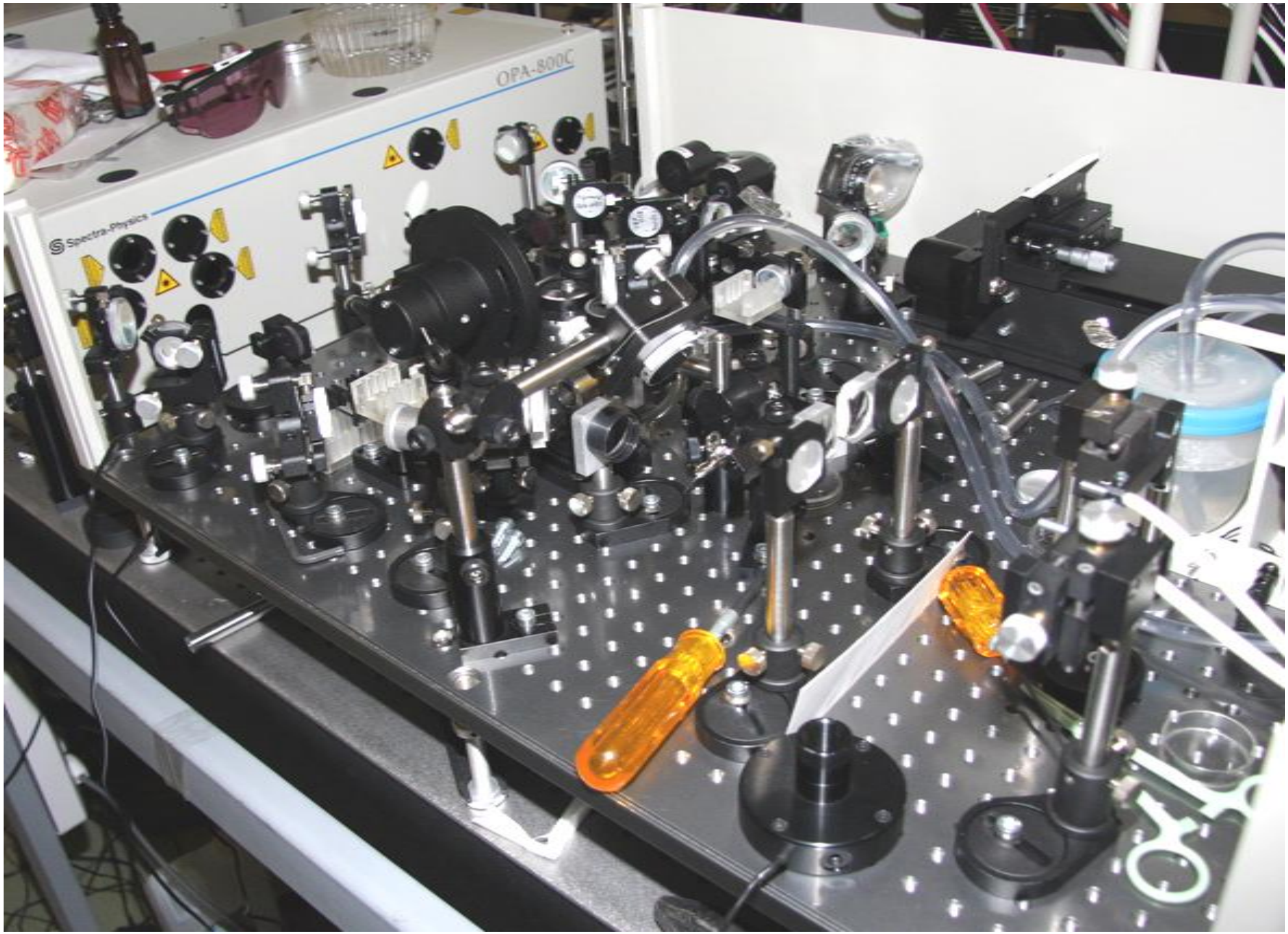
- задержка от pump-импульса от 0 до 1700 пс.

- В качестве возбуждения можно использовать:

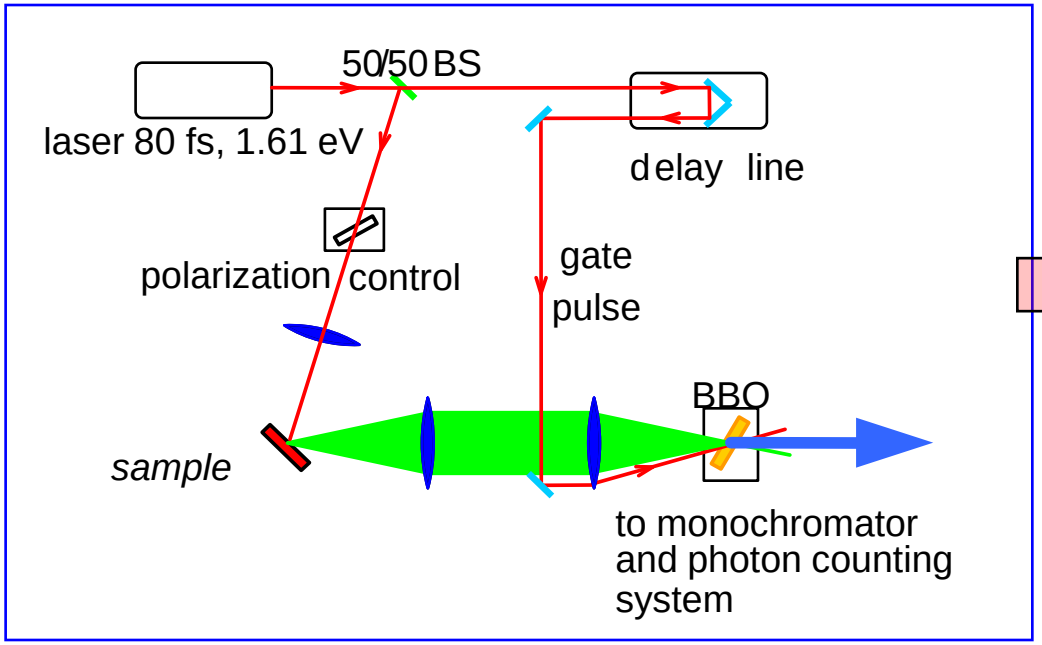
Регенеративный усилитель “Spitfire”
диапазон перестройки 750÷840 nm,
длительность импульса <130 fs,
мощность в импульсе 0.3 mJ (2GW),

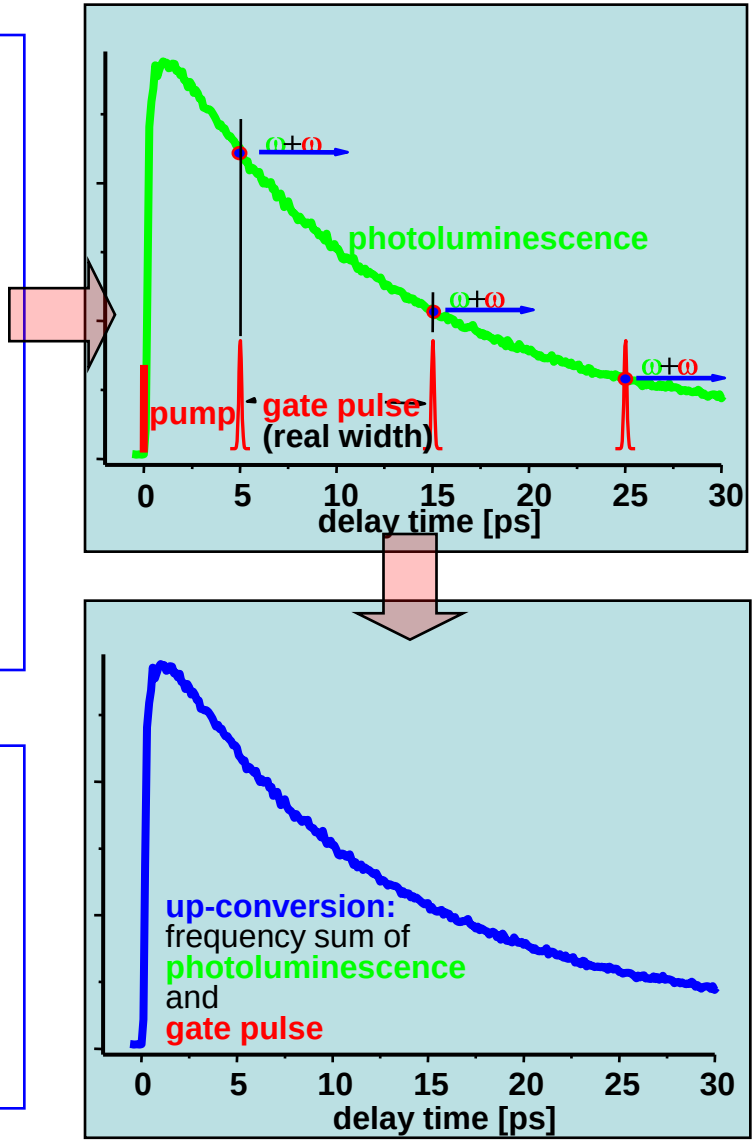
Оптический параметрический усилитель OPA-800C
диапазон перестройки 1.1÷2.8 mm
длительность импульса <130 fs
мощность в импульсе 18 μJ @ 1.3 mm; 10 μJ @ 2 .08 mm;

Генератор 2-й и 3-й гармоник
диапазон перестройки фикс. 400, 266 nm
длительность импульса <130 fs


OPA-800C
Spectra-Physics

# Time-resolved PL measurements by up-conversion technique




**Excitation:**

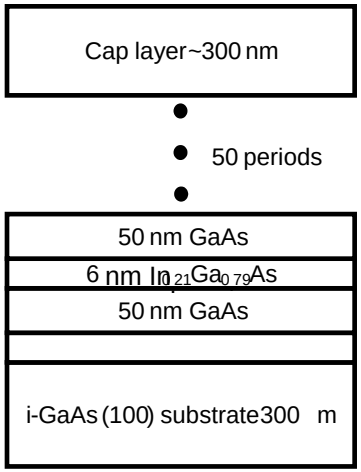
- Ti:Sapphire “Tscunami”
- wavelength 730-850 nm
- repetition rate 80 MHz
- pulse width <130 fs
- pulse energy > 0.1 W

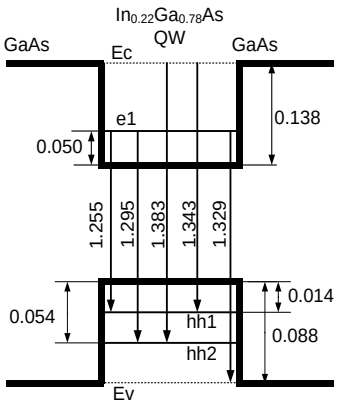
**PL detection:**

- wavelength 350-1800 nm
- delay up to 1700 ps
- time resolution ~100 fs

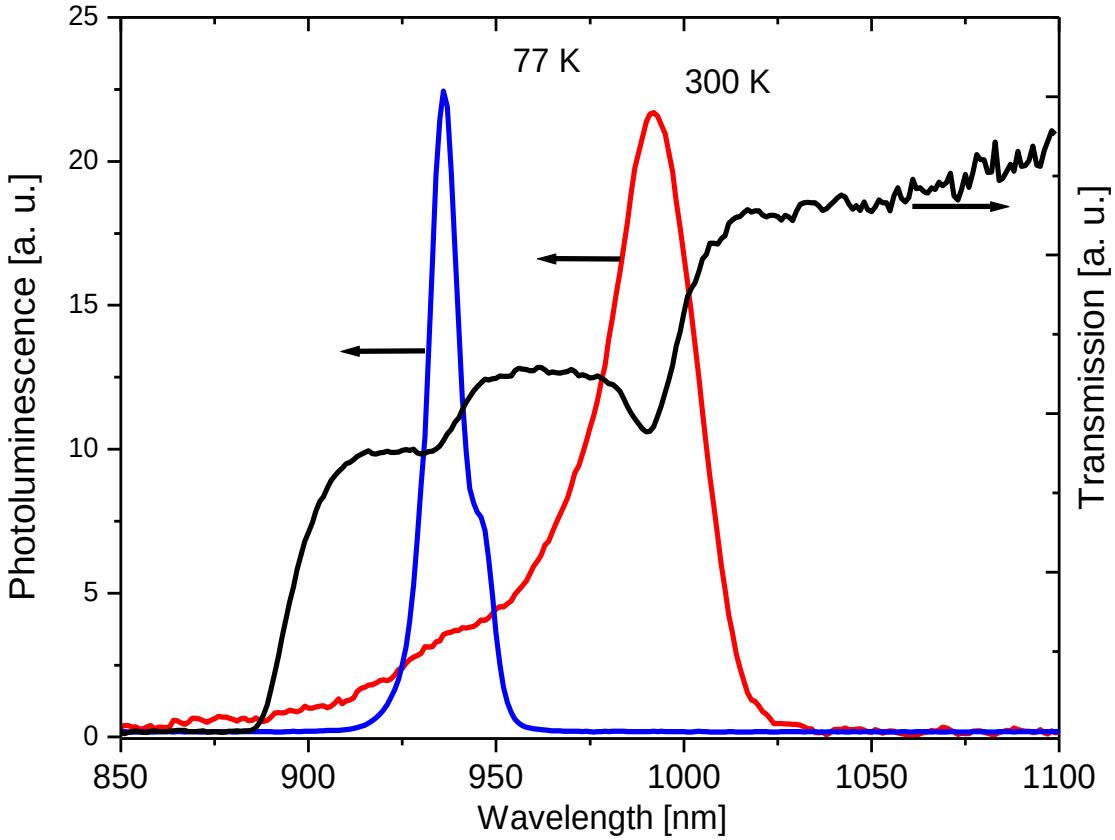
# Structure GaAs/InGaAs with multiple quantum wells

## Multiple QW structure

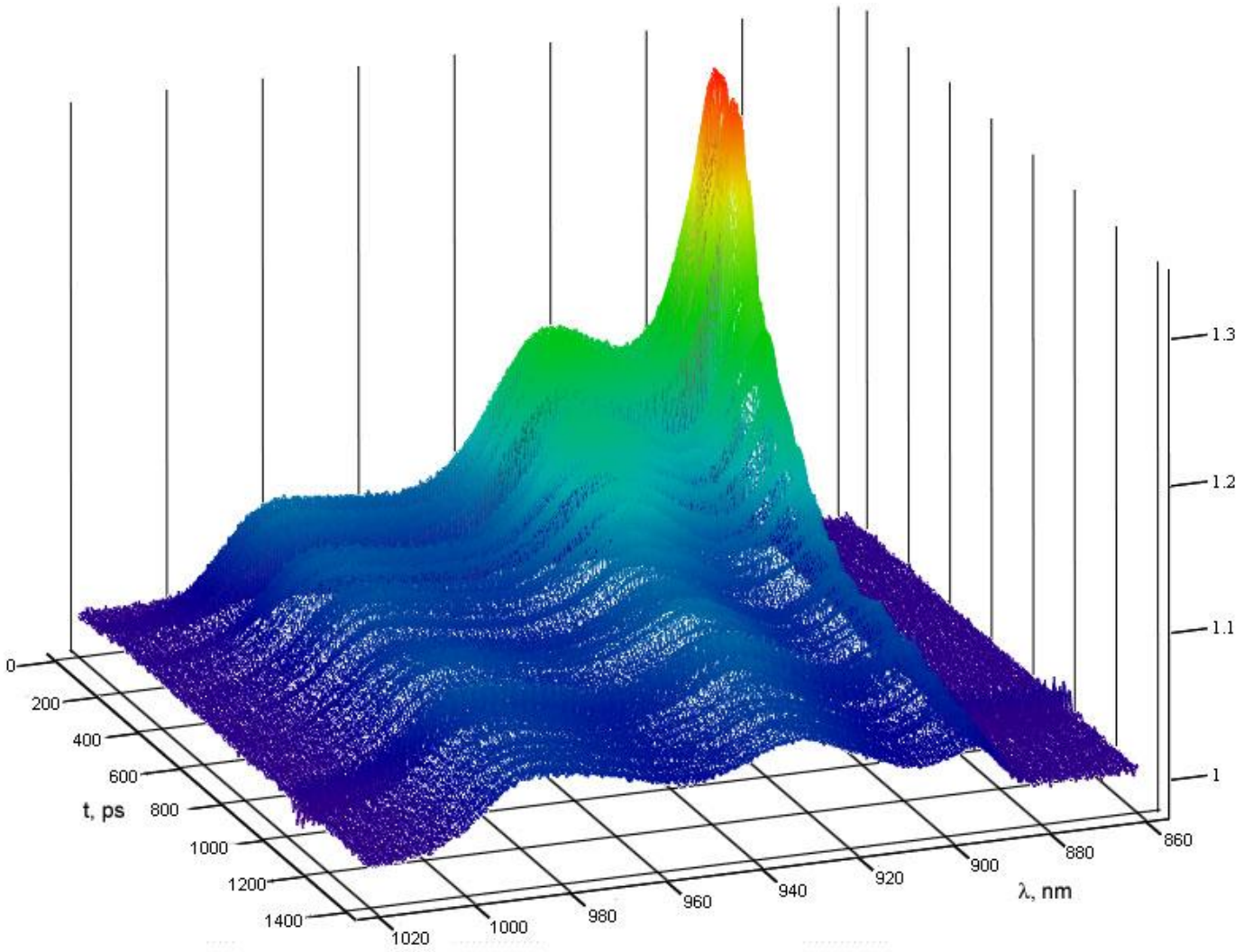


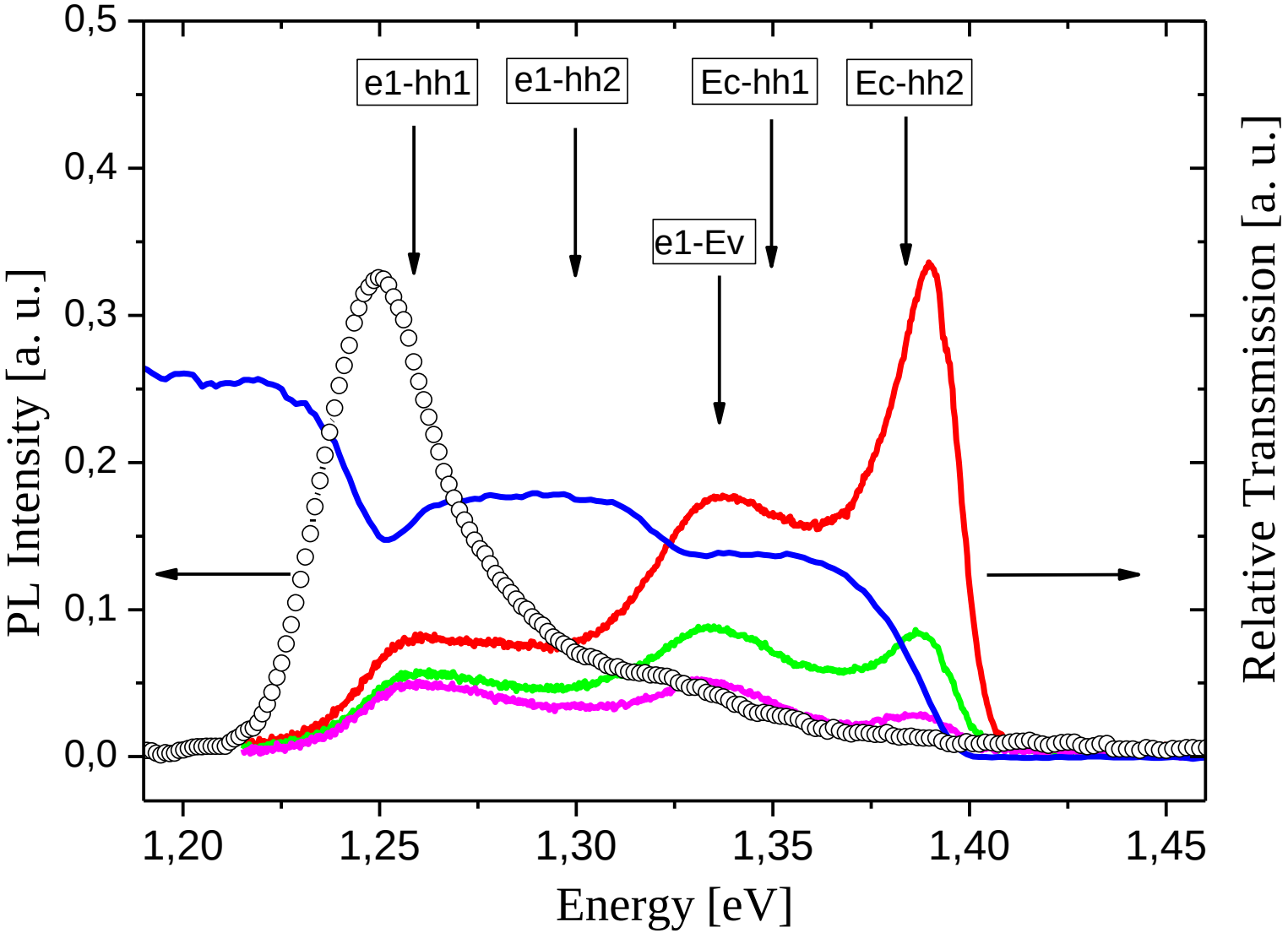

## Optical properties



# Спектры относительного пропускания δt от 0 до 1200 пс

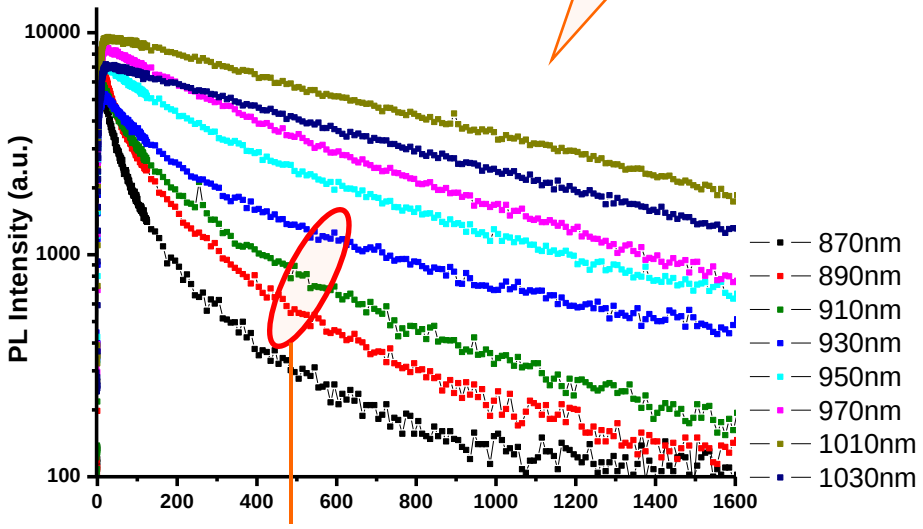


## Спектры относительного пропускания



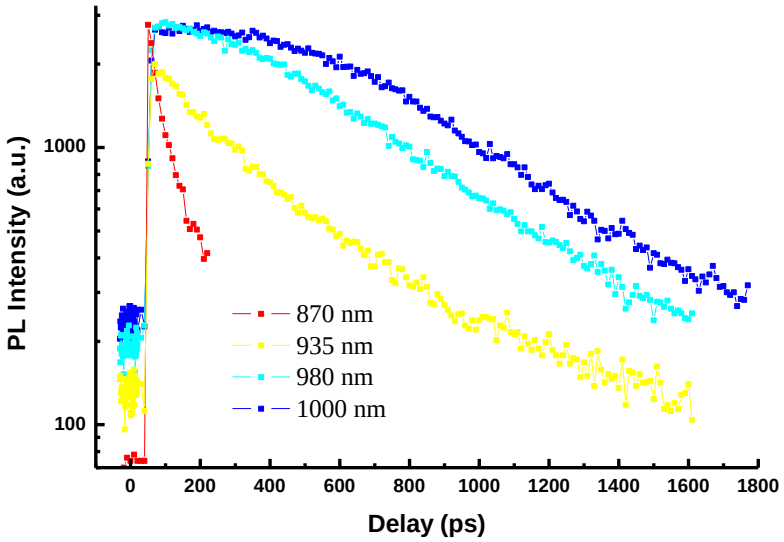
# Photoluminescence kinetics at 300 K

Lifetime of carriers in QW~ 600 ps




GaAs barriers PL

States in the QW are degenerated

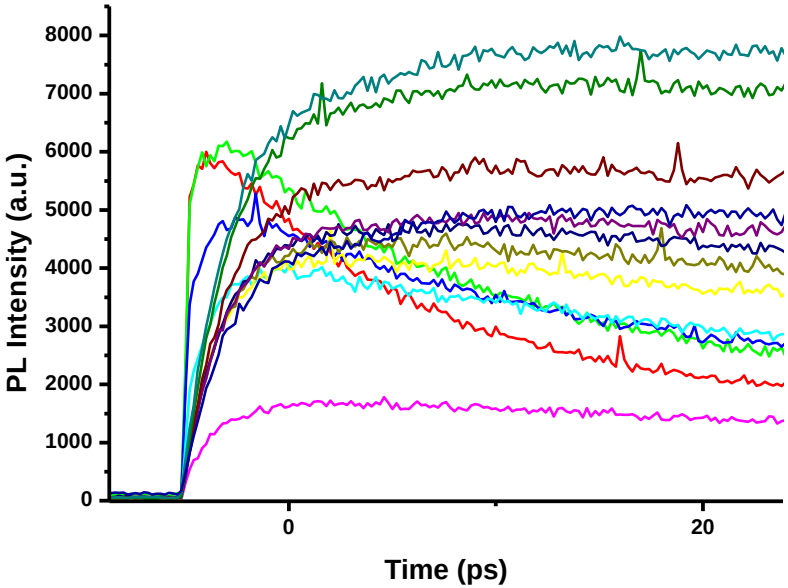


# Initial part of the PL kinetic curves at 300 K

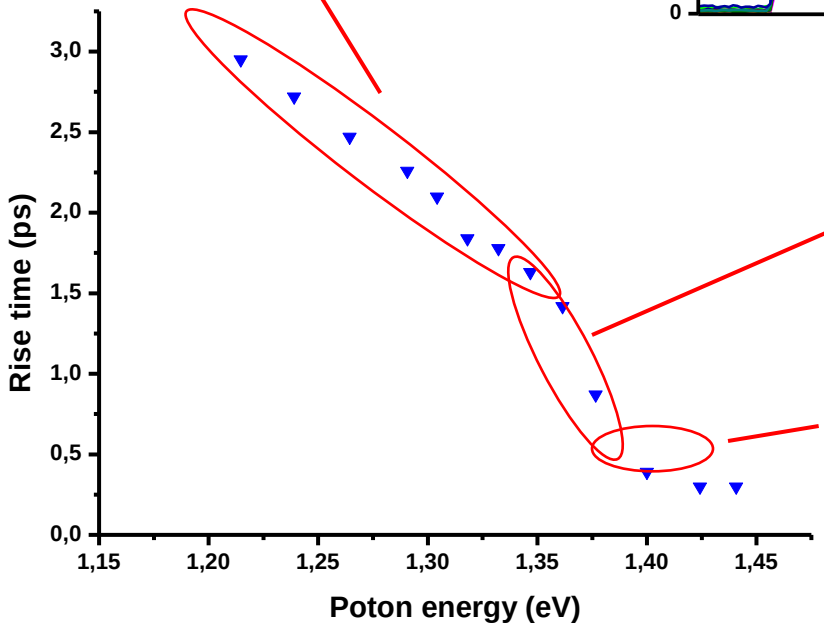
**Carrier thermalization within the QW by optical phonon emission**

Optical phonon emission

time is 0.3 ps



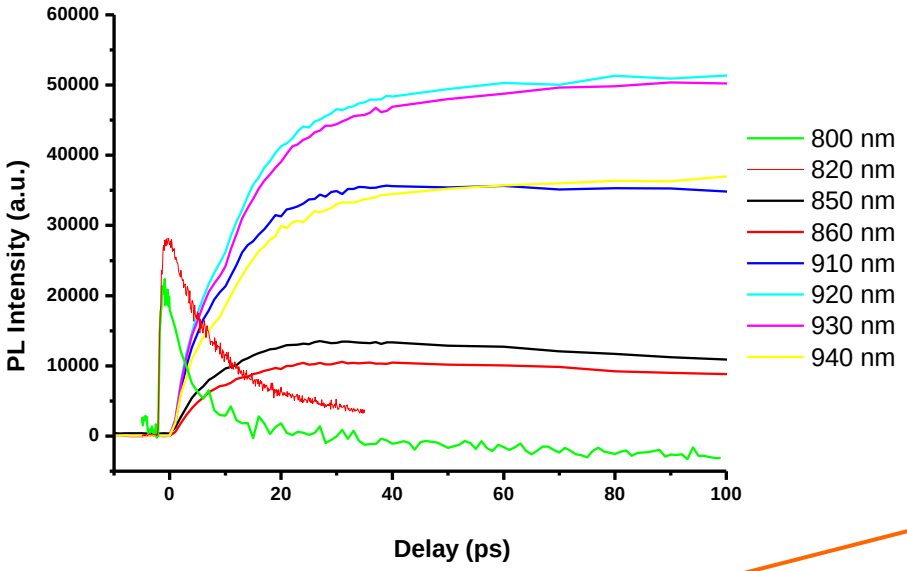

| Wavelength | Rise time |
|---|---|
| 860 nm | 0.3 ps |
| 870 nm | 0.3 ps |
| 885 nm | 0.39 ps |
| 900 nm | 0.87 ps |
| 910 nm | 1.42 ps |
| 920 nm | 1.63 ps |
| 930 nm | 1.78 ps |
| 940 nm | 1.84 ps |
| 950 nm | 2.10 ps |
| 960 nm | 2.26 ps |
| 980 nm | 2.47 ps |
| 1000 nm | 2.72 ps |
| 1020 nm | 2.95 ps |



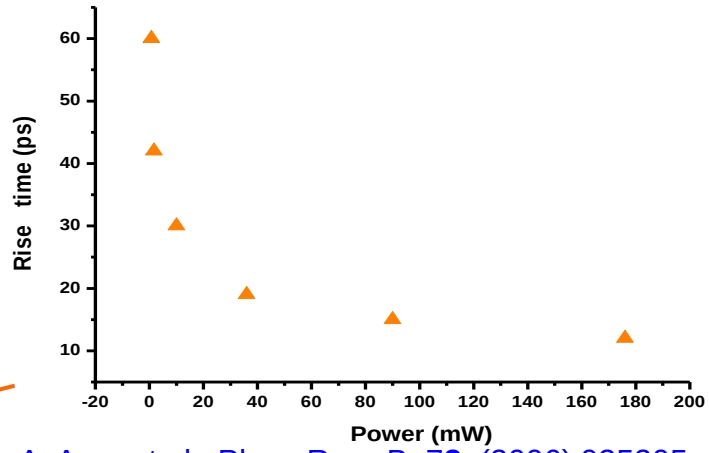

**Carrier trapping into QW ~ 1 ps**

**Carrier thermalization in bulk gallium arsenide**

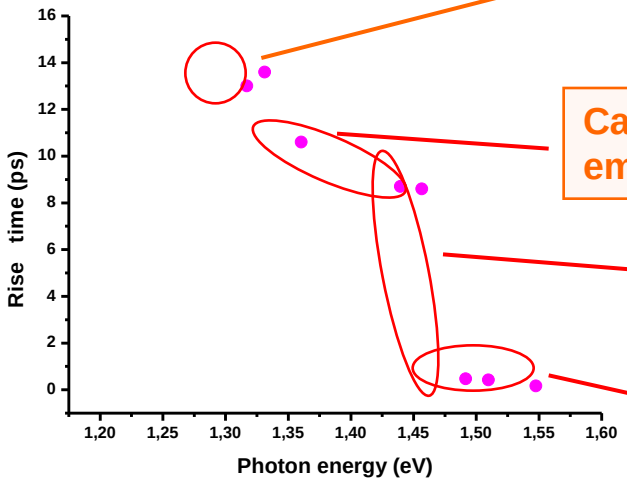
# Initial part of the PL kinetic curves at 10 K




**Dependence of the PL rise time on the excitation power at ground state of QW**



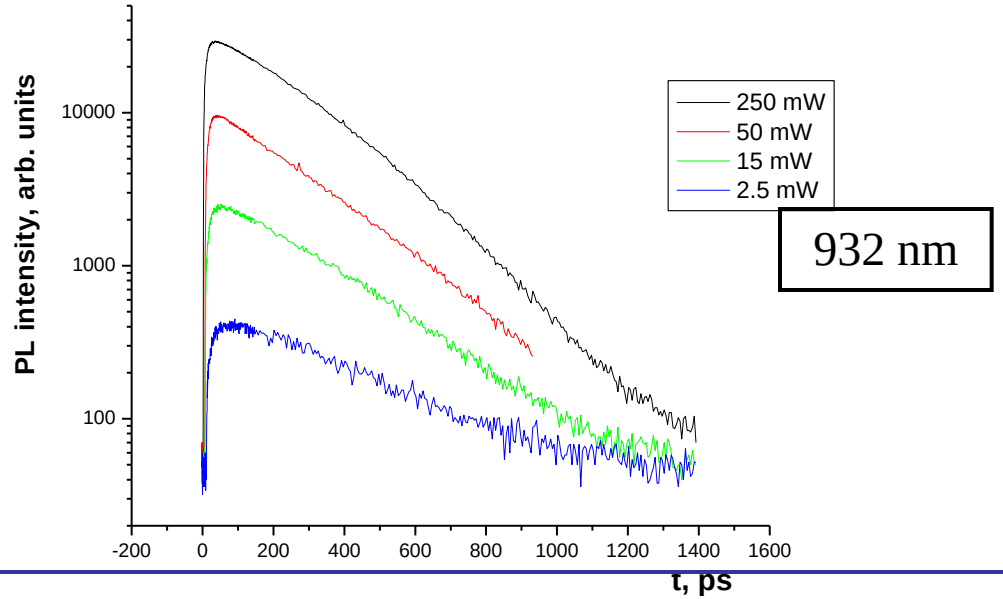

A. Amo et al., Phys. Rew. B, 7**3**, (2006) 035205

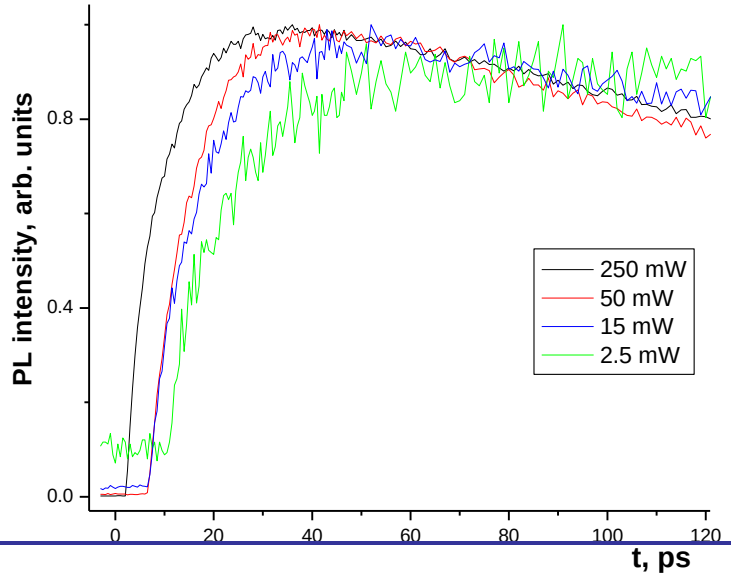


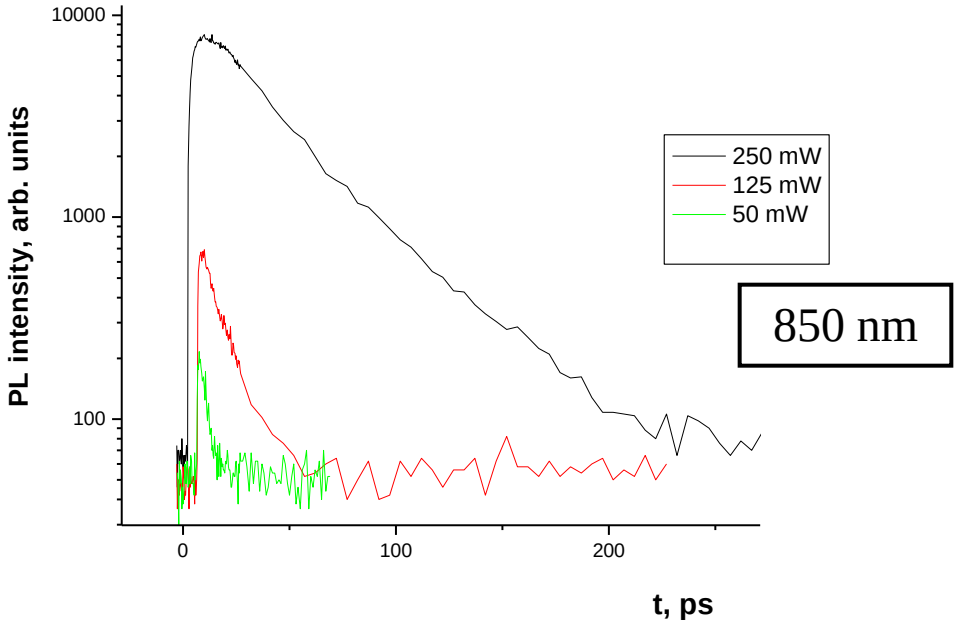

**Carrier thermalization within the QW by optical phonon emission**. Optical phonon emission time is 0.7 ps

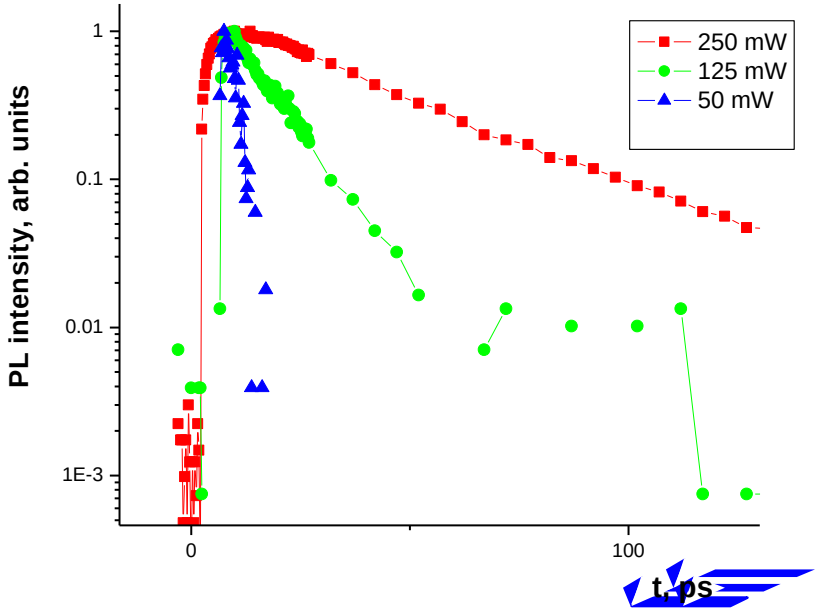
**Carrier trapping into QW ~ 6 ps**

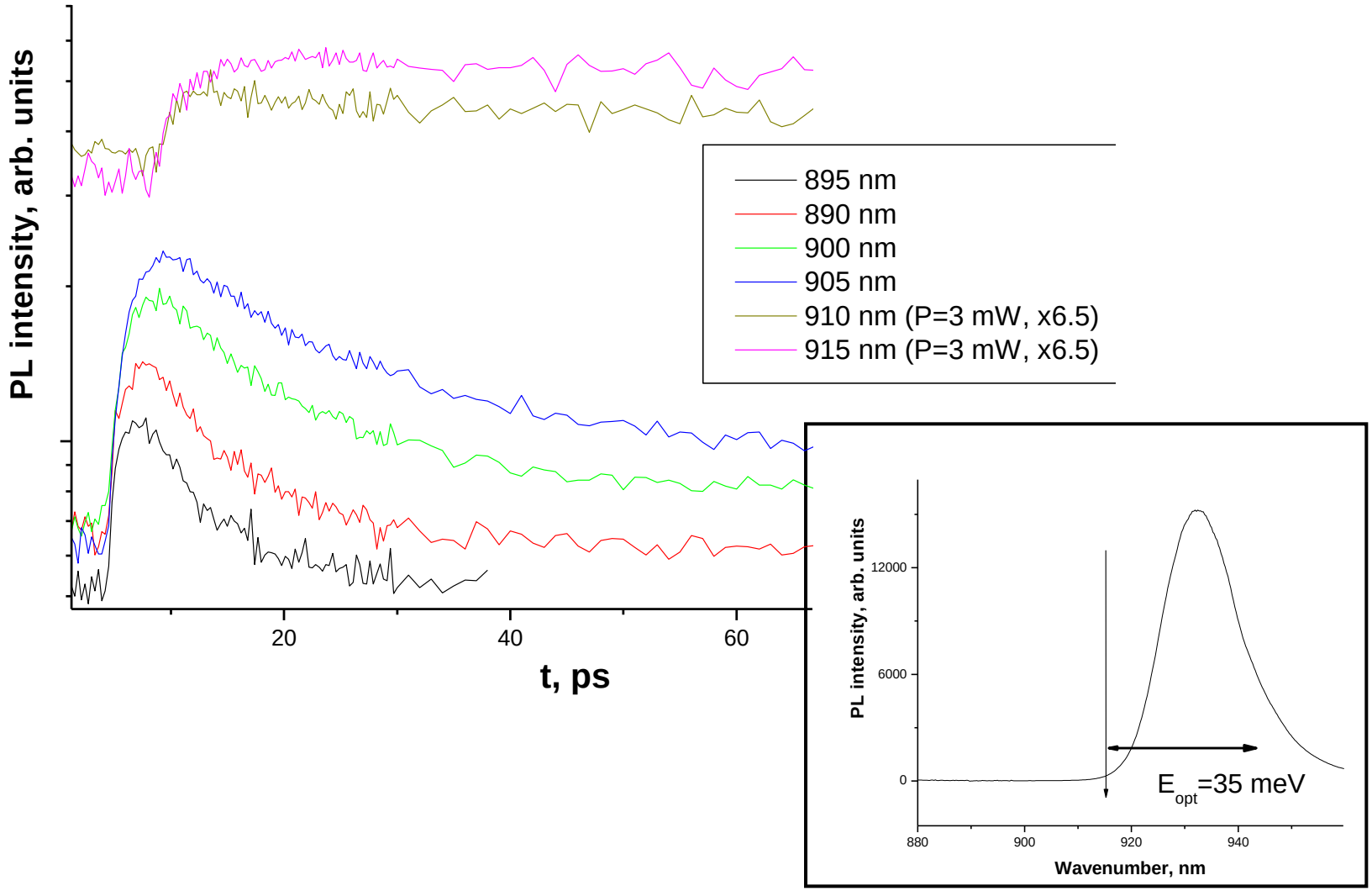
**Carrier thermalization in bulk gallium arsenide**

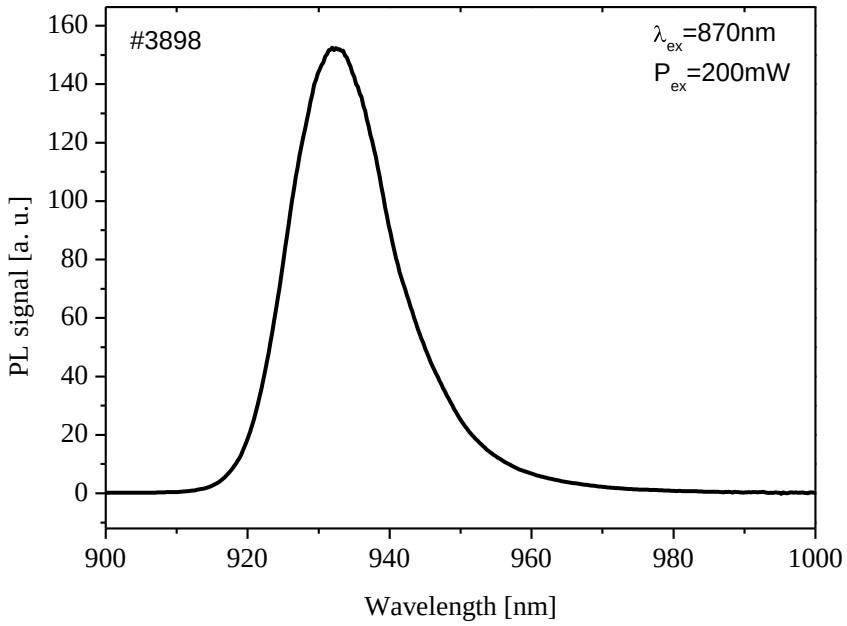

PL intensity, arb. units
10000
1000
100
-200
0
200
400
600
800
1000
1200
1400
1600
t, ps
250 mW
50 mW
15 mW
2.5 mW
932 nm

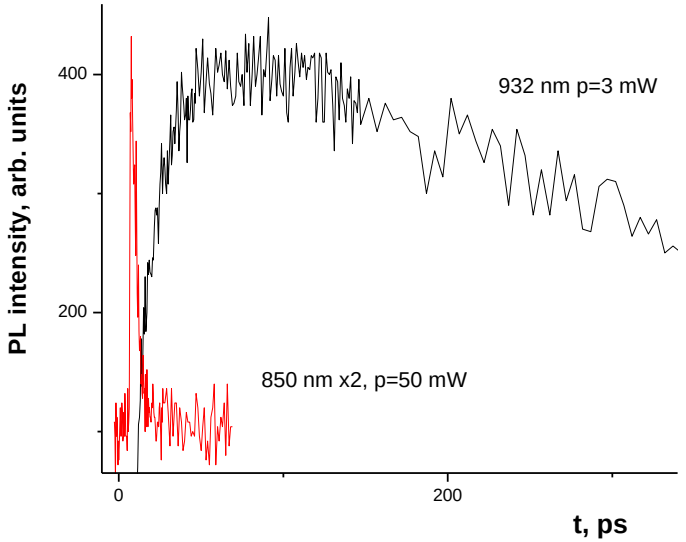

PL intensity, arb. units
0.8
0.4
0.0
0
20
40
60
80
100
120
t, ps
250 mW
50 mW
15 mW
2.5 mW

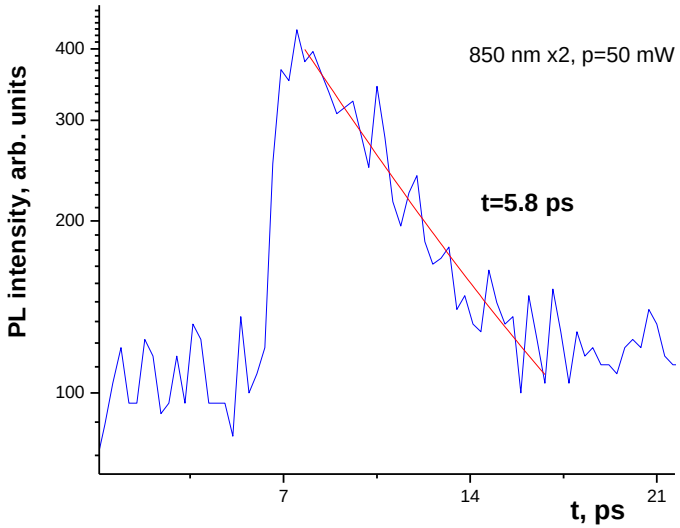

PL intensity, arb. units
10000
1000
100
0
100
200
t, ps
250 mW
125 mW
50 mW
850 nm


PL intensity, arb. units
1
0.1
0.01
1E-3
0
100
t, ps
250 mW
125 mW
50 mW


PL intensity, arb. units
t, ps
20
40
60
895 nm
890 nm
900 nm
905 nm
910 nm (P=3 mW, x6.5)
915 nm (P=3 mW, x6.5)
PL intensity, arb. units
12000
6000
0
880
900
920
940
Wavenumber, nm
E_opt=35 meV


#3898
λex=870nm
Pex=200mW
PL signal [a. u.]
Wavelength [nm]
160
140
120
100
80
60
40
20
0
900
920
940
960
980
1000


932 nm p=3 mW
850 nm x2, p=50 mW
PL intensity, arb. units
t, ps
400
200
0
200


850 nm x2, p=50 mW
t=5.8 ps
PL intensity, arb. units
t, ps
400
300
200
100
7
14
21