

Department of Semiconductor and Optoelectronics Devices

## Optoelectronics laboratory

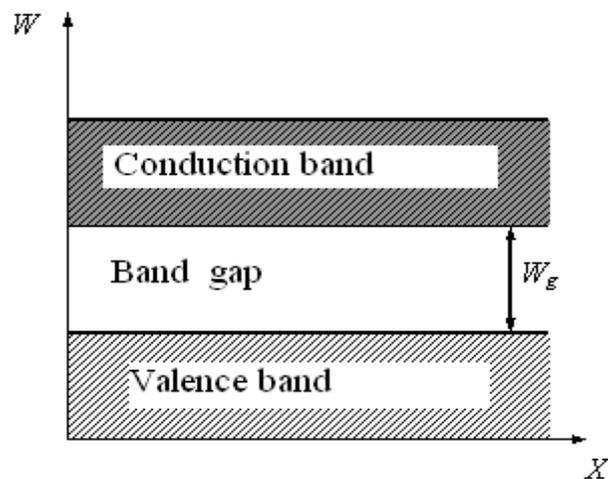
### Exercise 9

Measurement of optical emitters.

# 1. Theoretical basis.

## 1.1 Band gap model

Band gap theory of crystals explains differences between metals, isolators and semiconductors. In band gap models two basic energy levels exists: valence band and conduction band. Between them is the band gap (fig. 1).



*Fig.1 Band gap model.*

Value of  $W_g$ , called width of band gap, describes minimal energy which is required to take electron out of crystallographic lattice and bring it from the valence band to conduction one. It is measured in electronvolts ( $eV$ ).

## 1.2 Semiconductors.

### Intrinsic semiconductor

Intrinsic semiconductor is a monocrystal without any dopants, i.e. without different then eigen crystallographic lattice atoms. In presence of energy (for example when heated) some electrons obtain energy which is bigger than  $W_g$  and get through band gap to conduction band. These electrons become free negative charge carriers and can create electric current. Places abandoned by electrons become holes, which are positive charge carriers in valence band.

### Doped semiconductors

Doping of semiconductors, build usually from atoms from 4<sup>th</sup> group (for example silicon, germanium), is based on insertion of different atoms into crystal. It allows obtaining different properties of material. There are two basic types of dopants: acceptor and donor. Acceptor dopant is a trivalent element. This atom has three valence atoms, which is associated with crystal lattice. To complete the fourth bond lacks one electron. It shall be completed by taking an electron from a neighboring bond. In this binding the hole is formed. In this manner acceptor semiconductor is formed (**p-type** semiconductor; fig.2).

Donor dopants are done by the insertion to the semiconductor elements of 5<sup>th</sup> group. Through four valence electrons, they are associated with crystal lattice. Unused fifth electron becomes a free carrier of negative charge. Such a doped semiconductor crystal is called a donor, or n-type semiconductor material (Figure 3)

The consequence of doping is to introduce the new energy levels, respectively donor level (Fig.4) and acceptor one (Fig. 5).

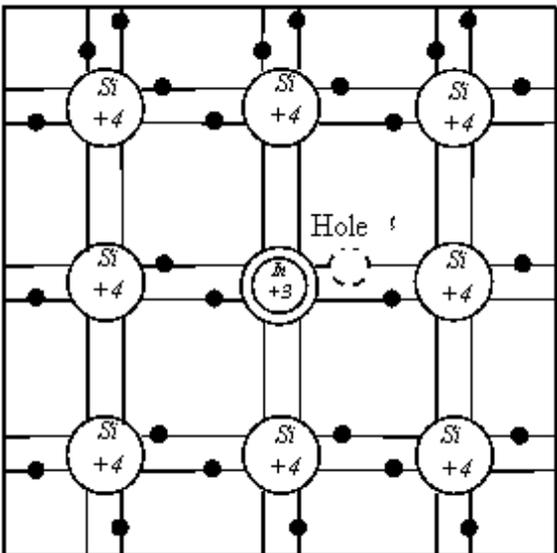


Fig. 2 Acceptor semiconductor („p”)

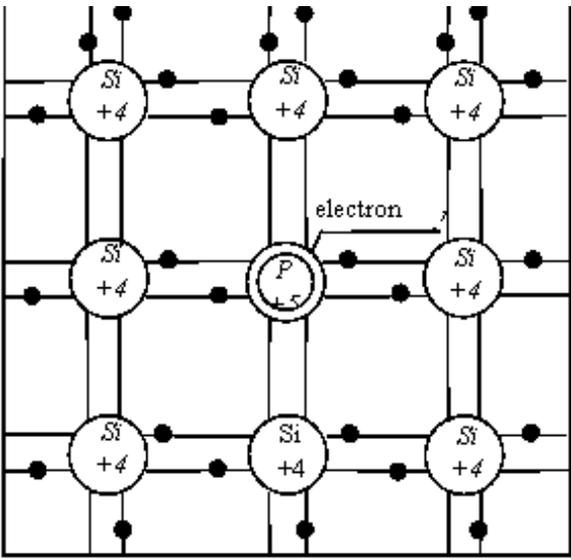


Fig. 3 Donor semiconductor („n”)

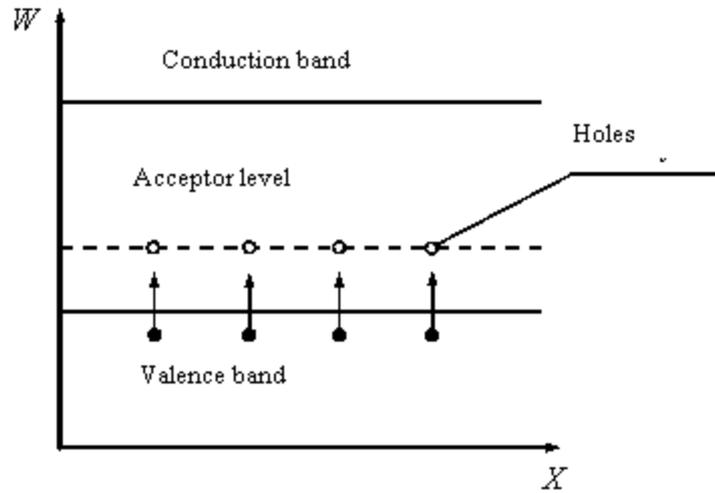


Fig.4 Acceptor semiconductor

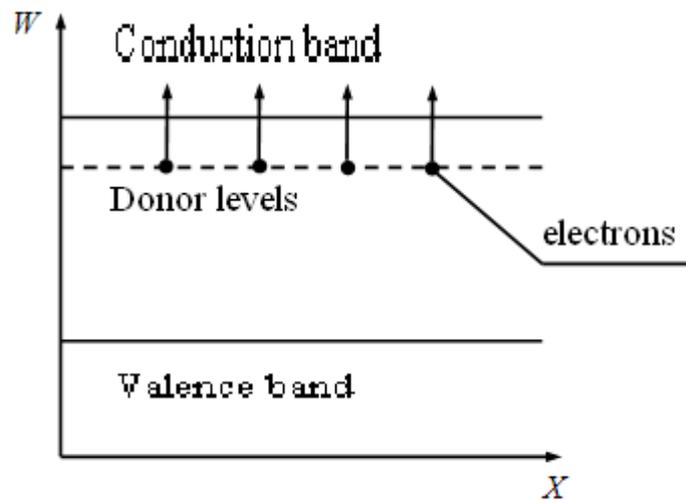


Fig.5 Donor semiconductor („n”).

### 1.3 Recombination

The intrinsic and doped semiconductors undergo recombination. These phenomena is based on merging of electrons and holes, resulting in two charge carriers disappear. They are described by the mathematical equations and parameters. These processes are always related to energy emission, the quantity and form is dependent upon the nature of these phenomena. In semiconductors we distinguish the following types of recombination:

- **Phonon recombination** - energy is transferred to vibrations of crystal lattice.
- **Auger recombination** - energy is transferred to charge carrier, the result is a "hot medium" (hot hot electron or hole) .
- **Radiation recombination** – associated with the electromagnetic radiation in the form of photon emission.
- **Surface recombination** – associated with phenomenon which take place near the surface of semiconductor

The most important for LED and LD is radiation recombination.. The way in which this phenomenon occurs is strongly dependent on the formation of energy bands of the crystal and the nature of the forbidden band gap. We distinguish two types of semiconductors: the straight line (Fig. 6) and cross (Fig.7) band gap. In the case of a straight band gap minimum of conduction and the maximum of valence band fall for the same value of the wave vector  $k$ . In the opposite case we are dealing with a cross band gap.

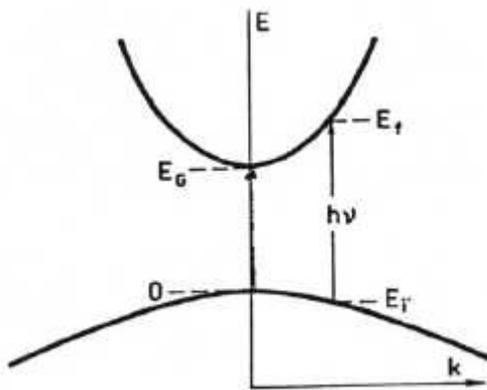


Fig. 6. Straight band gap

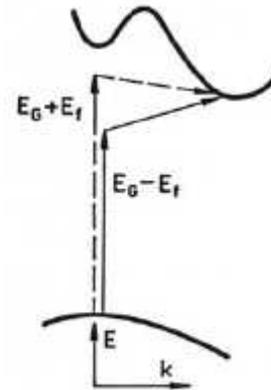


Fig.7 Cross band gap

In the LEDs construction only semiconductors with straight band gap are used. As a result of radiation recombination (merging of electron and hole) a photon is emitted. Wavelength of emitting light (color) is dependent on the width of the band gap. In the case of semiconductors with cross band gap radiation recombination is very rare and such semiconductors do not emit light.

Radiant recombination mechanism can take place in several ways:

**Recombination band-band** - conduction band electron recombines with a hole directly from the valence band, resulting in production of a photon with an energy equal to or greater than the energy band gap.

**Recombination through shallow donor or acceptor levels** - electron from conduction band recombines with a hole at the acceptor level or an electron from donor level recombines with a hole from the valence band.

**Donor-acceptor recombination** - an electron from donor level recombines with a hole at the acceptor level. Energy corresponding to this transition depends on the spatial distance of donor and acceptor.

**Recombination through deep levels** - in this case the photon energy is much lower than the band gap energy.

## 1.4 LED.

Light emitting diode is a source of electromagnetic radiation: visible or invisible (infrared LEDs). Photon emission occurs during the flow of electrical current through the diode in the direction of conduction (i.e. from layer P to layer N)

Wavelength of emitted light depends on band gap width and is given by equation:

$$\lambda = \frac{c * h}{W_g}$$

were:

c – light velocity,

h – Planck constant,

$W_g$  – width of band gap

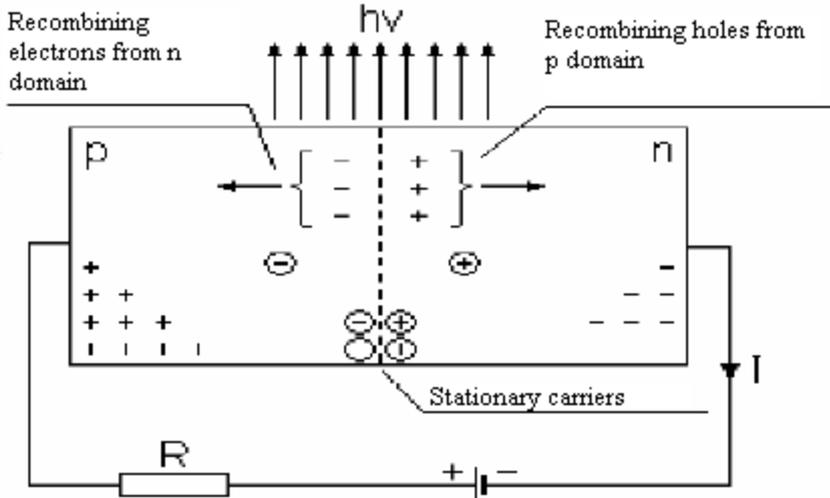
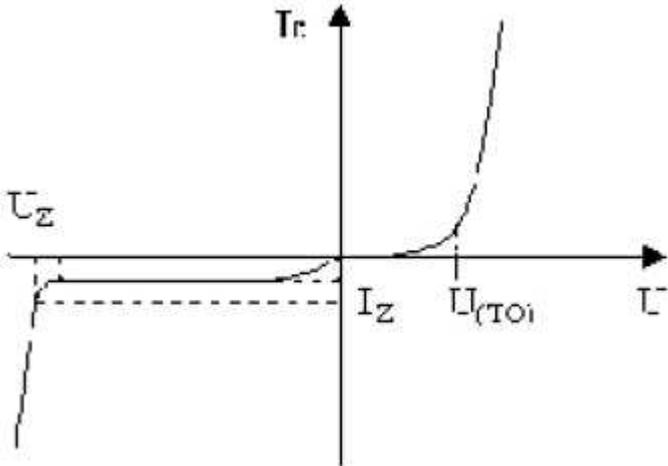


Fig.8 LED scheme phenomenon.

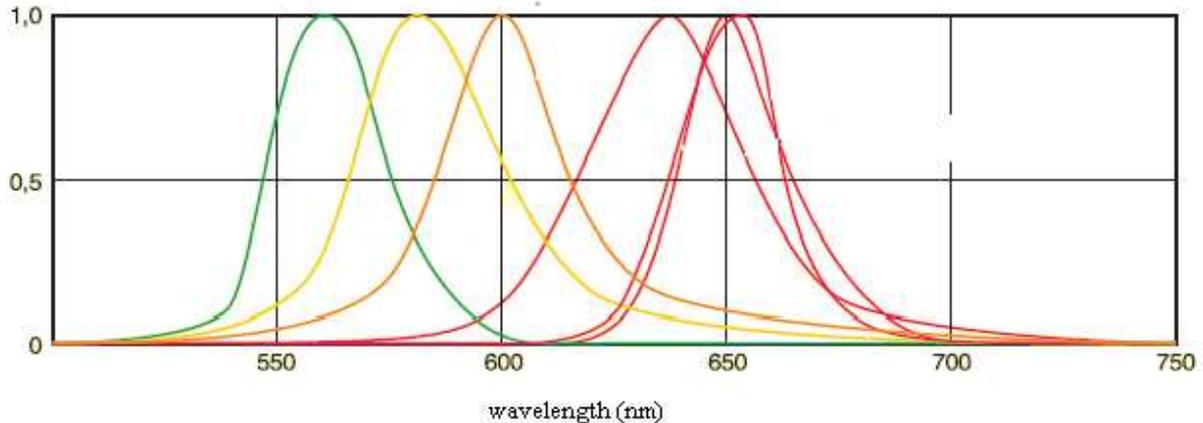


Res.9  $I(U)$  characteristics for LED (is similar to normal diode).

Material	$W_g$	Dopant	Light color
GaAs	1.443	Si	IR
GaP	2.26	N	Green

$GaP$	2.26	$N,N$	Yellow
$GaP$	2.26	$Zn,O$	Red
$GaAs_{0.6}P_{0.4}$	2.1	$N$	Red
$GaAs_{0.35}P_{0.65}$	2.1	$N$	Orange
$GaAs_{0.15}P_{0.85}$	2.1	$N$	Yellow
$Ga_{0.6}Al_{0.4}As$	2.1	$Zn$	Red
$Ga_xAl_{1-x}As(1 < x < 0.7)$	2.1	$Si$	IR

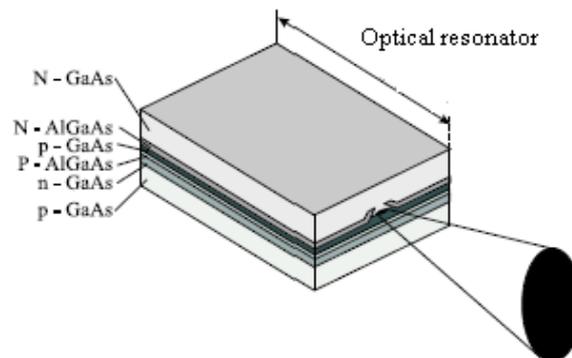
*Tab.1 LED comparison*



*Fig.10 Different spectrums of LEDs.*

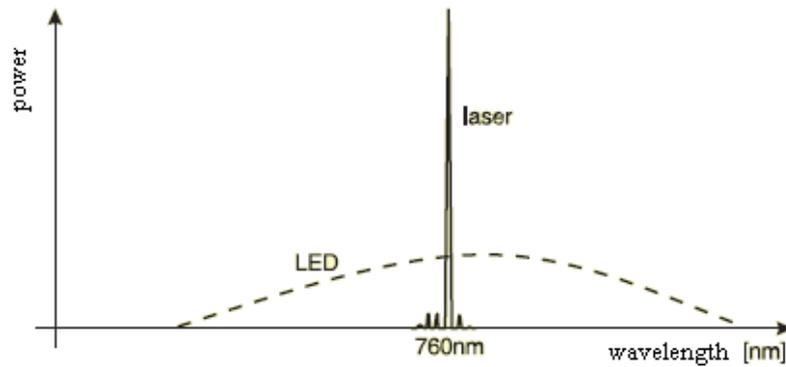
### 1.5 LD (laser diode).

The biggest difference between LED and LD is a presence of optical resonator in the second one. It is formed by two parallel and polished edges of the laser diode. These edges act as a mirror, with one having some light transmission.



*Fig.11 Structure of LD.*

Optical resonator force emitted photons to move only along junction. This leads to induced emission. Moving photon induce electron to recombine with hole and as an effect we have emission of light radiation, which has the same direction of propagation, wavelength and phase as an inducing photon. Induced emission is a phenomenon which determines the main characteristics of LD: a high power density, coherence and a narrow spectral range (as shown on fig.13).



*Fig.13 Spectral characteristics of LD and LED.*

## 2. Experience description.

### 2.1 Current / voltage characteristics.

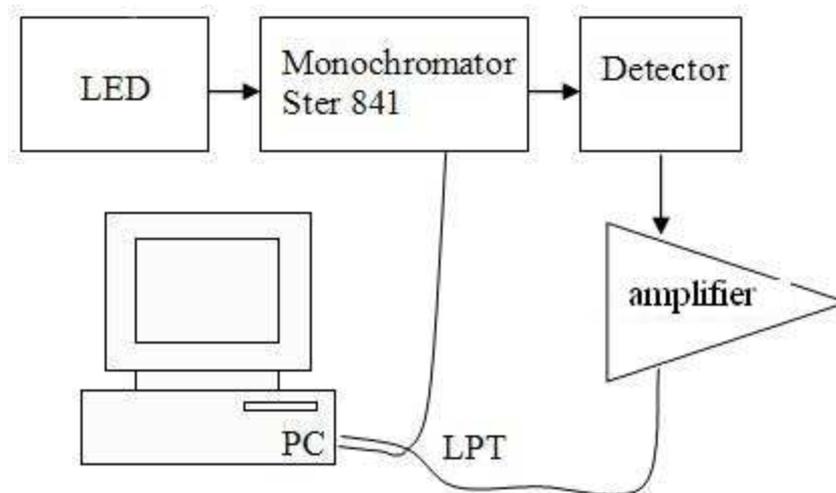
One should draw the I(U) characteristics for LEDs and LDs and compare them with traditional bulb. Measurements are based on following circuit:



*Fig.16 Measurement circuit to draw the I(U) char.*

### 2.2 Spectrum characteristics.

One should draw spectrum characteristics for LEDs, LDs and a standard halogen bulb. Measurement is based on a circuit presented on fig. 17.



*Fig.17 Configuration scheme for measurement of spectrum characteristics.*

### **3. Report preparation.**

Report should involve

- description of measured devices,
- tables with measurement results
- graphs with measurement results,
- conclusions