VA charakteristics of LED - Measurement of Planck constant

Tasks:

1. Familiarize yourself with the remote experiment.
2. Try measuring the VA characteristics in manual and automatic mode.
3. Measure the characteristics of all LEDs, record the data, and process them in appropriate software.
4. Determine the Planck constant h.

Remote experiment available at http://ises1.prf.ujep.cz/index_en.html.

Measurement principle

Electrons in atoms obey the Pauli excluding principle – there are no two electrons with the same sets of quantum number values. So, the electrons sit on energy levels from the lowest one. At zero temperature (0 K), there is no energy level from the lowest to the highest, which would not be occupied.

In solids, we observe a remarkable effect. The energy levels of the electrons are very close, so the electrons have a nearly continuous spectrum of energy (which is the result of too many electrons present in the solid). However, there are intervals of energy that none of the electrons can have; these energies are forbidden. The dependence of electron energy on the wavelength vector is called the band structure, since the allowed/forbidden energies form bands.

In semiconductors configuration, the difference between the highest ocuppied energy E_v and the first unocuppied energy E_c is called the forbidden band, its height is defined as $E_g = E_c - E_v$. The highest occupied band at zero temperatures is called the valence band, and the lowest unoccupied band is called the conduction band. In real semiconductors, at standard conditions (eg. non-zero temperature) some electrons difund from the occupied band to the unoccupied band because of thermal effect. The band structure of a semiconductor cannot be computed analytically, but can be computed using numerical methods. An example of a numerically computed band structure of a semiconductor of type III-V galium arsenid is shown in Figure 1.

In the conduction band $E \geq E_c$ the electron can increase its energy (e.g., in an electric field). In the conduction band E ≥ Ec, the electron can increase its energy arbitrarily (e.g. in an electric field), because in its neighbourhood there are enough unoccupied energy levels. In contrast, in the valence band $E \leq E_v$ the electron is bounded since the energy levels are occupied and it cannot jump so easily to another level. The valence and conduction bands are nearly connected in conductors; therefore, because of thermal movement, the electron can be released into the conduction band and conduct an electric current. In the case of semiconductors, it can be done by absorbtion of a sufficient amount of energy, e.g. by photon of energy E such that

$$E_g \leq E = h\nu = \frac{hc}{\lambda}$$

where h is the Planck constant, c is speed, ν frequency and λ is wavelength of light in a given material (we can assume vacuum). Semiconductors and insulators differ by the value of the forbidden band. (for insultators E_g 5 eV). Different semiconductors differ by value of E_g.

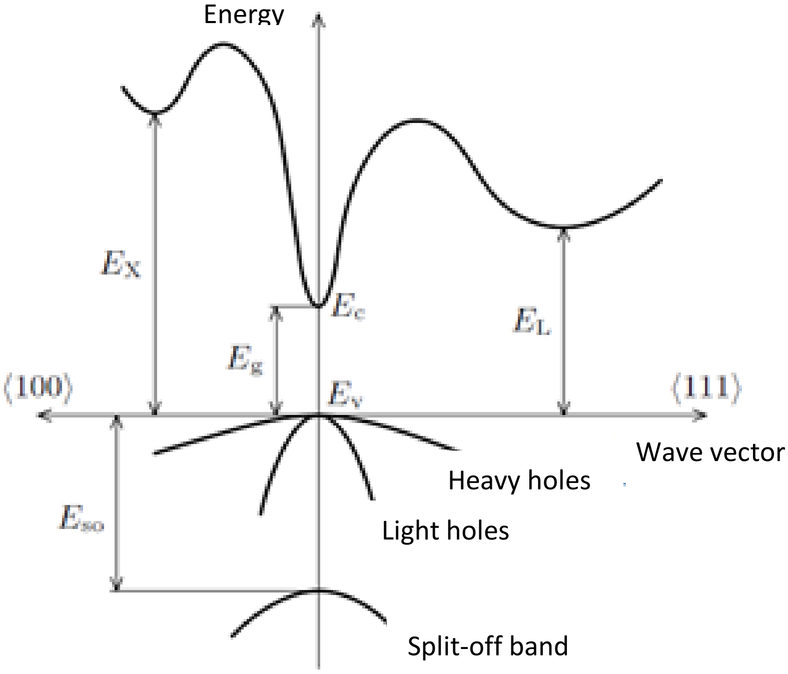


Fig. 1

The LEDs used are made of Ga-As semiconductors, which have a direct transition. This means that the absorbtion/emission of a photon is sufficient to transfer energy to/from the electron without impuls loss/gain. (In the band structure in Fig. 1 it means that the minimum energy E_c is directly above the maximum E_v.) The light-emitting diode (LED) uses an opposite jump from the conduction band to the valence band (this phenomenon is called spontaneous emission), and the photon of energy $E \geq E_g$ is emitted. First, sufficient energy is needed to transfer to the electron to jump into the conduction band. The mentioned thermal oscillation is insufficient, so the work W can be done by an electric field with voltage U

$$W = E_\mathrm{g} = eU$$

where e is the absolute charge of the electron. Then we obtain the inequality

$$\frac{hc}{\lambda} \geq eU \quad \Rightarrow \quad h \geq \frac{e}{c} \cdot U\lambda$$

Emitted wavelength λ and voltage U can be measured (in worst case it can be found in catalogue of components). The LED can glow only if certain minimal voltage is present, its existency is explained in eq. 1. In idealized state we can assume that voltage U can be measured in the moment, when the LED start glowing, and then the inequality becomes equality. Don't forget to discuss these asumptions in discussion.

Measurement procedure

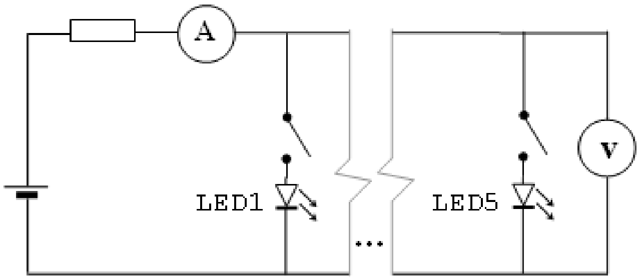
Experiment

Note: If more visitors are connected to the measurement page, they are ordered in queue by time of visit. Every visitor has approximately 15 minutes to measure, then the measurement is provided to the next visitor in queue. This state can be read from status field (e.g. Connected, Remaining ... seconds, Max. ... of waiting). When the user is inactive for minutes or the page is closed, his measurement is stopped.

Instructions

1. Click on link Run experiment
2. When the elements of the page are loaded, the camera and control elements are loaded.
3. Move to the section of **Choice of LED**. By clicking on the buttons, you choose a particular LED with its wavelength.
4. Move to the section **Control voltage for VA characteristics**, where you can manually or automatically change voltage.
5. In the graph **VA characteristics of LED** you can see measured data. Each LED is distinguished by its color. The graph can be cleared with the button **Clear graph**.
6. To start recording measured data, click **Start recording** in the section **Data recording**. Measure desired data and then click on **Stop recording** to end data recording.
7. Then move to **Select recorded data**, where a new data set appears. To export them to computer, click **Export values** (Excel or HTML table). Download the file (Excel option) or copy data from the a table (HTML option) from new window by pressing Ctrl + A to select all, Ctrl + C to copy, and Ctrl + V to paste into your software.

Scheme

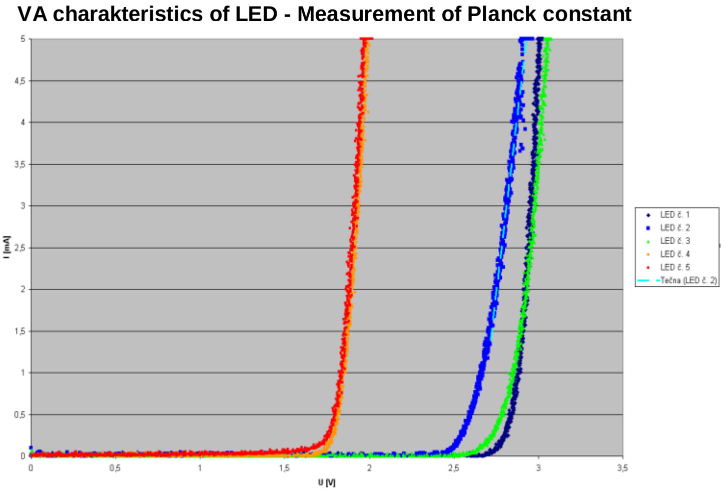


Instructions for Processing Measurements

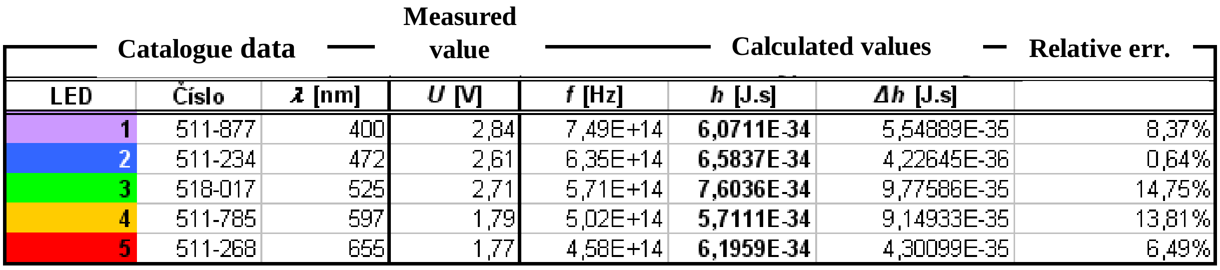
Data

We export measured data and process it in suitable software, e.g. MS Excel. To determine the Planck constant, we need to read the voltage of the diode in the switching direction. We proceed as follows. When the dependence of voltage on current is linear, we fit these values with linear regression. Then we read intersection of the regressed line and the x-axis (see graph, aqua line at LED 2, graph can be enlarged by clicking on picture) and write this voltage in table.

Graph



When we have all the voltage values for all LEDs, then we can calculate the Planck constant from the relation $h = Ue\lambda/c$, where U is the intersection voltage, e is the charge of the electron, λ is the wavelength of the LED, c is the speed of light. Absolute and relative error is calculated toward the tabelled value $h = 6{,}626.10^{-34}$ J.s.



Catalogue data			Measured value	Calculated values			Relative err.
LED	Číslo	λ [nm]	U [V]	f [Hz]	h [J.s]	Δh [J.s]	
🟪 1	511-877	400	2,84	7,49E+14	**6,0711E-34**	5,54889E-35	8,37%
🟦 2	511-234	472	2,61	6,35E+14	**6,5837E-34**	4,22645E-36	0,64%
🟩 3	518-017	525	2,71	5,71E+14	**7,6036E-34**	9,77586E-35	14,75%
🟨 4	511-785	597	1,79	5,02E+14	**5,7111E-34**	9,14933E-35	13,81%
🟥 5	511-268	655	1,77	4,58E+14	**6,1959E-34**	4,30099E-35	6,49%