ISSN 1392-9569
E-ISSN 2351-6011

Socialinis ugdymas / Ugdytinių ir ugdytojų kompetencijų kaita
Social Education / Learners and Educators competence change
2014, t. 1, Nr. 37, p. 155–161 / Vol. 1, No. 37, pp. 155–161, 2014

LIETUVOS EDUKOLOGIJOS UNIVERSITETAS

Interdisciplinary connections as a tool of learning process management

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Abstract. This article presents the example of use of the interdisciplinary connections between physics of the fiber-optic communication and quantum chemistry in a field of the "optical band semiconductor" concept. It is shown that without use of the mathematical apparatus of quantum chemistry the concept of the "optical band semiconductor" can't be formed correctly.

Keywords: *optical band semiconductor, physics of the communication, quantum chemistry.*

Introduction

Interdisciplinary connections have a significant role in the modern educational process. Interdisciplinary connections are the necessary condition for performance of the principle of long-life education which is defined by the Bologna declaration (*Текст Болонської декларації*). Interdisciplinary connections are the condition for use of the principle of synergy in education (Kremen, Illin, 2012) and they are derived from the principles of cognitive pedagogy (Chaffar, 2005).

The pedagogical researches in the field of search of the inter-subject communications are limited to the questions of establishment of a general subjects (Dalinger, 2003) or a general methods of logic of thinking in the course of teaching of various disciplines (Shvets, 2009).

However, fast rates of development of technologies and in particular the technologies of the fiber-optic communications, bring a new aspect in the development of interdisciplinary communications. This aspect consists of the formation of a modern concepts in the physics area, in particular in physics of the fiber-optic communication, which is impossible without use of interdisciplinary communications.

ISSN 1392-9569
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The aim of the article is to show how the interdisciplinary connections help to explain the concepts in physics of fiber-optic communication.

The discipline "Physics of Fiber-Optic Communication" appeared due to the influence of rapid development of fiber-optic communication lines. Interest in dielectric waveguides appeared in the 60th of the XXth century and due to the creation of semiconductor lasers in 1974, operating at room temperature. Low optical losses in such waveguides have became the factors due to which they were the main contenders for the role of an environment of the signal transmission on a distance from 10 km to 10000 km. Gorning Glass Company in 1970 created the first optical fiber with attenuation of 20 dB/ km at a wavelength of 0.6328 micron, and in 1979, were created a fibers with attenuation of 0.2 dB/km. Today the transport communication networks of a most countries of the world based largely on the basis of fiber-optic communication lines and require highly skilled professionals in this area. The program of discipline "Physics of Fiber-Optic Communication" includes educational material that serves to the aim of the preparation of specialists to the perception of professional disciplines in speciality "Computer sciences". In particular, the program of this discipline involves the study of such difficult topics as "Light-emitting diode (LED)" and "Semiconductor Lasers" (Zvelto, 1990). Clarification of the physical foundations of these devices requires the use of educational information which is studied in the course of quantum chemistry. Below presented method is developed by the author to study the "LEDs" topic.

Physical basis of the work of LEDs.

LEDs are the semiconductor devices which emit light at passing through it of an electric current. The first LED which radiated light in the optical area of the spectrum was created in 1962. LED has one transition, but the difference between an ordinary semiconductor diodes and LEDs consists in that the LEDs are manufactured from optical band semiconductors. Only in the optical band semiconductors recombination of majority carriers is accompanied by the process of an emission of light. The main difficulty in understanding of the physical basis of the work of LEDs is the concept of a "optical band semiconductor". The formation of this concept demands to involve such a category of quantum chemistry as a "dispersion law". The term of the "dispersion law" in turn, follows from the theory of the formation of zones for "Bloch's chain" (Levin, 1974). The initial idea of the appearance of bonding and anti-bonding energy levels from which are formed the energy bands in crystals has to be formed on the example of a hydrogen molecule. For these reasons, a method of formation of the concept of "optical band semiconductor" should contain the following items:

1. Fundamentals of molecular orbitals as combinations of atomic orbitals (MO LKAO). Two-centers task in the method of MO LKAO.
2. Bloch's functions for one-dimensional chain.
3. Energy bands in crystals, optical band semiconductors.

ISSN 1392-9569
E-ISSN 2351-6011

The basic concepts for the realization of such methods is the concept formed at the study of topic "Schrödinger equation" in course of general physics. Let us consider the educational content of these items.

Fundamentals of MO LKAO. Two-centers task in the method of MO LKAO.

Mathematical basis of the method MO LKAO is the presentation of a wave function of the physical system (molecule, molecular ion cluster, crystal) as a linear combination of atomic functions, which satisfy the normalization conditions. The simplest view of the molecular orbital for a hydrogen molecule (1):

$$\psi = c_1\varphi_1 + c_2\varphi_2 \tag{1}$$

Let's substitute the schedule for ψ in the Schrödinger equation for hydrogen molecule:

$$H\psi \quad E\psi \tag{2}$$

Using the linear properties of the Hamiltonian operator, we receive:

$$c_1\left(\hat{H} - E\right)\varphi_1 + c_2\left(\hat{H} - E\right)\varphi_2 = 0 \tag{3}$$

Multiplying the last equality at first by φ_1, and then by φ_2 and integrating across whole space, we obtain a system of two equations:

$$\begin{cases} c_1\left(\alpha - E\right) + c_2\beta = 0 \\ c_1\beta + c_2\left(\alpha - E\right) = 0 \end{cases}, \tag{4}$$

where $\alpha = \int \varphi_1\hat{H}\varphi_1 dV = \int \varphi_2\hat{H}\varphi_2 dV$ is Coulomb integral,
$\beta = \int \varphi_1\hat{H}\varphi_2 dV = \int \varphi_2\hat{H}\varphi_1 dV$ is hybrid integral.

The system of linear homogeneous equations has a unique solution when the main determinant of system (age determinants) is equal to zero:

$$\begin{vmatrix} \alpha - E & \beta \\ \beta & \alpha - E \end{vmatrix} = 0, \tag{5}$$

from where we obtain two solutions for the energy: $E^{(+)} = \alpha + \beta$ and $E^{(-)} = \alpha - \beta$. Because the hybrid integral has a negative value, the level $E^{(+)}$ is lower than $E^{(-)}$ (Fig. 1):

ISSN 1392-9569
E-ISSN 2351-6011

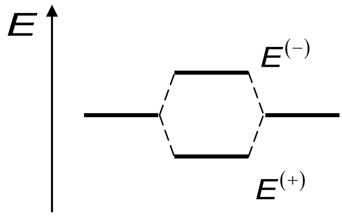

Fig. 1. *Scheme of energy levels of homo-nuclear diatomic molecules*

Thus, *the formation of a molecule leads to splitting of the atomic levels for two energy levels, one of which lies below the atomic and is called a bonding, and the other is above the atomic and is called anti-bonding.*

Bloch's functions for one-dimensional chain.

The simplest model of solids, which include semiconductors, is one-dimensional chain, in which the atoms are placed at equal distance from each other and with one valence atomic orbital. For the equivalence of the atoms the chain is locked in the ring (Fig. 2).

The wave functions of atoms in the chain have the properties of translational symmetry, which mathematically expressed in the fact that the wave function of each next atom multiplied by the multiplier $\exp\left[-2\pi i n / N\right]$.

By entering the radius-vector concept $\vec{R} = m\vec{a}$, where m - number of the atom, and of vector $\vec{k} = \dfrac{2\pi n}{Na}$, basic Bloch's ψ_j can be written as:

$$\psi_j\left(\vec{k} \mid \vec{r}\right) = \frac{1}{\sqrt{N}} \sum_{\vec{R}} e^{i\vec{k}\vec{R}} \varphi_j\left(\vec{r} - \vec{R}\right). \tag{6}$$

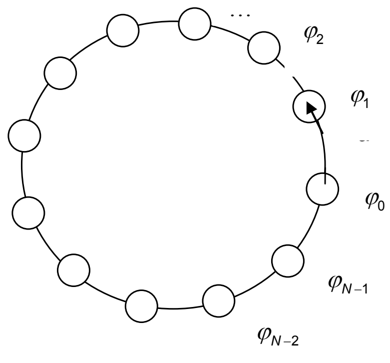

Fig. 2. *Cyclic chain of N atoms*

Energy bands in crystals, optical band semiconductors.

Hamiltonian eigenfunctions of the chain will look, according to the method of MO LKAO, as a linear combination:

$$\psi\left(\vec{k}\mid\vec{r}\right)=c_1\psi_1\left(\vec{k}\mid\vec{r}\right)+c_2\psi_2\left(\vec{k}\mid\vec{r}\right)+\ldots.+c_m\psi_m\left(\vec{k}\mid\vec{r}\right) \tag{7}$$

Then the age determinant will have the order equal to *m*:

$$\begin{vmatrix} \left\langle\psi_1\mid\hat{H}\mid\psi_1\right\rangle-E & \left\langle\psi_1\mid\hat{H}\mid\psi_2\right\rangle & \ldots & \left\langle\psi_1\mid\hat{H}\mid\psi_m\right\rangle \\ \left\langle\psi_2\mid\hat{H}\mid\psi_1\right\rangle & \left\langle\psi_2\mid\hat{H}\mid\psi_2\right\rangle-E & \ldots & \left\langle\psi_2\mid\hat{H}\mid\psi_m\right\rangle \\ \ldots & \ldots & \ldots & \ldots \\ \left\langle\psi_m\mid\hat{H}\mid\psi_1\right\rangle & \left\langle\psi_m\mid\hat{H}\mid\psi_2\right\rangle & \ldots & \left\langle\psi_m\mid\hat{H}\mid\psi_m\right\rangle-E \end{vmatrix}=0 \tag{8}$$

and provides *m* solutions, or *m* branches of the *dispersion law*:

$$E_1\left(\vec{k}\right),E_2\left(\vec{k}\right),\ldots,E_m\left(\vec{k}\right). \tag{9}$$

Let us consider the relationship between the branches of the dispersion law and the concept of energy bands in a crystal. Let us construct the inverse lattice, period of which is equal to $\frac{2\pi}{a}$. Let's divide each of the elementary cells of the inverse lattice to *N* parts. Then the obtained set of vectors $\vec{k}$ (Fig. 3) which is called the $\vec{k}$ – space. Let us construct a line chart of one branch of dispersion law in the inverse lattice. A set of projection of points of the dispersion law for the energy axis, creates the energy zone. *Optical band semiconductor* is such semiconductor, in which the minimum of the conduction band and maximum of the valence band projected at the same point in $\vec{k}$ – space (Fig. 4A), *non-optical band* is such semiconductor, in which the minimum of the conduction band and maximum of the valence band projected at the different points in $\vec{k}$ – space (Fig. 4B).

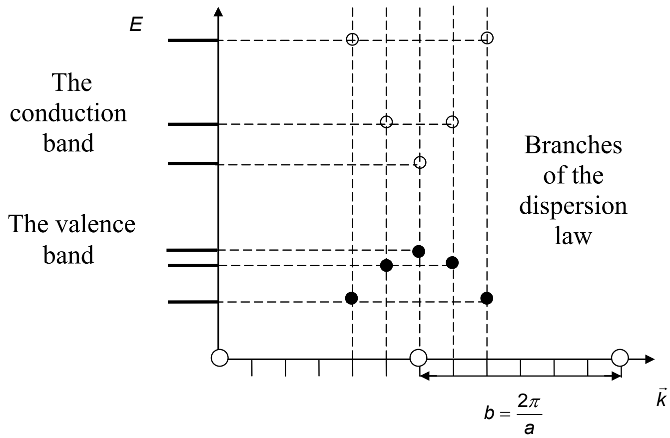

Fig. 3. *The inverse lattice* $\vec{k}$ *– space, branches of the law of dispersion, band structure*

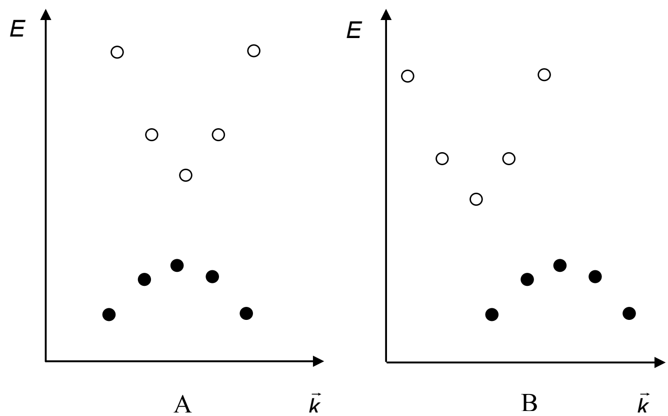

Fig. 4. *The energetic structure of the optical band semiconductor (A) and non-optical band semiconductor (B)*

The band structure of optical band have semiconductors of $A^{III}B^{V}$ ($GaAs, GaP, GaN, InP$) and $A^{II}B^{IV}$ ($ZnSe, CdTe$) type. Diodes made from non-optical band semiconductors, almost don't emit a light.

Conclusion

We see from Fig. 4 that the concept of energy bands cannot distinguish a structure of the optical band and non-optical band semiconductors. We have to apply the concepts and mathematical apparatus of quantum chemistry for formation of one of basic concepts of fiber-optical communication-concept of the optical band semiconductor.

ISSN 1392-9569
E-ISSN 2351-6011

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Tarpdalykinės jungtys kaip mokymosi proceso valdymo priemonė

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Santrauka

Autorė straipsnyje analizuoja tarpdiscipliniškumą, skirtą mokymosi proceso vadybai užtikrinti. Šiame straipsnyje pateikiamas tarpdalykinių ryšių tarp fizikos (šviesolaidinio ryšio) ir kvantinės chemijos pavyzdys.

Esminiai žodžiai: *optika, puslaidininkiai, fizika, kvantinė chemija.*

Įteikta / Received 2013-11-22
Priimta / Accepted 2013-12-13