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Ukrainian amber luminescence induced by X-rays and ultraviolet radiation

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ABSTRACT

The paper is devoted to the luminescence study of a number of Ukrainian amber samples excited by ultraviolet radiation and X-rays. The photoluminescence spectra of the samples of different morphology are similar in shape and have a close position of the emission maxima. The radioluminescence spectra also have a similar shape, but there is a greater variation in the position of the maximum in comparison with UV case. The photoluminescence and radioluminescence spectra were analyzed through Gaussian function fitting. The results led to the assumption that there are two sources of luminescence radiation. In the case of photoluminescence the positions of the Gaussian maxima are shifted by 0.25 eV toward higher energies in comparison with radioluminescence.

1. Introduction

Amber is commonly known natural polymer used by humankind for millennia. This natural material is formed from wood resin as a result of chemical reactions for millions of years [1]. From ancient times it was used not only as gemstone, but also as medical means in pharmaceuticals, as oldest glass-like substance and one of the best electrical insulator up to 1970's [2].

Nowadays amber is widely used in science and technology, because it has unique physical and chemical properties such as inertness to a wide range of solvents and hazardous substances. It is ecological friendly and contains the unique organic substances. Therefore, amber components actively used in medicine, perfumery as raw material for amber varnish and acid [3].

Amber deposits are widespread all over the world. From deposit to deposit amber properties can considerably vary depending on formation conditions (such as temperature, pressure, humidity and impurities in neighboring layers) [4].

Physical and chemical properties of amber are well studied. Its detailed descriptive analysis of chemical compound one can find in [4–7] and its mechanical properties reported in full in [1]. It should be noted that its optical properties are poorly studied and experimental data are fragmentary. There are several approaches in amber optical research. Methods of Raman's and infrared spectroscopy are most common. Infrared spectra of amber give information about the variations between different types of fossil resins [8], deposit location [9], and spectrum data can be used to study insect's inclusion [10] and so on. But most of those researches focused on archaeological and geological aspects of amber development.

Amber optical properties such as light transmission and luminescence spectra have been only partially studied experimentally. Furthermore, the occasional samples that were analyzed represented just several different deposits. The Baltic amber is the most studied one presently (see for example [7]), however, there are also some sporadic experimental papers on Mexican [11], Dominican [12], Myanmar [13], and Polish [14] ambers. Unfortunately, there is almost no data available on the optical properties of the Ukrainian amber, besides the luminescence spectra induced by laser radiation at three different wavelength (400, 800 and 935 nm) for one of the samples [15].

There are almost no theoretical studies in the field. As far as we know, one of the rare attempts to model the optical properties of amber was made in [16]. This is an important stage in the amber studies, however, there are some concerns regarding the author's assumption as for the “crystal structure” of the sample, because diffractometric analysis showed its essential amorphousness [17]. It should also be noted that the considered in [16] value of the optical transmittance is noticeably different from the other researchers' data [12].

There are no relevant papers on the amber luminescence induced by X-rays.

In this paper the photo- and radioluminescence of more than ten Ukrainian amber samples representing the Rovno's deposit (Ukraine) were studied.

2. Experimental setup

Detail description of the experimental setup for measurements of radio and photoluminescence one can see in [18]. We used low-pressure mercury lamp and X-ray lamp with a copper anode as sources

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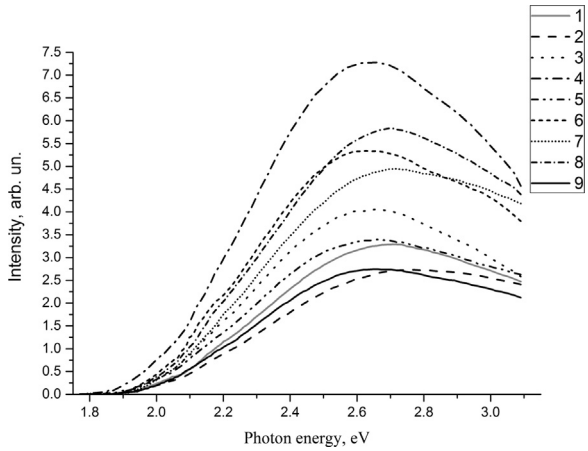

Fig. 1. Photoluminescence spectra of Ukrainian amber.

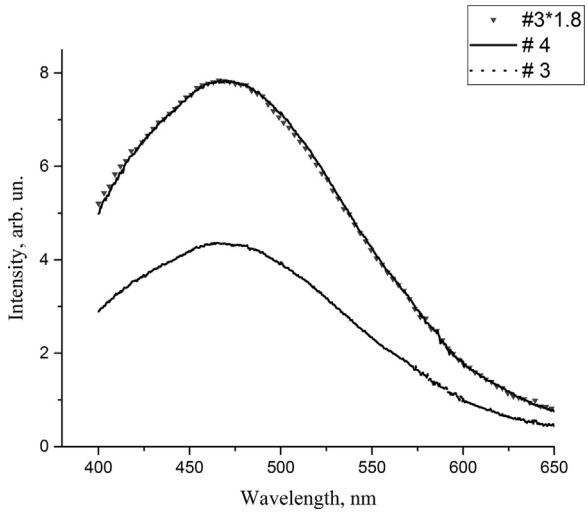

Fig. 2. Photoluminescence spectra for different amber samples: 1 is #3 (multiplied by 1.8); 2 — #4; 3 — #3.

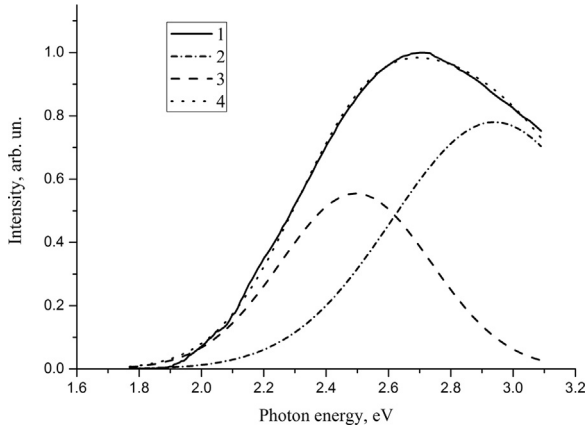

Fig. 3. The approximation results of normalized photoluminescence spectra for the sample #2: 1 is initial spectrum; 2 and 3 are the Gaussians with centers of 2.95 and 2.48, correspondingly; 4 is a sum of Gaussians.

of primary radiations. The power supply voltage of X-ray lamp was 60 kV at current of 10 mA in normal operation mode. The sample was mounted at angle of 40° ± 5° with respect to the direction of primary radiation.

Spectrometric measurements of amber luminescence were carried out by means of grating monochromator. The optical channel of the spectrometer was calibrated with tungsten spectrometric lamp with

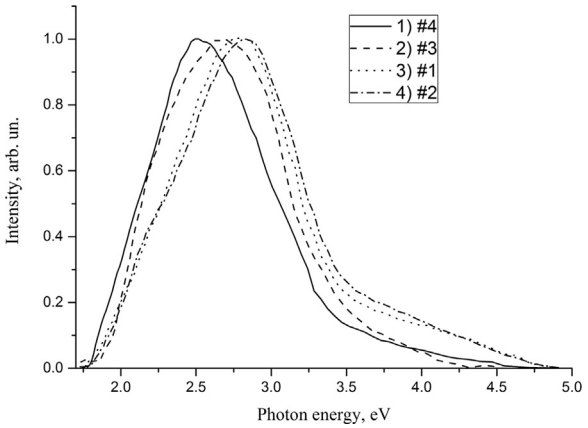

Fig. 4. Normalized radioluminescence spectra for different typical Ukrainian amber samples: 1 is sample #4; 2 is #3; 3 is #1 and 4 is #2.

subsequent correction of the experimental spectra. The spectra were normalized to maximum of the most intensive peak to perform a comparative analysis of spectrum shapes.

Each specimen was made from a whole piece of natural Ukrainian amber without inclusions. Amber pieces had irregular shapes and were treated by cutting to form plane-parallel plates with thickness of $(1.6 \div 3.1) \times 10^{-3}$ m and transverse dimensions of $0.01 \div 0.02$ m. The surface of the specimens was cleaned to remove oxide layers and polished.

3. Experimental results and discussion

Fig. 1 shows the photoluminescence spectra of nine samples. As one can see, all the spectra have the same shape of wide band with peaks close to 2.7 ± 0.1 eV. However, the integrated intensity and the shape of high energy wing are different for all the samples being studied. The spectra for analogous morphology samples are similar. So the samples # 3 and # 4 were cut from pieces of matte milky white amber and differ only in thickness. The luminescence spectra for these samples, reduced to a maximum intensity, are virtually identical (see. Fig. 2). The difference in thickness of samples corresponds to their luminescence intensity ratio (1.9 and 1.8 respectively). Thus, it can be concluded that the primary radiation penetrates the entire depth of the sample, and luminescence excited from the whole of the irradiated volume.

The similar results were observed for transparent yellow samples (# 7 and # 8). But such similarity did not occur for the samples with more complex structures due to chaotic arrangement of transparent and matte zones.

To analyze the structure of amber luminescence spectra we used a well-known method of curve fitting by a Gaussian function (for example, see [19]).

$$F_{gauss}(h\upsilon) = (A/(\omega \times (\pi/2)^{1/2})) \times \exp(-2 \times ((h\upsilon - x_c)/\omega)^2), \quad (1)$$

where $h\upsilon$ is quantum energy; A is normalized peak area; ω is normalized peak half-width; x_c — center of a peak.

As can be seen in Fig. 1 spectra of samples # 4, #6, #7 have obvious shoulder near 3 eV. It reasonable to use two Gaussian (1) model for fitting experimental data. The spectra of all samples are well approximated by the sum of Gaussians with $x_{c1} = 2.48$ eV, $x_{c2} = 2.95$ eV and half-widths $\omega_1 = 0.48$ eV and $\omega_2 = 0.75$ eV, respectively. For example, Fig. 3 shows, that the experimental photoluminescence spectrum for the sample #2 is matched with good accuracy with the sum of two Gaussian.

The spectra for the other samples differ only in the values of the peak areas. This structure of the spectra points out the presence of two luminescence centers in the amber.

We also measured radioluminescence spectra for Ukrainian amber.