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Processing of Photographic photoluminescence spectra using computer microphotometry on the example of copper iodide crystals

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The article discusses an approach to the „decoding" of luminescence spectra obtained by the photographic technique by presenting them in the form of graphs of the dependence of the luminescence intensity on the wavelength using a specially developed computer program (computer microphotometry).

Keywords: copper iodide, luminescence spectrum, photographic photoluminescence spectrum, computer microphotometry.

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Introduction

Various photoelectric techniques are currently used to obtain graphs of luminescence spectra. However, the photographic technique of capturing spectra also has a number of advantages. It is clear and yet allows to change the exposure to accentuate certain details of the picture. A disadvantage of the technique is that the processing of spectra photo-images is usually quite time-consuming.

In the archives of many laboratories, there are photographic films with spectra taken in the years when photographic technique was widely used. In some cases, the films may contain valuable information (e.g. from experiments that are difficult to replicate), and so it makes sense to subject them to new analysis. Therefore, the task of reducing the labor-intensiveness of film processing techniques and graphing the captured spectra is relevant.

Experiment procedure

We have developed a methodology for processing the films with the spectra under study by means of modern computer technology. The film is initially scanned using a slide scanner (e.g. Epson Perfection V600 Photo with slide module). When choosing the scan resolution, we were careful not to lose fine details of the spectrum for further processing. It turned out that a resolution of 1800 dpi was quite sufficient. In this mode, there are 10 pixels per 1 Å allowing the resolution of spectral lines that are $1-2$ Å apart.

The pixel numbers in the scanned image were then matched to the wavelengths of the reference iron arc spectrum using the iron arc spectrum atlas. In the next step, the software scanned a narrow band of one pixel wide and up to 100 pixels high the spectrum under study and calculated the average darkening factor of the photographic film for each wavelength. We plotted the dependence of the darkening factor (which in this intensity range is proportional to the illumination intensity) on wavelength. An example of such a graph (signal intensity I in relative units versus wavelength λ in angstroms) is also shown.

Correct averaging has significantly reduced the „noise" that is characteristic of the recorded spectra, which is associated with the presence of „grains" in the film. This film processing procedure, similar to micro-photometry, can be called *computer micro-photometry*.

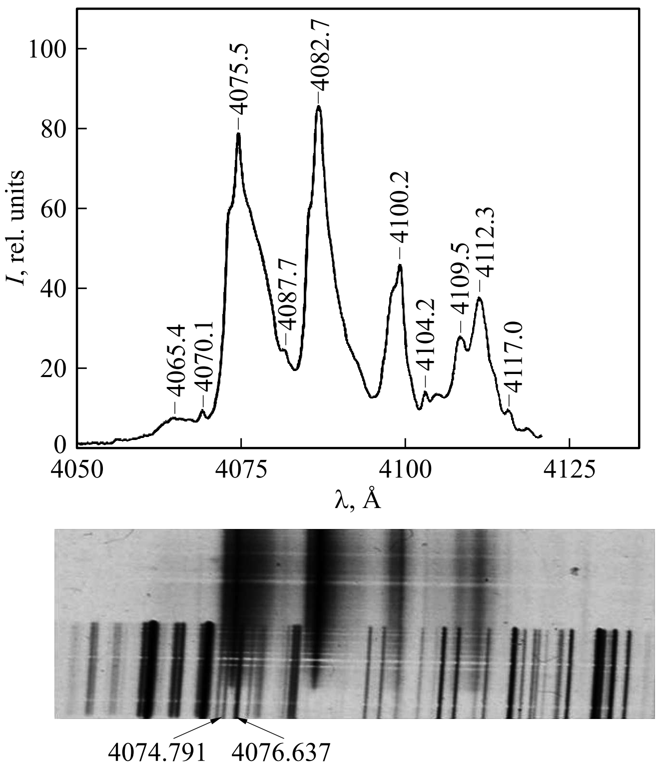
Photoluminescence spectra of copper iodide (CuI) single-crystals grown by hydrothermal method [1] cooled to liquid helium temperature $T = 4.2$ K were performed. A large number of crystal films of different growth lots and different types of doping were previously imaged by us using an ICP-51 spectrograph in the „Solid State Optics"Laboratory of St. Petersburg State University. These spectra have a rich structure of excitonic and non-exitonic edge luminescence, as we reported earlier [2–4].

Discussion of experimental results

As an illustration of the technique's capabilities, a fragment of the constructed luminescence spectrum of one of the unalloyed CuI single-crystals is shown in Fig. 1.

The upper part of the picture — is the photoluminescence spectrum constructed by the software; below it is an image of the original film, still below — the reference arc spectrum of iron. As an example, we show how the position of the line with wavelength ($\lambda = 4075$ Å ascribed by us to the annihilation of excitons bound on neutral acceptors with ionization energy $E_{A1} = 0.165-0.167$ eV [2–4]. The relative magnitudes of the luminescence line amplitudes are also in good agreement with the spectra photographs.

The wavelengths of the spectrum lines are determined in one click of the computer's „mouse" after the cursor is moved to the line, and the key is pressed. The wavelength is



Photoluminescence spectrum of unalloyed hydrothermal CuI single-crystal. Excitation by LHY-21 nitrogen laser ($\lambda = 3370$ Å) at $T = 4.2$ K. The upper part of the Fig. — the graph of the spectrum plotted by the software; the lower part of the Fig. shows the original photoluminescence spectrum and the reference arc spectrum of iron. The reference spectrum shows the wavelengths of the two lines closest to the 4075 Å line in the CuI photoluminescence spectrum.

automatically plotted on the graph without any painstaking calculation, based on the relationship between pixel number and wavelength in the software. The accuracy of this wavelength determination is up to 0.5 Å.

Copper iodide is one of the oldest semiconductor materials [5], and has attracted much interest worldwide over the last decade as it is considered promising for various optoelectronic devices [6–8]. This is one reason why we want to revisit and analyze the results of earlier studies in more detail.

The nature of a number of luminescence lines and bands in copper iodide [3,4] has been determined in our previous paper. In addition, generation-recombination patterns of non-exiton edge luminescence at 4180−4500 Å [9] and red-orange luminescence at 6000−8000 Å [10] were constructed. The program developed will make it possible to better present the available material and continue paper on the interpretation of the spectra.

Several hundred plots for different samples from various growth batches and alloyed crystals have been plotted using this program. All the constructions showed good agreement with the original photographic spectra.

Results

The methodology considered for the processing of luminescence spectra shot on photographic film will find application in the analysis of the results of data sets obtained earlier and requiring new consideration at the present level. This approach will contribute new information on the structure and properties of both well-known and promising new optoelectronic materials.

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Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] V.A. Nikitenko, V.I. Popolitov, S.G. Stoyukhin, A.Ya. Shapiro, A.N. Lobachev, A.I. Tereshchenko, V.G. Kolotilova. Pisma v ZhTF, **5** (19), 1177 (1979). (in Russian).

[2] S.G. Stoyukhin, V.A. Nikitenko, V.G. Kolotilova. Opt. i spektr., **64** (4), 947 (1988). (in Russian).

[3] I.K. Vereschagin, V.A. Nikitenko, S.G. Stoyukhin. J. Luminescence, **29** (2), 215 (1984). DOI: 10.1016/0022-2313(84)90020-6

[4] I.K. Vereshchagin, V.A. Nikitenko, S.G. Stoyukhin. Opt. i spektr., **64** (1), 207 (1988). (in Russian).

[5] M. Grundmann, F.-L. Schein, M. Lorenz, T. Böntgen, J. Lenzner, H. Von Wenckstern. Physica Status Solidi. A: Applications and Materials Science, **210** (9), 1671 (2013). DOI: 10.1002/pssa.201329349

[6] D. Ahn, J.D. Song, S.S. Kang, J.Y. Lim, S.H. Yang, S. Ko, J. Chang. Scientific Reports, **10** (1) 2020. DOI: 10.1038/s41598-020-61021-2

[7] S. Inagaki, M. Nakamura, Y. Okamura, M. Ogino, Y. Takahashi, L.C. Peng, X.Z. Yu, Y. Tokura, M. Kawasaki. Appl. Phys. Lett., **118**, 012103 (2021). DOI: 10.1063/5.0036862

[8] A. Liu, H. Zhu, M. Kim, J. Kim, Y. No. Advanced Science, **8** (14), 2100546 (2021). DOI: 10.1002/advs.202100546

[9] V.A. Nikitenko, S.G. Stoyukhin, M.V. Chukichev. J. Appl. Spectroscopy,**49** (5), 1148 (1988). DOI: 10.1007/BF00667239

[10] V.A. Nikitenko, S.G. Stouyhin, S.M. Kokin. J. Appl. Spectroscopy. **86** (5), 825 (2019). DOI: 10.1007/s10812-019-00901-6

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