Photoluminescence of plant leaves during high-temperature treatment

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Abstract. This work is devoted to the studies of the photoluminescence of plant leaves during their temperature influence. We show new results in the decay of biological processes in green leaves. The analysis of obtained results allows to conclude that the main result obtained in the high-temperature treatment of green leaves in the range from 300 K to 440 K does not lead to damping of the intense red photoluminescence characteristic of green leaves. These results may be of interest not only for biology and agriculture, but also for new applications of photonics.

1. Introduction
The study of physical and other properties of living systems is always relevant for solving many practical and theoretical problems in the development of biological and agricultural sciences and solving problems of national food supply security. In this regard, there is a growing need to use procedures and experimental methods that are well-proven in solving other scientific problems in research[1-3].

As a result of the application of such methods, it was found that when green leaves are excited with optical radiation with a photon energy of 1.96 eV, intense red photoluminescence arises consisting of two overlapping bands [4]. This led to the expansion of the application of methods for studying various characteristics of optical properties of plants in which green plant objects would be studied as ordinary solid-state semiconductor samples. In this case, the analysis of the results is carried out proceeding from the representations established for solid objects and obtain new information about plant objects. That is the reason why the application of the methodology of the study of photoluminescence [5, 6], which is well developed in the application to solid-state physics for the study of living green plants, seems to us to be entirely innovative and promisingly in demand [6, 7]. The produced work demonstrates the results of studying the radiative properties of leaves in the case of their heating above T = 300 K when the decay processes of life in the plant begin. The paper is actually a logical development of our research [4-7]. This allows us to establish new aspects of the decay of biological processes in green leaves, as well as to determine the prospects for using these objects in optoelectronics devices.
2. Method
The photoluminescence study was carried out on the green leaves of various plants immediately after they were separated from the plant. After that, the leaves were placed on the plane of a special holder made of red copper. The samples were heated by means of a heater coil, on which the temperature of the sample was varied, by changing the electrical power. The temperature was measured directly by the copper-to-constantan thermocouple method. The source of excitation of photoluminescence in the experiment was the emission of a helium-neon laser with a power of 10 mW [8-10]. The photoluminescence emission was then fed to the MDR-3 monochromator with a 600 grids per mm and detected by a photoelectric multiplier. The spectral resolution of the experimental setup was not less than 1 meV.

3. Result and discussion
The experiment showed up that the spectral photoluminescence contour includes two bands with maxima at 1.67 eV and 1.80 eV at T = 300 K. The intensities at the maxima of these overlapping luminescence bands are related as I_2/I_1 = 0.37 (figure 1 for the example of the Acer leaves), where I_1 and I_2, respectively, the long-wave and short-wave photoluminescence maxima.

![Figure 1](image_url)

**Figure 1 (a, b, c, d, e).** Spectral dependence of stationary photoluminescence Acer leaf in the process of isochronous heat treatment for different temperature T. For graphics (a), (b), (c), (d) and (e) corresponds to following temperatures in K: 300: 321: 347: 451: 476.

This indicates the dominance of the long-wave component of the spectrum (figure 1 (a, b, c, d, e)). In the process of temperature increase, the experiment showed that the shape of the spectral contour of photoluminescence changes. In this case, the short-wave component of the spectrum I_2 begins to dominate more and more. It is important to note that at temperatures above 440 K the short-wave component of the
spectrum begins to dominate. The long-wave band at room temperature is noted as being wider than the short-wave band. Thus, for the short-wave component in figure 1 it follows that the half-width at the half-maximum of the maximum lies in the range 20-30 meV. At the same time, at a long-wave maximum of photoluminescence this value is in the range from 50 to 60 meV. However, as the temperature increases, broadening of both photoluminescence bands is observed, and the energy maxima of the long-wave and short-wave photoluminescence bands are found to converge because of the increase in the energy of the long-wave maximum and, consequently, the energy drop of the short-wave photoluminescence maximum. According to figure 1, it can be concluded that when the temperature rises from 300 to 485 K, only the ratio of the photoluminescence intensities I1/I2 changes, but the doublet structure of the spectral dependence of the photoluminescence remains unchanged. We also investigated the effect of isochronous temperature influence of leaves (on the example of the same Acer leaf) on the magnitude of short-wave and long-wave photoluminescence peaks. We discovered that in the temperature range 310÷325 K ignitions of short-wave and long-wave luminescence peaks are observed, and their luminosity is 2 times higher than those parameters that were obtained in the study of the same leaf when he was still one with his parent plant. With a further increase in temperature, we can detect three stages of the process. This ranges from 330 to 340 K, the range from 345 to 350 K, and finally the self-extended stage with heating above 430 K. When the sample is heated above 430, charring begins and at temperatures above 480 K irreversible photoluminescence decay is observed.

It was stably reproduced in the experimental process that when the samples are heated up to 430 K, the intensities of the long-wave and short-wave photoluminescence peaks do not decrease below the values of these same leaves before they are separated from the system of the parent plant. If after heating to 430 K, the leaves try to cool, then the spectral photoluminescence circuit, characteristic of the initial state before heating, is detected. It should be noted that in this case the energy position of the photoluminescence peaks.

4. Conclusion
As the main result obtained in the high-temperature treatment of green leaves in the range from 300 K to 440 K, it should be noted that the increase causes the onset of irreversible transitions, but does not lead to damping of the intense red photoluminescence characteristic of green leaves. Particular mention should be made of the high thermal stability of the luminescent properties of these materials. These results may be of interest not only for biology and agriculture, but also for new applications of photonics [10, 11].

5. References
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