Photoluminescence spectroscopy features in the study of green leaves drying process

V.B. Fadeenko¹, V.Yu. Rud¹², Yu.V.Rud³, A.P. Glinushkin², V.Ch. Shpunt³, William Hogland⁴

¹Peter the Great Saint Petersburg Polytechnic University, Saint Petersburg 195251, Russia
²Department of Ecology, All-Russian Research Institute of Phytopathology, 143050, Moscow Region, Odintsovo district, B.Vyazyomy, Russia
³Department of Solid State Physics, Ioffe Physico-Technical Institute, Russian Academy of Sciences, St Petersburg 194021, Russia
⁴Faculty of Health and Life Sciences, Linnaeus University SE-391 82 Kalmar, Sweden

Abstract. The presented work demonstrates new results of studying the photoluminescence kinetics of green leaves of Brassica rapa L. that were separated from the parent plant and in fact is the logical development of our studies. We found that the time dependence of its intensity includes 2 stages characterized by the fact that in the first one there is an increase in intensity, reaching a maximum and then decrease, but with long drying times in conditions of constant room temperature, it does not fall below its characteristic value for a living plant.

1. Introduction

The importance of studying organization and the functioning of living systems is very relevant for solving practical and theoretical problems in the development of biological and agricultural sciences in connection with the threats of overpopulation of the planet Earth. The results of such studies make it possible to increase the efficiency of plant breeding methods leading to the development of sustainable agriculture. In this connection, there is a growing need to use scientific and experimental methods that are well-proven in other scientific issues in research. Thanks to the application of such methods, it was found that when green leaves are excited with optical radiation with a quantum energy of 1.96 eV, the intense red photoluminescence arises consisting of two overlapping bands [1]. 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 to obtain new information about plant objects. That is why the use of well-developed in application to solid-state physics methods for the investigation of photoluminescence [1] for the study of living green plants seems to us entirely innovative and perspective popular [2, 3]. The presented work demonstrates the results of studying the photoluminescence kinetics of green leaves of Brassica rapa L. that were separated from the parent plant and in fact is the logical development of our studies [1-3]. This allows us to establish new aspects of the decay of biological processes in green leaves at room temperature.

2. The method

The study of photoluminescence was carried out on green leaves of various types of plants. As a source for photoluminescence excitation used ILA 120-1 Carl Zeiss argon laser with excitation energies \( \hbar \nu_{exc} = 2.1; 2.50; 2.54; 2.6; 2.71 \) eV. For each of the above energies, the power density was 50-100 mW/cm². The photoluminescence radiation then fed to the MDR-3 monochromator with a grating 600 lines/mm and detected by a photomultiplier.
Figure 1. The spectral dependences of photoluminescence of leaf Brassica rapa L. at $T=300K$ ($h\omega_{exc.}, \text{eV}$: for curves 1-2.705, for curve 2-2.410). Spectral resolution setup is $1 \text{ meV}$.

The photoluminescence red visually observed at all of these energies, photoluminescence excitation spectra for green leaves in all cases represent two closely spaced bands (Fig. 1). In this regard, it is important to note that from fluorescence studies it is known that regardless of the wavelength of the incident light, the chlorophyll fluoresces in the red part of the spectrum. This indicates that red luminescence can be associated with chlorophyll associated with the life cycle of the plant world. Thus both energy bands for different types of plants did not differ from each other. It is seen that the values of half-widths of the component and the ratio of their intensities $I_2/I_1$ is close in leaves of different plants. When you change the flux density of the exciting radiation the intensity of the photoluminescence field detection of peaks is described by a linear dependence of $I \sim L$. It is important to note that the important thing for photoluminescence analysis in physics, the ratio of the photoluminescence peak of the solid and half-width at half-maximum values were also close to all types of plants [1].

This photoluminescence consists of two overlapping bands. This work logically continues previous studies on the properties of the plant world with the help of widely recommended methods of
semiconductor spectroscopy. In this work, we present the results of studying regularities in the transition of plant from a living to a dead condition. To do this, the photoluminescence spectrum of the living leaf in a single system with the plant is first studied, and then the spectral dependence of the same leaf, but already separated from the living plant, is studied. This allows us to study the processes of decay of living biological processes in a leaf separated from a living plant.

3. Results and discussions

These studies were conducted on a wide range of plants. As an example, the data of spectral dependences of the intensity of stationary photoluminescence of Brassica rapa L. leaves are presented and analysed. It should be noted at once that all the studied patterns of photoluminescence are practically identical for different plants. Photoluminescence in experiments was excited by the emission of helium neon or argon lasers [2]. We studied the spectral dependences of photoluminescence with a spectral resolution of not lower than 1 meV at room temperature, immediately after separation of the green leaf from the plant, depending on the time of their location in the separated state.

We find when the Brassica rapa L leaf is still in the system of a single whole with the plant is accepted for the origin of the sample \( t = 0 \). The further period of time up to 30 days already refers to the condition of the leaf separated from the green plant. The main regularity of these studies revealed that the spectral contour of red photoluminescence is practically insensitive to the decay process of leaves. Indeed, it was found that the spectral position of both maxima in the spectral dependence of the photoluminescence \( h\omega_1 = 1.6 \text{ eV} \) and \( h\omega_2 = 1.80 \text{ eV} \) and their half width at half height \((\delta_1 = 50-55 \text{ meV} \) and \( \delta_2 = 20-25 \text{ meV} \)), respectively, remain constant all the time (up to 30 days) of isothermal leaves decay at room temperature. Hence, we can conclude that for green leaves in the green plant and for the decayed leaves, separated from the plant, the spectral contour of red photoluminescence remains constant. It is also important to note the fact that those radiative processes that lead to the appearance of red photoluminescence in the green leaf remain for the decay condition after separation from the living plant.

We calculated that the ratio of photoluminescence intensities \( I_1 / I_2 \) in the region of maxima \( I_1 \) and \( I_2 \) with the time of leaves decay remains practically permanent. It is also important to note that the short-wavelength maximum \( h\omega_2 \) with increasing decay time becomes less marked in the spectrum with respect to the dominant long-wavelength maximum \( h\omega_1 \). The time dependences of the intensities of red photoluminescence at a fixed leaf temperature have a similar appearance, which can be explained by the preservation in time of their correlation.

Based on the isothermal time dependences of the intensities, we can draw an important conclusion that the transition to the decay condition in terms of photoluminescence patterns is a complex process in which at least 2 different stages can be distinguished. The first stage last about 23 hours and is accompanied by the ignition of photoluminescence. We also got the result that this stage is characterized by the fact that the intensity of stationary photoluminescence increases almost twofold. In the process of drying the leaf separated from the green plant at a constant temperature within 1.5-12 hours, it was found that the complex kinetics [3, 4, 5] of establishing stationary values of \( I_1 \) and \( I_2 \) after the inclusion of exciting radiation is manifested. This process is characterized by the fact that after the excitation radiation was turned on, the photoluminescence intensity \( I_1 \) and \( I_2 \) decreased in such a way that the stationary value of \( I_x \) was established in a time of 30-400 s. It is important to note that in this case, the time for achieving stationary intensities with increasing leaf decay time greater than 1.5 hours initially increased, then passed through a maximum in the vicinity of 6-8 hours exposure. After that, there was a sharp drop, so sharp that in the region of 12-15 hours the stationary value of the intensity of the photoluminescence was established almost instantaneously, which indicates a practically complete absence of any kinetics. We found that the process of intensity decrease takes place in accordance with the exponential law [6, 7]. It is important to note that at times of drying of 6 hours, the relaxation time
is 30 s, and at a drying time of 8 hours, the relaxation time is already 100 s. At a drying time of 9 h, the relaxation time decreases again, and so that for times of the order of 12 h the kinetics after the inclusion of the photoluminescence is practically not detected at all.

![Graph](image)

**Figure 2.** Dependences $I_1 = f(t)$ and $I_2 = f(t)$, where $I$ – intensity of photoluminescence, $t$- drying time for *Brassica rapa* L. leaf.

It was found that in the region of the manifestation of the kinetics in the photoluminescence decrease, a section of the brightly expressed minimum, the "saddle" (Fig. 2), is found on the curves for $I_1$ and $I_2$, which can be related to a drop in the radiation intensity with a characteristic time of relaxation. The revealed feature can be associated with the manifestation of the amplification of the non-radiative recombination channel in connection with the decay of the leaf (the dying of life in it).

4. Conclusion

Thus, we found that in leaves separated from the green plant during photoexcitation bright red photoluminescence continues to be present, the time dependence of its intensity includes 2 stages characterized by the fact that in the first one there is an increase in intensity, reaching a maximum and then decrease, but with long drying times in conditions of constant room temperature, it does not fall
below its characteristic value for a living plant. The founded features can cause a sharp splash of research in the study of the possibilities of practical use of luminescent properties of plant objects.

References

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