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Secondary Radiation in Color Optical Filter Glasses by the Action of Plasma

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Keywords: color optical filter glass, multi-photonic excitation, monochromatic light radiation, excited electronic states, inverse electronic relaxation, electrical discharges in impulse.

Abstract. This paper presents the results of experimental investigations and theoretical analysis of secondary physical phenomena that occur at interaction of electrical discharges in impulse (EDI) plasma radiation with color optical filter glasses. It was established that infrared filters (of type IKS) emit a violet secondary radiation, and dark filter (of type TS) emits a green secondary radiation. Detected phenomena can be explained by secondary radiation emission due to multi-photonic excitation of SiO_2 molecules and direct-inverse translating from one energy level to another. One of the resonance oscillatory levels (of the absorption bands) for molecules of SiO_2 is 780 cm^{-1}. Thus, for infrared filters the number of absorbed infrared photons is 33, and for dark glasses is 24. In this case, the wave length of secondary radiation is 388.5 nm (violet color) and 534.2 nm (green color) respectfully. This phenomenon can be applied in construction of equipment functioning based on monochromatic light radiation.

Introduction

A great contribution to quantum electronics spectroscopy is the possibility of systematic studies of vibration excited states of polyatomic molecules by high intensity light impulses. Multi-photonic excitation method with high intensity infrared radiation has become an effective research of vibration excited molecules on different possible energy levels. The need for quantitative description of multi-photonic oscillatory excitation was necessary to study the transition spectra of oscillatory excited molecules that led to the appearance of new research directions, i.e. of molecular spectroscopy. Currently, the qualitative and quantitative parts of photo-physical and photo-chemical processes that occur in polyatomic molecules situated in an intensive resonance field of the infrared region of the spectrum are well studied [1].

A special place is given namely to photo-physical processes of multi-photonic oscillation excitement by infrared radiation of polyatomic molecules, so to the spectroscopy of vibration excited molecules. These processes represent the nonlinear interaction processes of the oscillation resonance mode with high intensity infrared radiation as well as the interaction between oscillatory modes due to inharmony. Both these processes are interrelated and determine all features of polyatomic molecule situated in an infrared field.

The physics of multi-photonic molecules excitement in infrared region of the spectrum is related to a large number of oscillation degrees of freedom of the molecule S=3N-6 (where N is the number of atoms of the molecule) because only in this case a rather small inharmony is an important factor for oscillatory energy storage that provides energy introduction in the polyatomic molecule that has not too high level for resonance excitation of the oscillatory mode by infrared radiation. The number S (or N) determines characteristics of the polyatomic molecule, and namely the resonance Fermi density that determines the boundary of the oscillation energy storage. Molecules possessing a small number of atoms have a high oscillation energy storage boundary. As it is shown in [1], for triatomic molecules, such as for SiO_2 molecule, the excitation depends on the intensity of the light flux focused on it.

The multi-photonic excitation with infrared light of oscillatory states of the molecule usually occurs within the electronic base states. Polyatomic molecule can absorb a large number of infrared photons and in such a way its oscillatory energy becomes comparable with the energy of the excited electronic state. This is possible if the minimal energy of the excited electronic state is lower than the dissociation energy of the molecule. In these cases approximate description of the molecule dynamics corresponds to oscillation and electronic movements and is described as a process with adiabatic approximation. Here we must take into account the non-adiabatic bonds of states with lower levels of excited electronic states too. The average level of oscillatory excitement which is acquired based on multi-photonic excitation depends on the molecule size and is limited only by energy channel of the molecule. Another non-adiabatic process of which radiation becomes possible due to multi-photonic excitation represents the electron breaking from the negative ion of the molecule. In this case, as in the case of Inverse Electronic Relaxation (IER), the electron breaking requires a minimal oscillatory activation of the anion by infrared radiation and the existence of the electronic movement bond, as well as the core movement that occurs before the multi-photonic excitation process. Maximum possible excitation of the molecule is limited by the energy region where IER of electronic excited terms takes place. Because the typical frequencies of oscillation or electronic transactions are subjected to a known co-report $\omega_{osc} << \omega_{el}$, therefore the necessary condition for IER observation is: the molecule must absorb a large number of infrared photons. For molecule IER and the appearance of visible radiation it is necessary that the molecule can absorb from 20 to 40 infrared photons: $N_{IR} \cdot \omega_{osc} \approx \omega_{el}$ [1].

Methodology of experimental investigations

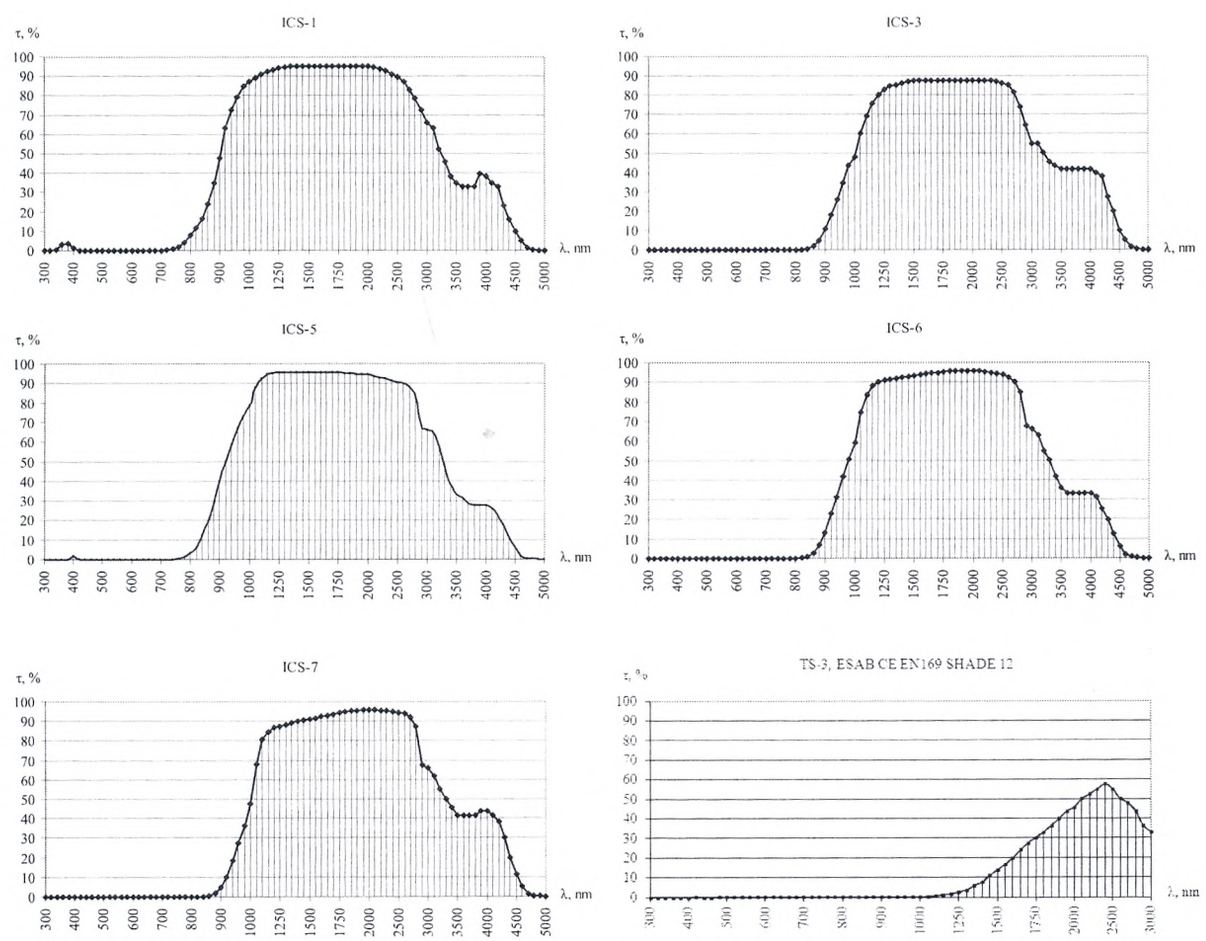


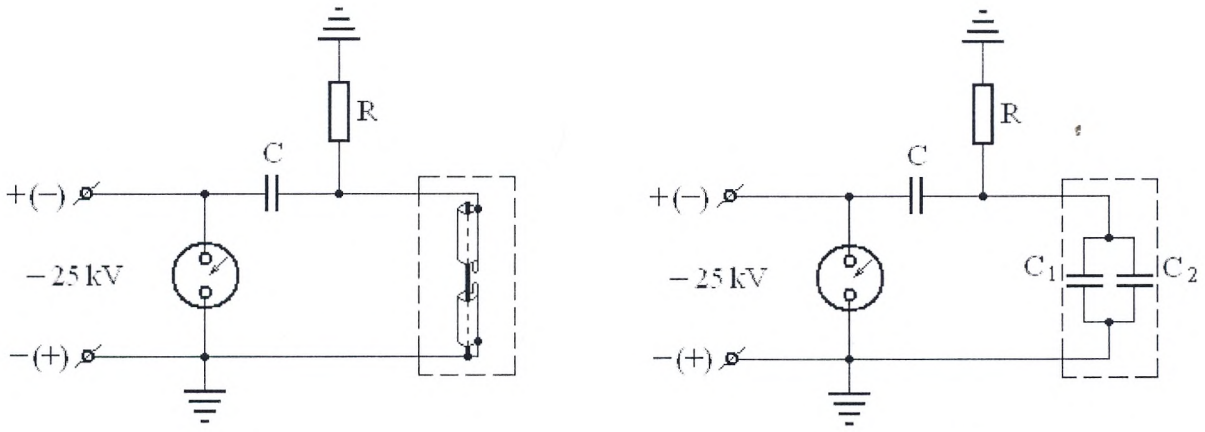
Fig. 1. Spectral characteristic of color optical filter glass of type IKS and TS [2-4]

As the test material we used color optical filter glass of type IKS (infrared glass) and TS (dark glass). Spectral characteristic of glass (filter transmittance dependence on wavelength) is shown in Fig. 1 [2-4].

As can be seen from Fig. 1, the selected types of filters "cut" the visible spectrum and are transparent for the infrared region.

Dimensions of the samples: length×width×thickness = 40×40×2 mm.

The electrical discharge plasma created by the generator of electrical impulses was used as a source of high intensity light. The principal electrical scheme of the generator is shown in Fig. 2,a.



a) b)

Fig. 2. Principal (a) and equivalent (b) electrical scheme of the generator of electrical impulses

The capacity of condenser bank is C=1/12 μF, and the ballast resistance is R=8,2 MΩ. Power supply voltage of the generator is U=25 kV.

The energy accumulated on the condenser bank:

$$W_C = \frac{CU^2}{2} = \frac{1/12 \cdot 10^{-6}\left(25 \cdot 10^3\right)^2}{2} \approx 26(J)$$

Because used scheme of the impulse generator is unipolar and taking into account losses in the electric circuit, the useful energy emitted in the interstice:

$$W_S \approx 0.25 \cdot W_C = 6.5(J)$$

The equivalent scheme in which the working electrodes are represented as two condensers connected in parallel C_1 and C_2 is shown in Fig. 2, b.

The condensers' capacity (dimensions by Fig. 4) is calculated by the relations:

$$C_1 = \frac{2\pi\varepsilon_1\varepsilon_0 L}{\ln\frac{a}{b}} = \frac{2 \cdot 3.14 \cdot 3.75 \cdot 8.85 \cdot 10^{-12} \cdot 90 \cdot 10^{-3}}{\ln\frac{2}{3.5}} = 33.5 \cdot 10^{-12}(F) = 33.5(pF)$$

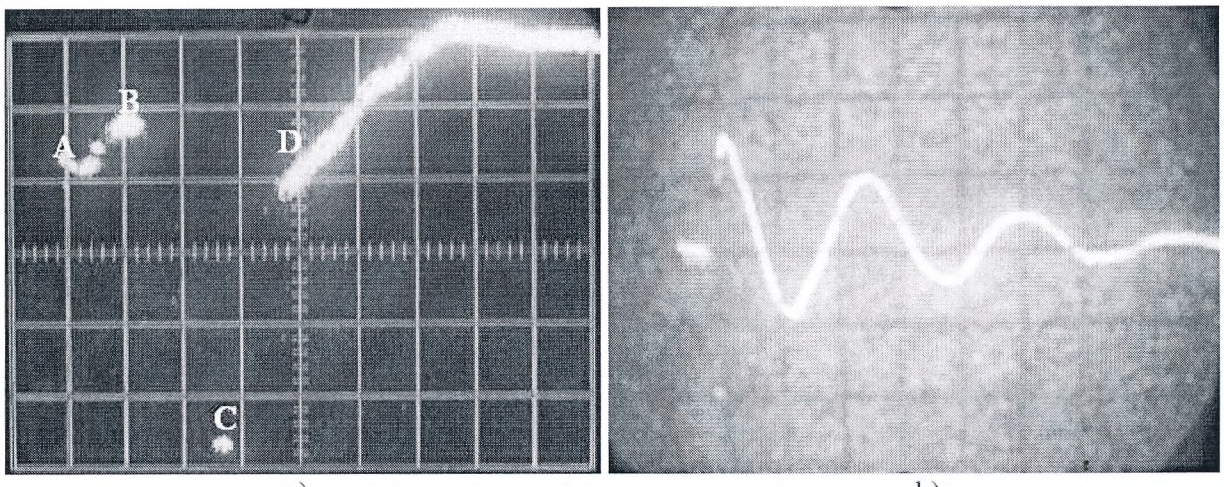
$$C_2 = \frac{\varepsilon_2\varepsilon_0 S}{d} = \frac{\varepsilon_2\varepsilon_0 lh}{d} = \frac{1.00057 \cdot 8.85 \cdot 10^{-12} \cdot 4 \cdot 10^{-3} \cdot 1 \cdot 10^{-3}}{15 \cdot 10^{-3}} = 2.4 \cdot 10^{-15}(F) = 2.4 \cdot 10^{-3}(pF)$$

Thus, the total capacity of the discharge cell:

$$C_{1-2} = C_1 + C_2 \approx C_1 = 33.5(pF)$$

The capacity of the discharge cell was determined by measurements $C_{1-2} = 35(pF)$ (using high-frequency device for determining induction and capacity of type E7-5A).

Impulse shapes (measured using the oscilloscope with memory of type C8-13, with different sweep of the time axis) is shown in Fig. 3, a (1 division = 0.1 μs) and Fig. 3, b (1 division = 10 μs). Sweep according to the vertical axis is 200 V/div.



a) b)

Fig. 3. The shape of electrical impulse discharges
(sweep of the time axis: a – 0.1 μs/div, b – 10 μs/div)

The duration of the discharge impulse (Fig. 3, a, sector BC) τ = 150÷180 (ns).

The amplitude value of the discharge current (according to the oscillogram) I=250 kA.

The luminescence intensity of the electrical impulse discharge:

$$L = \frac{W_S}{S\tau} = \frac{6.5}{4 \cdot 10^{-2} \cdot 150 \cdot 10^{-6}} = 10^8 \div 10^9 \left(\frac{W}{cm^2} \right).$$

According to [1], at intensities $L \geq 10^{11}$ W/cm^2 the dissociation of molecules takes place.

In this particular experiment, the luminescence intensity is of 2-3 orders lower than that of dissociation.

The experimental installation (Fig. 4) consists of: 1 – "black box" (wooden box painted in black) 2 – the test color optical glass; 3 – copper working electrodes; 4 – quartz tube; 5 – copper rod; 6 – registration device (video camera).

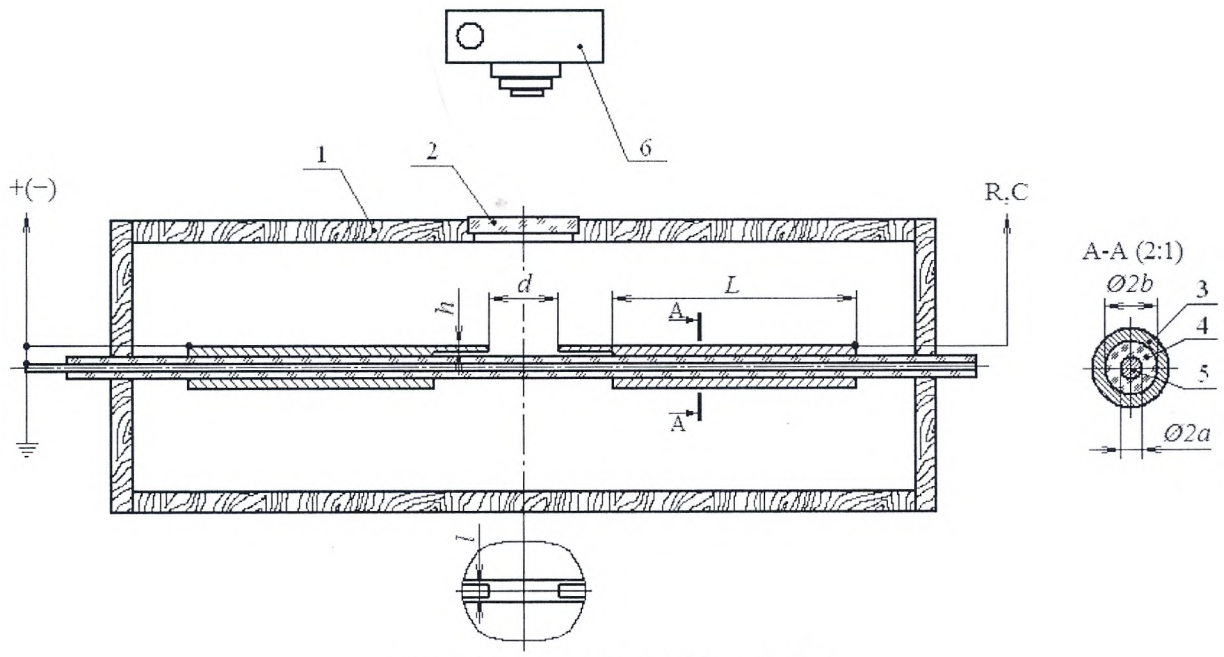
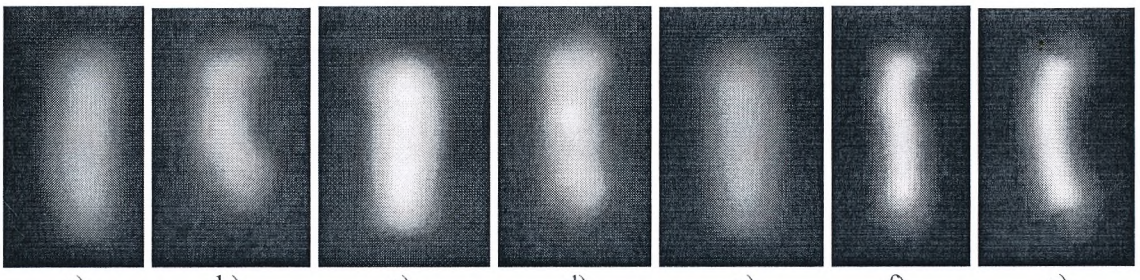


Fig. 4. The experimental installation

The main discharge occurs between the working electrodes 3, followed by release into the cell of an impulse of the light. The infrared light flux interacts with SiO_2 molecules of investigated samples 2. The multi-photonic absorption of infrared radiation by SiO_2 molecules at resonance band leads to a transition of the vibration energy in the electronic one, then, after the transition from the excited to the normal state, the monochromatic light quanta is emitted having a specific wavelength from visible region of the spectra, which is recorded by the video camera 6.

Results of experimental investigations

It was established that infrared filters (of type IKS) emit a violet secondary radiation, and dark filters (of type TS) emit a green secondary radiation (fig. 5).



a) b) c) d) e) f) g)

Fig. 5. Secondary radiation through optical filters:
a – IKS-1; b – IKS-3; c – IKS-5; d – IKS-6; e – IKS-7; f – TS-3; g – ESAB CE EN169 SHADE 12

Detected phenomena can be explained by secondary radiation emission due to multi-photonic excitation of SiO_2 molecules and direct-inverse translating from one energy level to another.

The wave length of secondary radiation in the investigated glasses is calculated by relation:

$$\lambda = \frac{1}{\omega_{el}} = \frac{1}{\omega_{osc} \cdot N_{IR}},$$

where ω_{osc}=780 cm^{-1} is one of the resonance oscillatory levels (of the absorption bands) for molecules of SiO_2 [5,6]; N_{IR} is the number of absorbed infrared photons.

Thus, for infrared filters the number of absorbed photons is 33, and for dark glasses is 24. In this case, the wave length of secondary radiation is 388.5 nm (violet color) and 534.2 nm (green color) respectfully.

Conclusions

Based on the above, we can conclude the following:

– The multi-photonic absorption of infrared radiation by SiO_2 molecules at resonance band leads to a transition of the vibration energy in the electronic one, then, after the transition from the excited to the normal state, the monochromatic light quanta is emitted having a specific wavelength from visible region of the spectra.

– The number of absorbed by the molecule infrared photons depends on the luminescent intensity of the light flux. For investigated infrared filters of type IKS the number of absorbed infrared photons is 33, and for dark glasses of type TS is 24.

– Under the light action of electrical discharge in impulse plasma the wave length of secondary radiation in infrared filters of type IKS is 388.5 nm (violet color) and in dark glasses of type TS is 534.2 nm (green color). This phenomenon can be applied in construction of equipment functioning based on monochromatic light radiation.

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