CURRENT OSCILLATIONS IN $Ag_3In_5Se_9$ STIMULATED BY ELECTRIC FIELD AND IR-IRRADIATION

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В работе приведены результаты исследований низкочастотных осцилляций тока в, стимулированных электрическим полем и ИК-облучением, $Ag_3In_5Se_9$. В зависимости от интенсивности и длины волны ИК-излучения, напряженности электрического поля и температуры наблюдаются осцилляции тока в диапазоне частот 0,8÷200 Гц. Показано, что полевая зависимость сечения захвата носителей заряда на локальные уровни стимулирует примесную фотопроводимость при возбуждении образца ИК-излучением в интервале длин волн 1,12÷1.2 мкм и 1,56÷1,75 мкм. Выявленные особенности объясняются на основе трехуровневой системы.

The results of study of the current oscillations in $Ag_3In_5Se_9$, stimulated by electric field and IR-irradiation have been presented. The current oscillations in a range of frequencies 0,8 ÷200 Hz, depending on intensity and wavelengths of IR-irradiation, intensity of the electric field and temperature are observed. It is shown, that field dependence of the capture cross-section for charge carriers on local levels stimulates intrinsic photoconductivity at excitation of the sample by IR-irradiation in the wavelength range 1,12÷1.2 μm and 1,56÷1,75 μm. The revealed features are explained on the base of three-level system.

INTRODUCTION

In this report the study results of photoelectric properties of $Ag_3In_5Se_9$ single crystals in strong electric fields at presence of the IR-irradiation are present. At study of the photoconductivity spectrum of the specified crystal it is revealed that a strong electric field in the certain temperature range (200÷220 K) induces intrinsic photoconductivity. Thus, with increase of intensity of the electric field the peak amplitude of the intrinsic photoconductivity increases. Since some value of electric field intensity ($E >$ 400 V/cm) under an irradiation of the sample by the light from IR-region of a spectrum in samples made of $Ag_3In_5Se_9$ single crystals the low-frequency current oscillations occurs, expressed on oscillograms as periodically repeating pulses of a various form. The current oscillations in a range of frequencies 0,8 ÷200 Hz, depending on intensity and wavelengths of IR-irradiation, intensity of the electric field and temperature are observed.

It is necessary to note that the investigated samples possess appreciable anisotropy of electric and photoelectric conductivities, and the degree of the anisotropy strongly increases at reduction of temperature below 230 K. It is also established that at such temperatures on current - voltage characteristic (CVC) of the crystal in the direction perpendicular to crystallographic axis "C" sub-linearity as well as a saturation of the current caused by acoustoelectric effect are observed. However, occurrence of the low-frequency oscillations testifies that in a crystal exist sticking levels with capture cross-section depending on the intensity of an electric field.

Let's note, that earlier a low-frequency current oscillations caused by influence of an electric field on the effect of the charge carriers capture by deep recombination centers have been found out in alloyed *n*-Ge, GaAs, CdS and in some solid solutions on the basis of these compounds [1-3].

EXPERIMENTAL RESULTS AND DISCUSSION.

Let's consider conditions of the occurrence and the form of the current oscillations in $Ag_3In_5Se_9$.

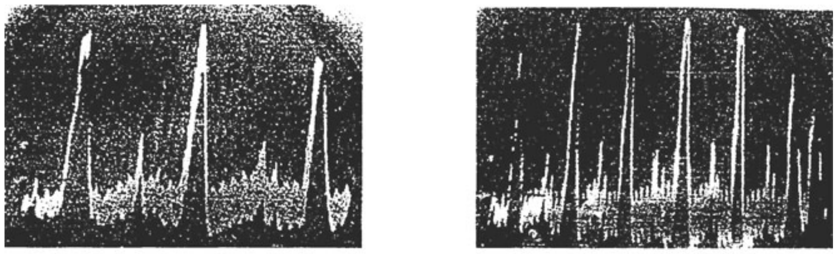
The oscillogram of the current oscillations observed at T = 213 K; E = 600 V/cm and λ = 1.135 μm, is presented on Fig.1, *a*. The rise-up portion of the big pulse (the first kind of the oscillations) is generated by gradual increase of a current with small oscillations. After attainment of the certain maximal current value there is an instantaneous relaxation and a current decreases to its dark level. Then the high-frequency oscillations (oscillations frequency is equal ν = 200 Hz) in the sum of the second kind of oscillations with frequency of 53 Hz are observed. Between two big pulses it is seen two more small pulses which we shall call oscillations of the third kind. At reduction of the wavelength of the stimulating radiation to λ = 1.130 μm a frequency of all oscillations decreases (Fig. 1, *b*). The first kind of oscillation has frequency ν = 10 Hz, the second one - ν = 80 Hz, and the third one - ν = 10 Hz.

At the further reduction of the wavelength of the radiation, the oscillations frequency insignificantly increases and at λ < 1.12 μm the current oscillations cease, and the current manifest a constant value corresponding to a maximum of the big pulse.

At the threshold wavelength current oscillations have the form shown in Fig. 2, *a*. the Oscillations frequency under conditions: λ = 1.190 μm, E = 460 V/cm and T=205 K is equal 0.8 Hz. In the range of wavelengths λ =1.20 ÷1.12 μm the oscillations frequency linearly increases from 0.7 to 80 Hz with reduction of the stimulating radiation wavelength (Fig. 2, *b*).

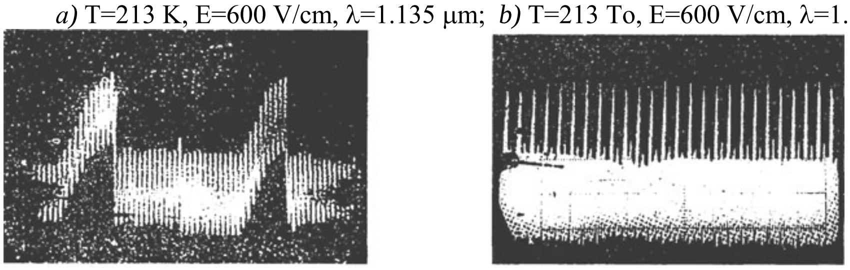
At the fixed radiation wavelength at a constant temperature the oscillations frequency increases with growth of the intensity of the electric field. It is necessary to note, that the oscillation amplitude in all dependences changes in direct proportion to the oscillations frequency. In case of a constancy of the intensity and a radiation wavelength, the oscillations frequency very weakly depends on sample temperature in a temperature range 110÷210 K. A threshold electric field intensity at λ = 1.12 μm and T = 210 K is equal E_{thr} = 400 V/cm. In the specified temperature range a threshold wavelength λ_{thr} increases from 1.120 to 1.125 μm with rise in temperature. At the fixed values of the electric field intensity, wavelength of the stimulating radiation and the sample temperature the amplitude of the oscillations of the first kind depends in direct proportion on the radiation intensity.

Irradiation of the sample with IR-radiation in the range λ =1.56÷1.75 μm stimulates another series of current oscillations at the applying an electric field E_{thr} = 570 V/cm. The dependence of the oscillations frequency on the stimulating radiation wavelength has complex character (Fig. 3). As it is seen from Fig. 3, the oscillation frequency at first exponentially grows with increase in the wavelength from λ =1.56 to 1.65 μm and then monotonously decreases with increase in wavelength from λ =1.65 to 1.75 μm.



a) b)

Fig. 1. The oscillogram of the current oscillations in $Ag_3In_5Se_9$.
a) T=213 K, E=600 V/cm, λ=1.135 μm; *b)* T=213 To, E=600 V/cm, λ=1.130 μm



a) b)

Fig. 2. The oscillogram of the current oscillations in $Ag_3In_5Se_9$.
a) T=205 K, E=460 V/cm, λ=1.190 μm; *b)* T=205 K, E=460 V/cm, λ=1.120 μm

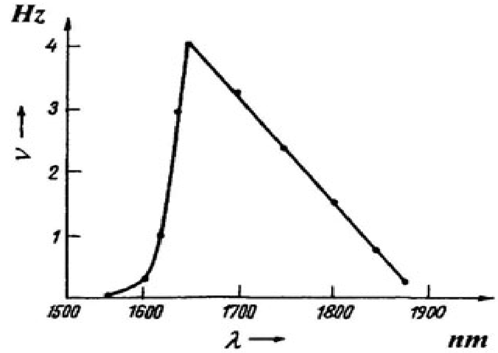


Fig.3. Dependence of the oscillations frequency on the stimulating IR-radiation wavelength. T=215 K, E=690 V/cm

The field dependence of the oscillations frequency under condition T=210 K and λ =1.70 μm is shown in Fig. 4. This dependence has two inclinations that testifies the fact that the capture cross-section of two levels in a crystal depends on the intensity of the applied electric field.

On Fig. 5 oscillograms for various intensity of the stimulating radiation are presented at a constant electric field intensity E = 600 V/cm, wavelength λ =1.68 μm and temperature T = 210 K. It is seen that amplitude and the oscillation frequency depend in direct proportion on IR-radiation intensity.

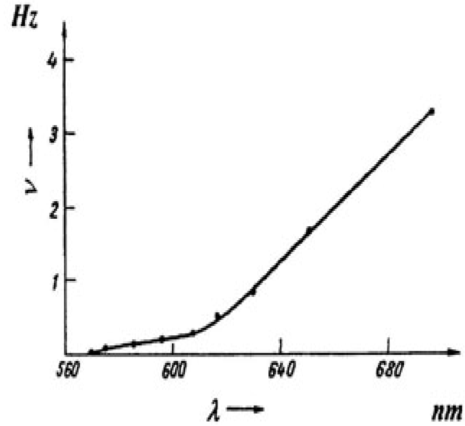


Fig.4. Field dependence of the oscillations frequency at T=210 K, λ =1.70 μm

The above-stated characteristics of the current oscillations stimulated by electric field and IR-irradiation, allow to explain the observed current oscillations on the basis of three-level model where three types of recombination centers are considered together with results of early works on studying properties of $Ag_3In_5Se_9$ (Fig. 6).

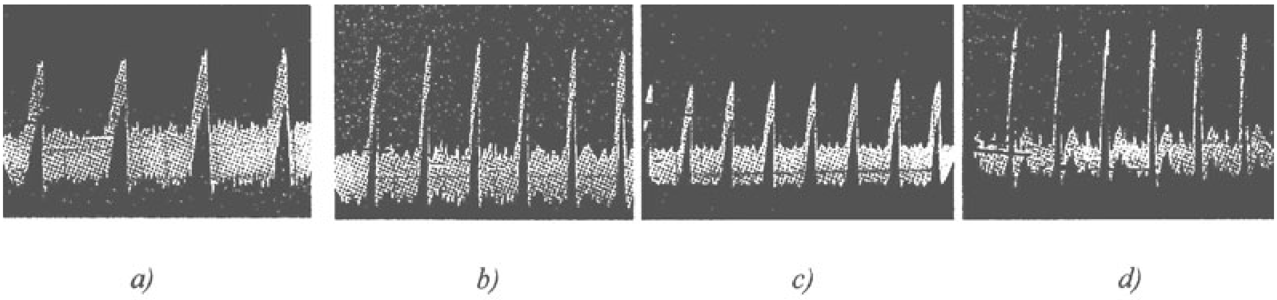


Fig. 5. The oscillograms of the current oscillations of in $Ag_3In_5Se_9$ for different stimulating radiation intensities: *a)* $I=I_0$; *b)* $I=4\ I_0$; *c)* $I=9\ I_0$; *d)* $I=16\ I_0$ (T =210 K, E=600 V/cm, λ =1,68 μm)

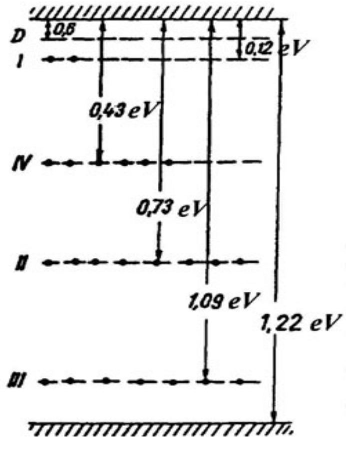


Fig.6. The energy diagram

The traps, creating a deep level *II*, serve as the recombination centers for electron-hole pairs. The level *III* operates as the sticking centers for holes. They are depleted in enough strong electric fields due to reduction of the capture ratio for holes at them heating, as well as due to increase in the emission factor for trapped holes, owing to the autoionization effect. At last, traps from the level *I* exchange electrons only from a conductivity band and their role will consist in accumulation of a negative bulk charge of sufficient extent. At hole release from level *III* the rate of the recombination through level *II* sharply grows, as results of falling concentration of electrons, responsible for conductivity. The shallow sticking level *D* is depleted at rather weak electric fields.

The mechanism of the occurrence of the current oscillations is shown on Fig. 1 consists in the following. The acoustic domains are created at the applying to the sample of the electric field $E_{cr} > (\nu_s / \mu_D)$ (where ν_s is a speed of the transversal acoustic waves in a direction of the current flow), in a crystal. At the moment of leaving the domain from the anode, an intensity of the electric field in the sample reaches its maximal value. At such fields shallow donor level, lying in depth 0.06 eV, is depleted and on the oscillogram a pulse of the *III* kind appears. Repeated capture of the conductivity electrons and the subsequent depletion of this level could be casual character, therefore across beyond this pulse we observe stochastic auto-oscillation, which is ordered under certain conditions. The first kind of oscillation (the big pulse) is caused by the capture of the non-equilibrium electrons by level *I* and formation of hole conductivity due to transitions of the valence band electrons on the level *III* is depleted under the effect of IR-radiation. As the electrons by the level *I* of a capture cross-section are depended on the intensity of the applied electric field [4], at the moment of full filling of the level *I* a concentration of the non-equilibrium holes in valence band increases, and it is the result of current increase in the sample. This process promotes also increase of the non-equilibrium electrons lifetime in conductivity band. In turn the increase in a current in a sample leads to decrease of the voltage drop on the sample. Hence, reduction of the electric field intensity results in recombination of electrons, captured by level *I* and in reduction of the capture cross-section of this level. Recombination process of the non-equilibrium carriers again promotes increase in intensity of the electric field. After that moment new oscillations are begun.

CONCLUSION

Thus, field dependence of the capture cross-section for charge carriers on local level *I* stimulates impurity photoconductivity at excitation of the sample by IR-radiation in the range λ =1.12÷1.20 μm and λ =1.56÷1.75 μm that allows to recommend this material for manufacturing selective photodetectors with high resolution for operating in the specified spectral range.

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