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Stimulated by heating-up changes of lux-brightness characteristics of semi-insulating specially undoped GaAs crystals

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Abstract. It was shown that thermal treatment of semi-insulating specially undoped gallium arsenide leads to significant changes of lux-brightness characteristics of inter- impurity and impurity bands in the spectra of impurity luminescence. The indicated changes are due to transformations in the system of non-radiating channels of hole recombination in it that took place in the process of thermal treatment. The effect observed can lead to variation of the correlation between the intensities of bands in the spectrum of impurity photoluminescence even if the change of concentration of luminescence centers does not occur. Such changes in lux-brightness characteristics of impurity bands should be concerned while using photoluminescence spectra for the analysis of changes occurring in impurity-deficient composition of gallium arsenide during its thermal treatment.

Keywords: semi-insulating gallium arsenide, photoluminescence, intensity of bands, lux-brightness characteristics, thermal treatment.

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1. Introduction

While studying the influence of heating-up on the spectrum of low-temperature (4.8 K) photoluminescence (PhL) of semi-insulating undoped gallium arsenide crystals (further – SIU GaAs), we discovered alterations of lux-brightness characteristics (further-LBC) of elementary impurity and inter-impurity luminescence bands in it, stimulated by thermal treatment. We'll further deal with the description of this effect, its explanation, as well as with all the ensuing consequences.

2. Methods

Investigation was carried out on semi-insulating undoped SIU GaAs crystals, their characteristics are described in detail in [1]. Thermal treatment of crystals was held at temperature $T = 950$°C, for 4 hours, followed by quick cooling.

The photoluminescence spectra of the investigated crystals were measured at $T = 4.8$ K using a spectrometer MDR-23 with 0.3 meV resolution. The signal registration was fulfilled by the cooled PMT-62 (photomultiplier tube). Luminescence was excited by a strongly absorbed radiation of He-Ne-laser with quantum energy 1.96 eV, depth of light absorption being $1/k = 0.25$ μm, illumination intensity L varied from 10^{16} to 10^{19} quanta/(cm^2·s). A typical spectrum of the investigated SIU GaAs crystals is represented in Fig. 1. There are two bands of luminescence observed in the investigated crystals. One of them is the inter-impurity (with maximum radiation $h\nu_{m1} =$ $= 1.491$ eV and intensity I_{da}), conditioned by electron transitions in pairs shallow donor d – shallow acceptor a. The other is the impurity one (with maximum radiation $h\nu_{m2} = 1.495$ eV and intensity I_{eA}), conditioned by transitions of a free electron e to a shallow acceptor A, connected with background neutral donors, i.e. to an associate [2]. The position of maxima of those bands in initial and thermally treated SIU GaAs crystals did not differ.

3. Results and discussion

Fig. 2 shows lux-brightness characteristics of inter-impurity and impurity bands of PhL in the initial crystals. Apparently, in the initial crystals intensity dependence of inter-impurity PhL band on the excitation level is linear ($I_{da} \sim L$) at low L ($L < 8\cdot10^{17}$ quanta/(cm^2·c)) and sub-linear ($I_{da} \sim L^{0.3}$) at high L ($L \geq 8\cdot10^{17}$ quanta/(cm^2·c)). At the same time, the intensity of the impurity PhL band is at first super-linear ($I_{eA} \sim L^{1.6}$ at $L<2.5\cdot10^{18}$ quanta/(cm^2·s)),

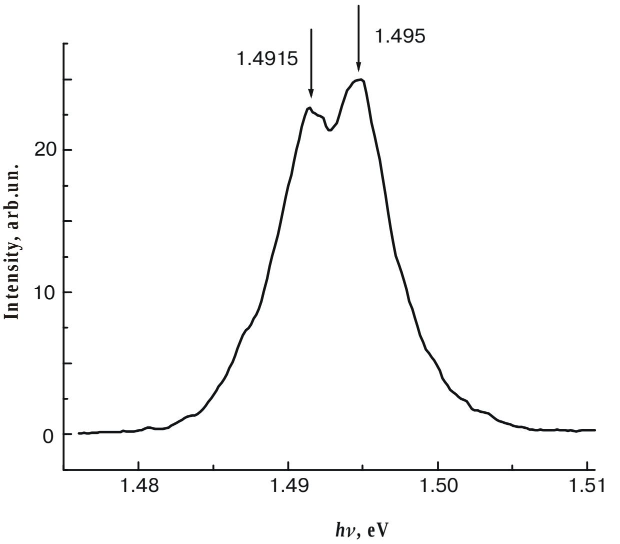

Fig. 1. Typical spectrum of an impurity luminescence of SIU GaAs crystals at 4.8 K and L = 5·10^{18} quanta/cm^2·s.

and then is sub-linear ($I_{eA} \sim L^{0.45}$ at $L \geq 2.5 \cdot 10^{18}$ quanta/(cm^2·s)). Such a complicated form of LBC can be explained by a nonlinear dependence of concentration of excess electrons (dn) and holes (dp) on the excitation intensity. Really, it should be expected that in the investigated crystals (see correlations (20), (21) in [3]) $I_{da} \sim \delta p$, and $I_{eA} \sim \delta n \delta p$. Then for the observed dependences I_{da}, I_{eA} on L, it is necessary to assume that dn, dp vary essentially in regions of low L and quite weakly (are almost saturated) at high L, in particular: $\delta p \sim L$, and $\delta n \sim L^{0.6}$ in the region $L < 2.5 \cdot 10^{18}$ quanta/(cmI·s) and $\delta p \sim L^{0.3}$, and $\delta n \sim L^{0.15}$ in the region $L \geq 2.5 \cdot 10^{18}$ quanta/(cm^2·s)).

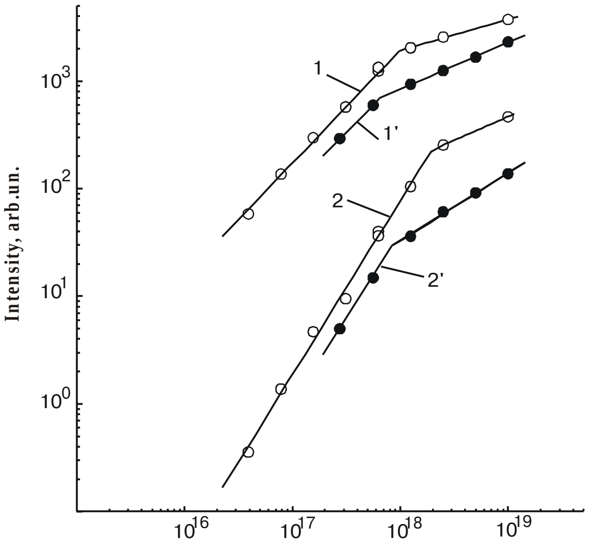

Fig. 2. Lux-brightness intensity characteristics of photoluminescence bands with $h\nu$ =1.491 (1, 1′) and 1.495(2, 2′) eV in initial (1, 2) and thermally treated at 900є (1′, 2′) SIU GaAs crystals. Correlation between luminescence intensities of corresponding bands is optional.

Thermal treatment of crystals, as it follows from Fig. 2, does not change values of LBC at low excitation intensities and changes them at high intensities, namely: $I_{da} \sim L$, and $I_{eA} \sim L^{1.6}$ in the region of low L and $I_{da} \sim L^{0.45}$, and $I_{eA} \sim L^{0.6}$ in the region of high L. Besides, due to thermal treatment, a shift of LBC inflection points to the region of lower PhL excitation intensities is observed (Fig. 2).

As a comparison of dependence I_{da}, $I_{eA} = \varphi(\delta n, \delta p)$ in initial and thermally treated crystals shows, such LBC changes of thermally treated SIU GaAs crystals at high L are connected with stimulated by heating up changes of dependence δp on L. It is most likely to be conditioned by changes in the system of non-radiating channels of hole recombination caused by thermal treatment. The same changes cause the shift of the inflection point to the region of lower illuminations. For a more precise identification of nature of stimulated by thermal treatment LBC changes, additional (although quite complicated at helium temperatures) direct measurements of δn and δp dependences on L are necessary.

It should be mentioned that the value of the effect described by us essentially differed in various SIU GaAs crystals. In many of them, this effect was rather weak and only in some – great enough. It might be caused by the difference in impurity-deficient composition of SIU GaAs crystals, conditioned by a weakly controlled difference in technology of obtaining them and the details of their thermal heating (time of heating-up, mode of cooling, etc.)

Thus, as follows from the mentioned data, changes in the system of non-radiating channels of recombination current carriers, taking place in the result of thermal treatment, can cause changes of LBC of impurity and inter-impurity PhL bands of SIU GaAs crystals. This effect can lead to changes of intensity correlations corresponding to the bands in PhL spectrum, even if the changes of the luminescence centers concentration does not take place. It should be taken into the consideration while using PhL spectra for the changes analysis (in particular, concentration of luminescence centers), occurring during thermal treatment of gallium arsenide crystals (see [2] and references [2,10-17] therein).

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