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BISTABLE OPTIC MODULATORS MADE FROM MONOCRYSTALLINE LAYERS GaSe (Cu)

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Fabry-Perot interferometer was constructed on the basis of parallel - slides plates cut off from the GaSe(Cu) single crystals with Cu concentration of 0.05 at%. The thickness of these plates was equal to 5 ÷ 10 μm. Dielectric glass, which consisted of 7 ZnS layers and 7 MgF_2 layers with λ/4 thickness, was placed on lateral surfaces of the plates. The reflectance of the glass was equal to ~ 73%. The dependence of interferometer transparency on the intensity of incident radiation with 0.6328 μm wavelength is studied. The threshold intensity, for which periodic pulsations of transmission are observed, is determined from this dependence.

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1. Introduction

The compound of type $A^{III}B^{VI}$ are crystallized as slides consisted of packages of type Hal-Me-Me-Hal. The halogenous (Hal) atoms are arranged in such a way that the relationship of valence upon the surface layer is practically closed. As a result, there exist only weak cohesion forces of polarization type between the stratified packages. These specific features of the composites GaSe, GaTe, InSe and GaS allow for getting parallel-slided plates, through splitting, with the granularity at the atomic level ($\Delta d \approx 10^{-9}$ m) (ideal surface) and with the sufficient widths to be used as functional element of the Fabry-Perot interferometers.

2. Experimental

As known [1] the contrast coefficient k which characterised the correlation between the maximum and minimum intensities of the interference (picture) for the Fabry-Pérot interferometer depends only on the reflection coefficient, r, of the mirror:

$$k = \left(\frac{1+r}{1-r}\right)^2 . \quad (1)$$

This does not exceed the value 2.3 for the reflection coefficient of the crystal surface GaSe equal to ~ 0.21.

The high grade of perfection of the structure of GaSe monocrystals leads to the appearance of excitonic bands of absorption localized in the vicinity of the red edge of the fundamental band. As established in the paper [2-4], the doping of GaSe crystals with Cu of quantities up to 0.05 at.% leads to the elimination of defects in the metal sub-network. As a result, the absorption coefficient in excitonic band n=1 grows up to ~2.5 times, while the half-width of the absorption excitonic band does not change with the concentration of the Cu atoms (C≤0.05% at.).

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The absorption spectra in the region of the absorption fundamental band edge for crystals GaSe doped with 0.02 at.% of Cu at room temperature (293K) and boiling temperature of nitrogen (78 K) are shown in the Fig. 1, curves **a** and **b,** respectively. The energy, at which the maximum excitonic absorption band n=1 is localized, is equal to 2.062 eV and 2.102 eV for the temperature 293 K and 78 K respectively. The half-width of excitonic line n=1 increases along with the temperature of crystals from the 0.015 eV at the temperature of 78 K up to 0.050 eV at the room temperature. As an additional confirmation that the impurity atoms of Cu under low concentrations (C<<0.05% at.) remove the defects in the sub-network of the current metal, but do not protect the impurity centres, is the decrease of electric conductivity of the respective crystals [5-9].

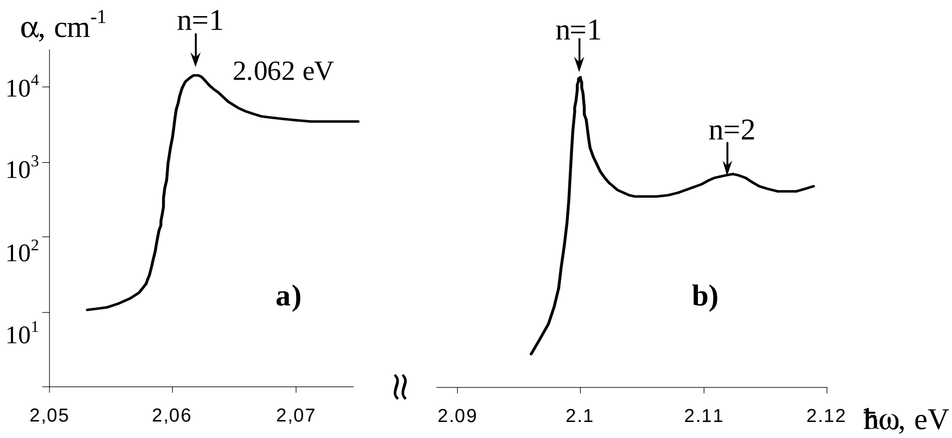

Fig. 1. Spectral dependence of absorption factor for GaSe crystals doped with 0.02 at% Cu in the absorption edge region. T = 293 K (a), T = 78 K (b).

3. Results and discussion

The dependencies of light intensities with the wavelength corresponding to the maximum extension absorption of intensity of a supplementary beam of light incident on the parallel plan surface manufactured from a single-crystal of GaSe doped with Cu (0.02 at.%) at the temperature 293 K (curve 1) and 78 K (curve 2) are shown in Fig. 2. As a beam that creates a supplementary concentration of the free charge carriers it was taken the second harmonic of the laser Nd^{3+} (λ=0.53 μm). The intensity of the laser beam could be varied in a wide range of values using a set of optical neutral filters of type NS.

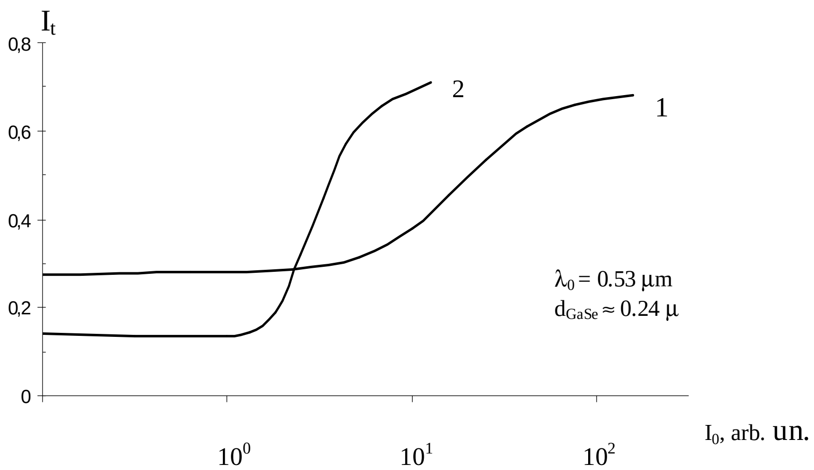

Fig. 2. Intensity of probing beam, I_t, versus intensity of incident beam for λ=0.53 μm ($\hbar\omega >> E_g$). 1 – T = 293 K, $\lambda_{probing}$ = 0.601 μm; 2 – T = 78 K, $\lambda_{probing}$=0.591 μm.

As observed, the growing transparency of the crystal is noticed starting from a certain intensity of the stimulating beam, I_p. The threshold intensity I_p depends upon the temperature and is less with approximately one degree at the temperature 78 K than it is at the room temperature. As it was proved, the growing of the local temperature of the crystal under the intensive stimulation imposes the variation of intensity of the stimulating beam that passes through the crystal at the temperature of 293 K. The experimental results, represented in Fig. 2, could be interpreted if one takes into account that the hole-electron (excitons) relationship could be applied to free charge carriers. Thus, the absorption coefficient in the range of excitonic band can be controlled through the variation of the concentration of free electronic charge carriers at both room temperature and nitrogen boiling temperature.

The parallel position of the GaSe (Cu) plate's surface obtained by splitting bulk monocrystals, determines the maximum value of the reflection coefficient of the Fabry-Perot interferometer mirrors. If one admits that the nonuniformity of mirror surfaces is of $\Delta d \approx 10^{-9}$ m, then the instrumental contour of the Fabry-Pérot interferometer does not exceed the calculated theoretical value for the reflection coefficients of the mirrors $r \leq 0.9$.

The active optical environment of the Fabry-Perot resonator was manufactured from the single-crystalline slides of GaSe (Cu) with the thickness for which the maximum absorption of the interference picture coincides with the excitonic line n=1 at the corresponding temperature (293 K or 78 K). Rotating the crystal toward the direction of the incident beam did a slight correction. The dielectric mirrors were extended on two surfaces freshly split from a single-crystal of GaSe (Cu), through the thermal vaporization in vacuum ~10^{-6} Pa. Consequently, the slides ZnS (n=2.36) and MgF_2 (n=1.38), whose thickness satisfies the equation $nd = k\lambda/4$ (k – integral number), were deposited. The total number of slides in the resonator mirror did not exceed 11.

The schematic model of the interferometer is shown in Fig. 3a and the reflection coefficient as a function of λ (got in the spectrophotometer Specord M-40) is shown in Fig. 3b.

The reflection coefficient of the dielectric mirrors made of 11 consecutive slides of ZnS and MgF_2 at the wavelengths that correspond to the maximum absorption in the excitonic bands at the temperature 78 K and 293 K is ~ 0.9. At the same time, the optical transparent electrodes were deposited on the lateral mirror surfaces.

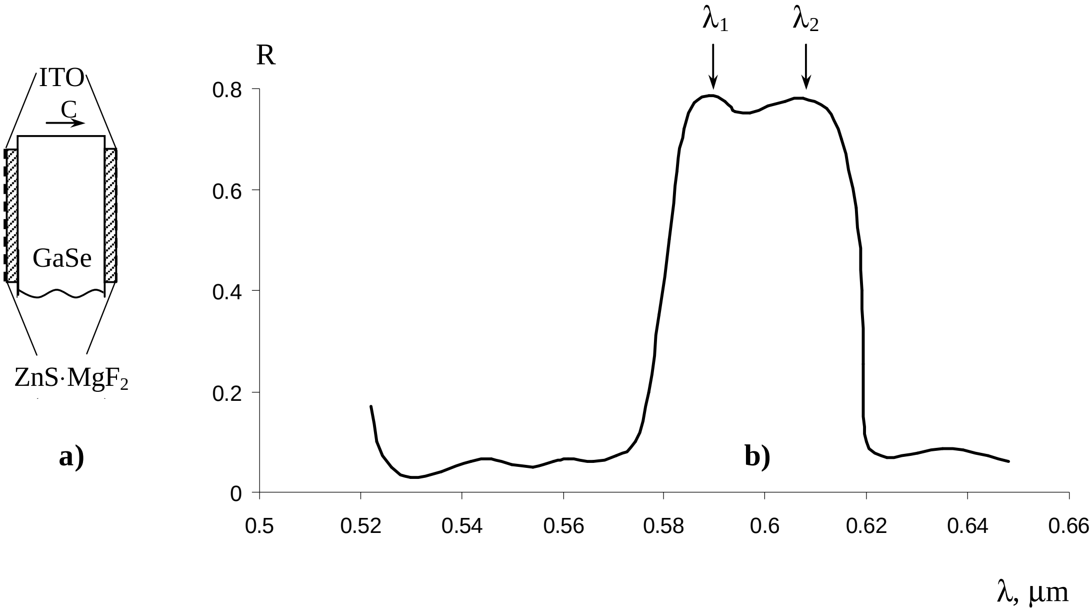

Fig. 3. a) The scheme of Fabry-Perot interferometer with the optic active medium constructed on the basis of Cu-doped GaSe single crystalline plates. b) Spectral dependence of reflectance for dielectric glass consisted of 11 ZnS (n=2.3) and MgF_2 (n=1.38) layers with $\lambda/4$ thickness.

The variation of the intensity of the passing beam was studied by means of Fabry-Pérot resonator with the active medium from GaSe (Cu) depending on the wavelengths ranged in the contour of the excitonic absorption bands at the temperatures 293 K and 78 K. The studies were performed in a photometer apparatus consisting of the spectrograph ISP-51 and camera UF-89. The slots that determined the spectral width did not exceed 1 Å were installed in the focal plane of the camera. The light beam passed through corresponding slots was registered using a photo-multi-amplifier FME-87 with the temporary resolution less than 5×10^{-9} s. The signal from the charge resistor of the anodic circuit of the photo-multi-amplifier was amplified with the amplificatory "wide band" (type U 3-7A) and was registered using the oscillograph with memory S8-2. As a source of light, the impulse lamp with Xe of type ISS-500 was used, which was fed up by a cylindrical condenser with the capacity of 0.1 μF, being charged up to 5 kV. The impulse lifetime of the light at the level 0.5 was $\sim10^{-6}$ s. The light beam from the impulse lamp passed through a set of optical filters, by means of which the corresponding spectral region of electronic bands was selected at the room temperature 293 K and 78 K respectively, was focused on the interference surface. Initially, the position of the interference was chosen in such a way that at the intensity much weaker than the threshold intensity of the signal generated by the photo-multi-amplifier to be minimal.

The spectral dependency of the beam intensity variation passed through interferometer at the intensity of the incident beam of $\sim2I_p$ is represented in the Fig. 4a for the excitonic band with the maximum wavelength of 6012 Å and corresponding temperature 293 K; and in Fig. 4b, for the absorption excitonic band with maximum wavelength of 5910 Å and the corresponding temperature at 78 K. As can be observed from these graphics, the light intensity variation passed through the Fabry-Pérot interferometer with the active medium from GaSe (Cu) both at the room temperature and at the temperature of 78 K, reaches the maximum rating point in the vicinity of the red edge of the absorption excitonic band.

It is important to be mentioned that the beam passed through the interferometer is variable upon the intensity with a lifetime much less than the temporal resolution of the apparatus: ~7÷10 ns.

In Fig. 5, it is shown the dependency of the modulation coefficient ΔI/I at the wavelength 590 nm. The crystal was placed in the liquid nitrogen. As shown in the Fig. 5, at intensities higher than the threshold intensity, I_p, the modulation coefficient ΔI/I has a linear growth along with incident intensity. The reaching of the maximum rating is limited by the local warming of the crystal, because at these intensities the maximum absorption is not completely saturated.

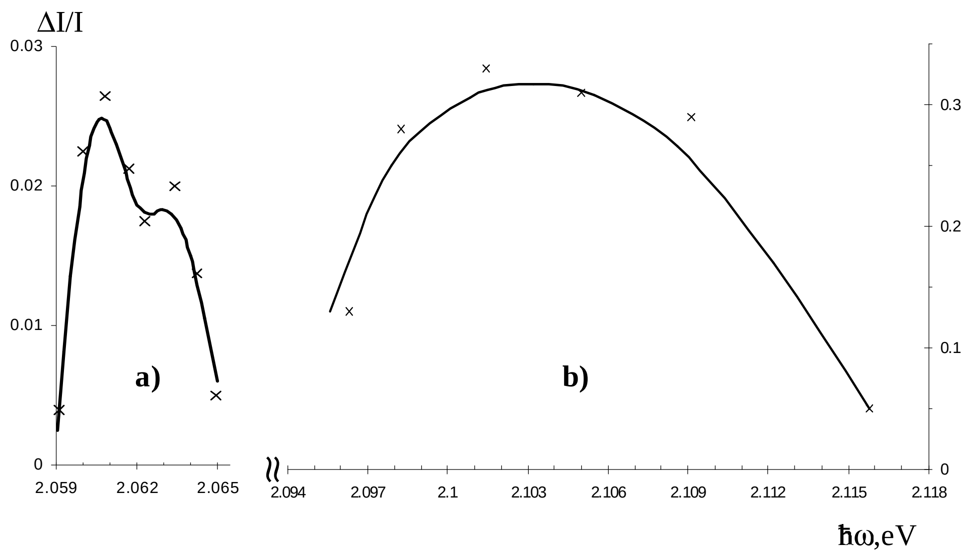

Fig. 4. Spectral dependence of ΔI/I modulation factor for Fabry-Perott interferometer with the optic active GaSe(Cu) medium. T = 293 K (a), T = 78 K (b).

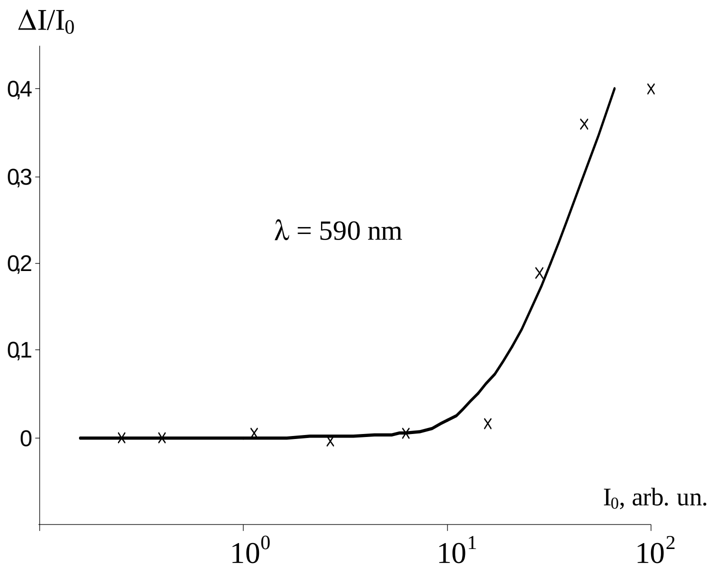

Fig. 5. ΔI/I modulation factor versus relative intensity of incident light for Fabry-Perott interferometer with the optic active GaSe(Cu) medium. The thickness of parallel-sided plates is equal to 0.27 μm. T = 78 K. Probing beam wavelength $\lambda_{probing}$=590 nm.

4. Conclusions

The edge absorption spectrum consists of excitonic absorption band with a maximum at 2.062 eV at T = 293 K and 2.102 eV at T = 78 K. The doping of GaSe crystals with Cu concentration less than 0.02 at% leads to an increase of excitonic absorption intensity both at T = 293 K and T = 78 K.

Absorption factor at the light energy, which corresponds to maximum of the excitonic absorption band, is equal to ~ $1.3\times\cdot10^4$ cm^{-1} at T = 293 K and ~ 1.8×10^4 cm^{-1} at T = 78 K. The bandwidth increases from 0.015 eV to 0.05 eV along with increasing temperature from 78 K to 293 K.

Charge carriers generated by transitions “valence band –conduction band” shield the electron-hole interaction. As a result, absorption factor decreases for all the region of excitonic absorption band. The slope of the $I_t=f(I_0)$ dependence decreases along with the increasing temperature from 78 K to 293 K.

Fabry-Pérot interferometers were constructed on the basis of GaSe(Cu) parallel-sided plates. Reflection band is localised in the 575÷626 nm wavelength region. The maximum reflectance is equal to ~ 73% at 590 nm wavelength.

Spectral dependence of ΔI/I modulation factor of the interferometer is analyzed in the region of excitonic absorption. It is established that ΔI/I modulation factor has a maximum value in the red threshold region of the excitonic absorption band. The maximum effectiveness of modulation increases from 0.025 to 0.32 with decreasing temperature from 293 K (λ_{max}=601.6 nm) to 78 K (λ_{max}=590.0 nm).

Beginning with the threshold intensity, specific for particular sample, the intensity of monochromatic light (λ=590 nm) transmitted through the interferometer increases super-linearly with increasing intensity of incident light.

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