Spectrometer based on p-$Al_xGa_{1-x}As$/n-GaAs heterojunctions

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Two types of spectrometers are manufactured into one single crystal, on the basis of p-$Al_xGa_{1-x}As$/n-GaAs heterojunctions. The first type measures the wavelength of the laser which emits the same light intensity. The second one is the differential spectrometer measuring the laser wavelength which operates on different intensities of the emitted light. These spectrometers can measure the wavelength in the interval from 0.6 to 0.85 μm, or photon’s energies in the interval from 1.45 to 2.0 eV.

(Received March 5, 2008; accepted April 2, 2008)

Keywords: Spectrometer, Heterojunctions p-$Al_xGa_{1-x}As$/n-GaAs, Liquid-phase epitaxy, Variable forbidden band, Spectral sensitivity

1. Introduction

In industrial conditions of manufacturing of the heterojunction-based lasers which emit beams in different regions of the spectrum, it is necessary to sort these lasers by emitted wavelength using a photoreceiver manufactured in one unique crystal [1].

The operation principle of this spectrometer is based on the properties of the heterojunctions. Superficial film with a larger forbidden band performs the function of optical window which means that photons with smaller energy than the gap of the forbidden band pass through this film without absorbtion, and can be absorbed by forming electron-hole pairs in substrate with a smaller forbidden band. Minority charge carriers are separated by p-n heterojunctions and form photocurrent. If the forbidden band of the superficial film is variable on the surface, then in the creation of the photocurrent participate only those photons which can pass through this film. It is necessary to mention a condition. The superficial film’s thickness should be bigger than the diffusion length of the minority charge carriers. On the contrary, in creation of the photocurrent could participate also the photons which are absorbed in the superficial film.

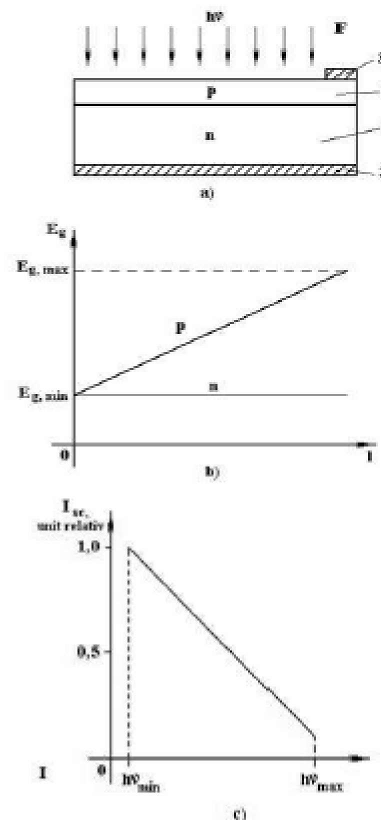

Fig. 1. Construction and principle of operation of the spectrometer which operates on the constant intensity of the source of light: a – spectrometer construction (1 – n-GaAs; 2 – p-$Al_xGa_{1-x}As$; 3 – contacts); b – variation of the forbidden band along the length of the device; c – idealized curve of the short circuit current as a function of photons’ energy.

2. The principal of operation

The spectrometer is manufactured on the base of p-$Al_xGa_{1-x}As$/n-GaAs heterojunctions, where the region “p” has variable forbidden band in the parallel plane to heterojunction as shown on the Fig. 1.

Under total illumination of the surface of the spectrometer with coherent light, photocurrent can be determined by following expression:

$$I_F = \left(\frac{e}{h\nu}\right)\eta QFS,$$

where e is the charge of the electron, ν - frequency, h- Plank constant, η - quantum output of inner photo effect, Q - efficiency of electron-hole pair separation, F – light flux, S - illuminated surface which participates in creation of photocurrent. Under the illumination of the spectrometer, depending on the energy of the photons (wavelength), the whole surface of the device or a part of it participates in creation of the photocurrent. As an example, if the structure shown in Fig. 1 is illuminated with photon whose energy $h\nu = 1.6$ eV, then the light with such energy can pass through optical window in those region of the device where forbidden band of the film p-$Al_xGa_{1-x}As$ is bigger than $Eg \geq 1.6$ eV. This light is absorbed in n-GaAs and forms hole-electron pairs which are separated on the hetero-boundary and form photocurrent measured between the contacts (3, Fig. 1). The light with the same energy of the photons getting to the surface of region “p” where $Eg < 1.6$ eV are absorbed in this region and if its thickness is bigger than the length of the diffusion of the minority charge carries (≈5 μm), then these pairs recombine till they reach the hetero-boundary and cannot participate in the photocurrent creation (Fig. 1c).

As we can see from the above expression, photocurrent depends not only on the illuminated surface but also on the intensity of the light flux F that means that if one changes this parameter, the intensity of the photocurrent will be also changed. That is why for using this spectrometer first of all it is necessary to calibrate the laser with respect to the intensity of emitted light.

In order to exclude this disadvantage, we elaborated the construction of differential spectrometer allowing one to measure the photons energy from the coherent sources, which work on different intensities of emitted light. This spectrometer represents a biphotoreceiver (Fig. 2), manufactured on the base of p-$Al_xGa_{1-x}As$/n-GaAs heterojunctions, on which the illuminated surface is divided with a cross-split. In the left part of the biphotoreceiver the film p-$Al_xGa_{1-x}As$ has the maximum forbidden band and is constant along the surface of the device ($Eg_{max} = 2.0$ eV), but in the right part the forbidden band of the film p-$Al_xGa_{1-x}As$ it changes between Eg_{min} and $Eg_{max}(1.45 - 2.0\text{eV})$ (Fig. 2b). In this way the left part of the biphotoreceiver represents a photo element with a constant sensibility to the change of the photons’ energy between Eg_{min} and $Eg_{max}(1.45 - 2.0\text{eV})$, but the right part represents a spectrometer, analyzed above (Fig. 1).

In the process of illumination of the entire surface of this differential spectrometer with coherent rays, in the left part of the bi-photoelement the whole illuminated surface participates in creating of the photocurrent I_{F1} and performs a function of comparing elements. In the right part of the bi-photoelelement, in the same way as described above (Fig. 1), depending on the wavelength of the light source in photocurrent creation (I_{F2}), only a part of the surface of this structure participates. The measured wavelength or the energy of the photons is a linear function relative to the relation of the currents:

$$\left[h\nu = f\left(\frac{I_{F2}}{I_{F1}}\right)\right]$$

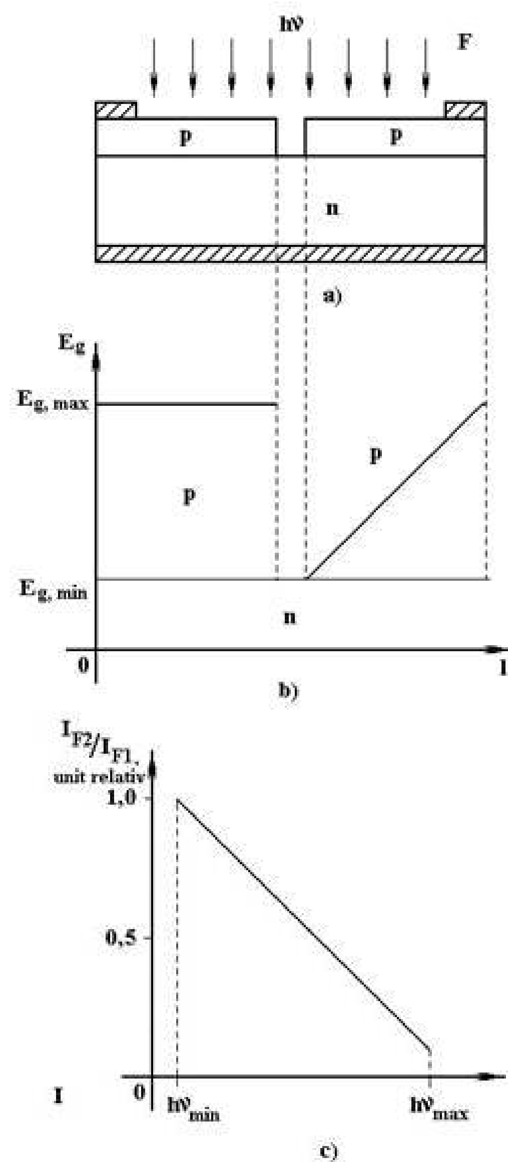

Fig. 2. Construction and principle of operation of the differential spectrometer: a – construction (1 – n-GaAs; 2,3 – p-$Al_xGa_{1-x}As$ with constant and variable forbidden band, respectively; 4-6 – contacts). b – the change of forbidden band on the heterojunctions; c – the currents ratio versus the photon energy.

In such case, the influence of the intensity of light source on the determination of the wavelength is excluded

because of the intensity change of the light, the currents I_{F1} and I_{F2} are also changed, however their ratio remains constant for the given wavelength (Fig. 2c).

If this spectrometer is illuminated with a light flux with photons' energy $h\nu > 2$ eV, then $I_{F1} = I_{F2} = 0$, because the window effect in heterojunctions will be absent. But, if the photons' energy is $h\nu = 1.7$ eV, then the whole left part of the bi-photoreceiver, due to the "window" effect, will participate in the creation of photocurrent I_{F1}. At the same time in the right part of the bi-photoreceiver, due to variable change in the forbidden band, in creation of the photocurrent I_{F2} only that part of the surface where $Eg \geq 1.7$ eV participates. With further increase of the photons' energy, I_{F2} decreases. Making up the relation $\frac{I_{F2}}{I_{F1}}$ relative to energy of the photons we can graduate this spectrometer (Fig. 1c).

3. Technological method

As can be seen from the Figs. 1 and 2 the main problem of manufacturing the spectrometer is in obtaining of the film p-$Al_xGa_{1-x}As$ with a variable forbidden band on the surface of n-GaAs wafer. It is known that the solid solutions $Al_xGa_{1-x}As$, grown in general way, by means of liquid-phase epitaxy [2] are characterized by decrease of the concentration of Al (or of forbidden band) in the direction of film growth, due to big value of the segregation coefficient of Al in liquid phase Al-Ga-As.

The simplest process of obtaining of variable forbidden band on the surface of the wafer is possible if film $Al_xGa_{1-x}As$ is polished under a given angle. However, mechanical processing of the film results in the defect appearance which influences the electrophysical parameters of the film. In other work [3] it is described the method of obtaining these films without mechanical processing, by means of displacement the liquid phase on the surface of the wafer during the cooling of the molten alloy Al-Ga-As.

However, during the wafer extracting from the molten-alloy, liquid phase does not detach uniformly from the surface of created film, due to the superficial tension power, and on the surface of the film defects in form of meniscus remain. Such defects diminish the quality of the photogravure processes. The method proposed by us consists of isothermal change of the liquid phase Ga-As composition by means of Al diffusion from molten alloy Al-Ga-As [4]. Diffusion of Al in liquid phase, according to the three-phase diagram of system Al-Ga-As, results over supersaturation of As in liquid phase and growth of the film $Al_xGa_{1-x}As$. On the surface of GaAs wafer, which is situated closer to liquid phase, enriched with Al, a layer $Al_xGa_{1-x}As$ is formed with a higher concentration of Al. Due to the fact that the wafer is placed further from the source of Al, the concentration of Al in the film decreases.

This method of growth consists of the following technological operations:

- heating the reactor till the necessary temperature, which is maintained with precision of ±0.5 °C during the whole process;
- moistening of the wafer in molten alloy Ga-As;
- contact of molten alloy Ga-As with solution which contains Al till the definite concentration;
- maintaining the system till the constant temperature;
- removal of molten solution from the surface of created film.

Defining the diameter of the orifice of the contacting between the solutions (without Al and enriched by Al) the gradient E_g on the surface of the wafer is defined.

In Fig. 3 one can see the change of forbidden band of the film p-$Al_xGa_{1-x}As$ supplied with Zn on the surface of n-GaAs wafer. The film was increased at constant temperature T=800 °C, the time of increase 10 min after contacting of the substances.

The value of E_g was determined from energetic position of the maximum of the photoluminescence line in the region of short wavelengths at the temperature of 4.2 K. As can be seen from Fig. 3, there is a degree of $E_g = 0.06\ \frac{eV}{mm}$.

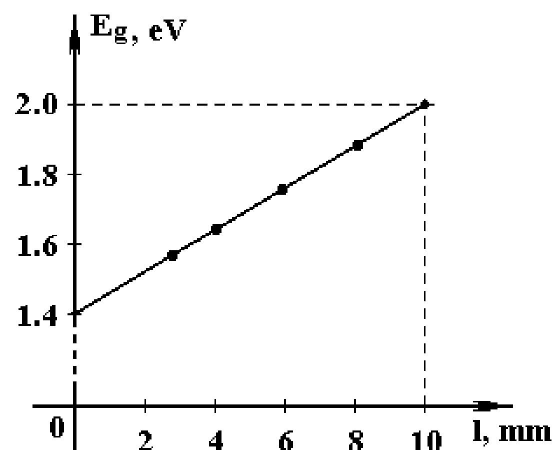

Fig. 3. The change of forbidden band along the surface of the wafer.

4. Results and discussion

n-GaAs:Te with [100] surface orientation was used as wafers for manufacturing the spectrometer. The concentration of the charge carriers in wafer was 5×10^{17} cm^{-3}. The film p-$Al_xGa_{1-x}As$ doped with Zn was synthesized by the method described above, where the change of forbidden band in the direction parallel to heterojunction is linear as it can be seen from Fig. 3. Experimental samples are slices with dimensions 10×1 mm^2. Ni contacts were precipitated by electrochemical method. The geometry of the contacts on the frontal part was formed by photolithography technique.

The base characteristic of the spectrometer which operates at a constant intensity of the source of coherent light, represent the spectral characteristic of the

shortcircuit photocurrent (Fig. 4). The sensitivity of the spectrometer determined from this graph is at the level of $1.75\ \frac{mA}{eV}$. The sensitivity depends also on the illuminated area; however it is clear that more uniformly can be illuminated the smaller surfaces.

The spectrometer which can operate at different intensities of the light is manufactured on the base of two photoreceivers:

- etalon, which indicates the same current (I_{F2}) under the changing of the wavelength;
- measurement of the current I_{F1} which depends on the wavelength (Fig. 4).

Each photoreceiver has dimensions 5×1 mm^2. This spectrometer can operate in two modes:

- measuring the currents I_{F2} and I_{F1} (contacts 5-6 and 4-6 (Fig. 2), respectively) and construct relation of the currents $\frac{I_{F2}}{I_{F1}}$ as a function of the wavelength (Fig. 2);
- measuring the voltage between the connections (4-5) which is a function of the wavelength: junctions of the photoreceivers (etalon and measured) are connected vice versa, that's why from the current I_{F2} which is bigger, and constant is taken the current I_{F1} which depends on the wavelength of the light source, and on the internal resistance of the voltmeter which can be registered (Fig. 5).
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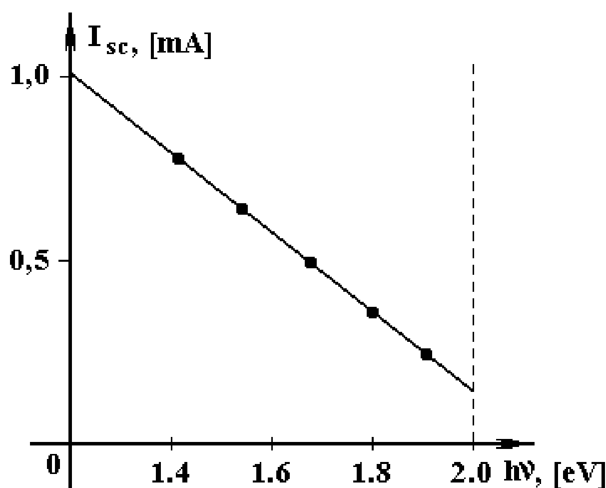

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Fig. 4. The dependence of the short-circuit current (I_{SC}) versus photons energy (wavelength).

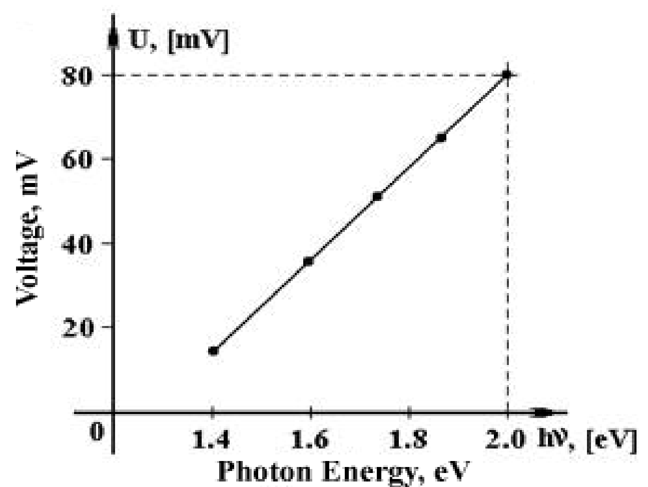

Fig. 5. The voltage between the contacts (4-5) versus Energy of photon.

As we can see from this graph the sensitivity of this spectrometer and is on the level of $165\ \frac{mV}{eV}$.

5. Conclusions

Manufacturing of these spectrometers is possible because in the heterojunctions p-$Al_xGa_{1-x}As$/n-GaAs used as photovoltaic elements, the short-circuit current has a constant value in spectral region of the sensitivity [5]. From these considerations the manufactured spectrometers have linear characteristic in the spectral region 1.4÷2.0 eV.

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