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SENSOR OF MAGNETIC FIELD BASED ON A LIGHT-EMITTING DIODE

New effects of modification of spectrum of radiation of light-emitting diode in magnetic field, which give the chance to use a LED as an optoelectronic magnetic field sensor, are discovered. Physical phenomena that appear in light-emitting diodes in a magnetic field are considered.

Amplitude-modulated by a magnetic field the optical signal can be obtained if to use a LED with narrow base, where it is possible to gain 50 % magnification of energy of an emission light in a magnetic field. If a LED with long vary-band base is being used as magneto-sensitive element, the magnetic field will shift effective region of recombination to a section with other energy gap, and the LED's radiated frequency will change. Thus, we obtain a frequency-modulated by a magnetic field optical signal, which is resistant to noises in optical channels.

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1. Introduction

Development of the modern informational technologies and communication systems requires diversification of elements of optoelectronics, development of new and improvement of existing electronic devices of generation, receiving and storage of the optical information. Though optoelectronic devices are principal components of telecommunication webs, however even more often they are used in industrial measurements, in data reduction systems, etc. Expansion of application area of optoelectronic systems gives the chance to use specified devices as sensors of certain physical quantities, in particular - of magnetic field [1, 2].

In the paper the new effects of modification of spectrum of radiation of light-emitting diode (LED) in magnetic field, which give the chance to use a LED as an optoelectronic magnetic field sensor, are investigated. Physical phenomena that appear in light-emitting diodes in a magnetic field are considered.

2. Discussion of outcomes of experiment

During the moving of charge carriers in semiconductor sample in magnetic field, transversal to the direction of movement, the Lorentz force acts on them. It deflects charge carriers to one of the sides of semiconductor, consequently their concentration there increases, and decreases on the opposite side. Therefore, in the semiconductor, that is placed in transversal magnetic field, at electric current passing because of acting Lorentz force curvature of current line happens. However, as a result of spatial separation of charges, an electric field, that will impede charges separation, arises, and as soon as force, produced by this field, becomes equal to Lorentz force, further separation of charges by magnetic field stops and current lines straighten out. Thus, in semiconductor sample placed into magnetic field the transversal Hall's voltage appears, that depends on both charge carriers' concentration and size of magnetic field. Owing to this Hall's effect different sensors of magnetic field are constructed.

If we place diode into magnetic field, then it is possible to determine three main physical phenomena:

Firstly, in consequence of magnetoresistance effect, charge carriers' mobility decreases, and, subsequently, diode conductivity strongly decreases. Meanwhile the magnetoresistance effect will be increasing in tens and hundreds times due to the change of injection of charge carriers.

Secondly, curvature of current lines increases concentration of charge carriers on one side and decreases on another side. Since effective lifetime of carriers in thin plat is determined by surface recombination, then redistribution of carriers leads to change of role of surface recombination and effective lifetime of carriers. Role of recombination on the side, to which the charge carriers deflect, increases, and recombination on another side almost doesn't play any role.

Thirdly, since concentrations of electrons and holes nearby p-n junction are practically identical, the Hall's electric field will be absent. That's why current lines will always be curved. Elongation of current line leads to reduction of penetration depth of unbalanced carriers and extra reduction of modulation of base region conductivity by injected carriers.

Such phenomena were also observed in magnetotransistors. It is obvious that in transistor, placed into magnetic field, increasing of average path, which charge carriers pass in base region, happens as well. That leads to increase of quantity of charge carriers, whic h will recombine in transistor's base region. Current transmission coefficient increases.

First two phenomena are well studied. We researched magnetic field impact on characteristics of semiconductor radiating heterostructures, taking into account

As a sensing element of optoelectronic's sensor of some physical quantity it is possible to use either a LED, or a light guide, or a photodetector. The operating principle of the majority optoelectronic sensors is based on a changing of absorption coefficient at light transiting through medium or on a modification of a transmission factor of light during the reflection from interfaces of mediums.

Magneto-sensitive properties of light-emitting diodes we tested in papers [3]. We have obtained, that intensity and spectrum of radiation of a light-emitting diodes varies in a crosswise magnetic field.

The emission intensity of light-emitting diodes in a magnetic field can be either increased up to 50 % or decreased depending on diode structure.

Only in light-emitting diodes with vary-band structure a changing of spectrum of radiation is detected. For these light-emitting diodes the energy of a maximum of a spectrum of radiation in a magnetic field with an induction 0.4 Tesla shifts on 10-15 % relative to the position in lack of a magnetic field.

We experimentally researched the AlAsGa triple-compound light-emitting diodes doped by silicon with a heterojunction as an injecting contact. Samples have been made on substrates of gallium arsenide on which the epitaxial method spliced two stratums: light-emitting p-layer from $Ga_{1-x}Al_xAs$<Ge> and electrons-injecting n-layer from $Ga_{1-y}Al_yAs$<Te>, where x=0,5…0,6 and y=0,22…0,25. The radiating layer had a thickness 4,9 μm, and injecting layer - 11,2 μm. Traversal sizes of samples were 500×500 μm. The working current of light-emitting diode samples had value 10 mA. We applied a magnetic field with an induction up to 0.4 Tesla across to a direction of motion of the injected charge carriers in light-emitting diodes.

Two types of samples with various structure of base were investigated. For the first type of samples, the semiconductor had an equal energy gap on all volume of base. Base length *W* was less, than a diffusion length *L* of injected charge carriers. In this case the injected charge carriers recombine with radiation in whole bulk of base. But a part of charge carriers near the lateral surface of base, through which there is a radiation, recombine without radiation through the surface states.

The transverse magnetic field bends a mechanical trajectory of the injected charge carriers, deflecting them from a surface. The angle φ on which the injected charge carriers are being deviated from an electric field direction, is being defined as

$$\mathrm{tg}\varphi = \mu B, \qquad (1)$$

where μ – mobility of injected charge carriers; B – induction of external magnetic field.

Thus in an optimum case the linear deviation of the injected charge carriers from an electric field direction

$$D = L\cos\varphi = L\cos[\mathrm{arctg}(\mu B)]\ , \qquad (2)$$

as only on this area of p-region equal to diffusion length L there is light generation.

At big values of D only the passive part of p-region is being increased, that leads to decrease of efficiency of LED. Recombination rate of the injected charge carriers near the current-carrying contact of p-region is essential more than in its volume. Therefore near the contact there is no accumulation of charge carriers.

At a forward bias of the light-emitting diode there is an injection of electrons from n-region to a p-region where they radiative recombine with holes. The radiation output is carried out through n-region perpendicular to plane of p-n- junction. In a traversal magnetic field the trajectory of the injected charge carriers is bent, therefore their path through radiating area of p-region is increased, that is equivalent to increasing of effective length of radiating area. Thus, the amount of recombined electrons in radiating field is increased.

The part of a surface nonradiative recom-bination decreases, that leads to growing of effective diffusion length L of injected carriers and to increasing of intensity of radiation of LED. In this case for light-emitting diodes with small length W of base the radiation spectrum does not vary.

The other type of light-emitting diodes had variband base with decreasing of an energy gap from n – region to p – region, and length of base W turned out more than diffusion length L. Therefore the injected charge carriers recombine in a narrow section of base with a certain energy gap (see fig. 1).

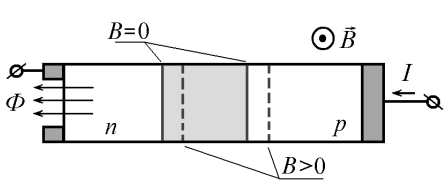

Fig. 1. Structure of magneto-sensitive LED with variband base in a magnetic field

Effect of the surface recombination was insignificant in contrast to light-emitting diodes with small length of base. At turning on of a magnetic field we have obtained some decreasing of radiant intensity of these light-emitting diodes. Obviously, because of the elongated shape of base, the magnetic field presses the injected charge carriers to one of surfaces of base, where they nonradiatively recombine.

In light-emitting diodes with variband base in a transversal magnetic field we observed phenomenon of displacement of a maximum of a spectrum of radiation relative to its position in lack of a magnetic field (fig. 2). It can be explained that the region of a recombination of charge carriers is being translated along base (on fig. 1 is marked out by a dot line B>0), therefore charge carriers will radiatively recombine in the region of base with other energy gap E.

As diffusion length L in a magnetic field is being decreased, we expected that the spectrum of radiation of a LED will become narrower. However experimental measurements have shown that the half-width of a spectrum of radiation in a magnetic field does not vary.

In some samples at turning on of a magnetic field we have obtained displacement of a spectrum of radiation in other side. As the half-width of a spectrum of radiation of a LED in a magnetic field does not vary, therefore the displacement to one or another side of electron-hole plasma in a magnetic field we explain by a change of sign of bipolar mobility. This phenomenon is observed in p-n-junctions with high-resistance base [4].

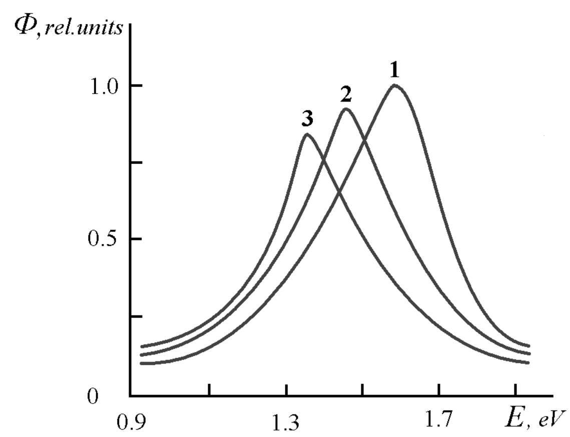

Fig. 2. Spectrums of an electroluminescence of a LED with variband base without a magnetic field (1) and at affecting of a magnetic field (2 – 0.37 Tesla, 3 – 0.4 Tesla)

On fig. 2 the dependence from magnetic induction *B* of relative photon energy in a maximum of radiation *E* and relative intensity of radiation *Φ* for a LED with variband base are presented. We can see that the effect of displacement of frequency of photon energy in a maximum of a spectrum of radiation is more essential, than decreasing of intensity of radiation of a LED at magnetic field turning on.

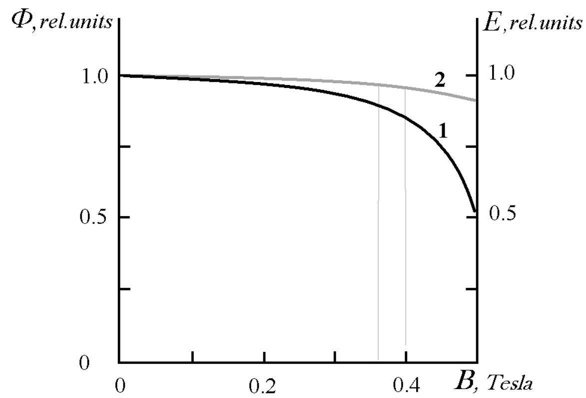

Fig. 3 Dependence of photon energy in a maximum of radiation (1) and intensity of radiation (2) of a LED with variband base from magnetic induction

As seen on fig. 2 and 3, key parameter depending on a magnetic field can be either light intensity, or frequency of radiation. Advantage of using of light intensity as an informative parameter is a simplicity of registration of its variations by a usual photodetector. However, in this case certain difficulty arises if it is necessary to consider absorption of light during its transmission through a light guide, especially at switching of optical channels.

If one uses the frequency of radiation as informative parameter, then necessity of consideration of properties of a LED and optical channels disappears, but transformation of a variation of frequency of radiation to a variation of amplitude of an output current of a photodetector is more difficult, than light intensity transformation.

3 Conclusion

We have considered two possibilities of making optoelectronic magnetic field detectors.

At first we used a usual LED with narrow base. The transversal magnetic field deflects the injected charge carriers from a base surface where they recombine without radiation through the superficial states. In volume of base the charge carriers recombine with radiation therefore radiation intensity of a LED is being increased. If one correctly uses features of structure of such light-emitting diodes, it is possible to obtain 50 % magnification of energy of radiation in a magnetic field. For photoelectric registration of a variation of radiant intensity it is possible to use usual the photodetector. For production of such magneto-optical devices a special manufacturing methods is not required, therefore they are low-price. However at using of such devices in optical information processing systems it is necessary to consider absorption in transmission channels.

For elimination of influence of absorption in optical channels on the level of useful signal it is possible to use more complex structure of the detector in which magnetic field changes frequency of radiation. As a magneto-sensitive device we suggest a LED with long base along which an energy gap of the semiconductor should be various. At such structure the radiation recombination of charge carriers happens in narrow region of base with a certain energy gap. The magnetic field shifts the effective field of a recombination along the base on a section with other energy gap, as a result the frequency of radiation will be changed. Thus, we obtain a frequency-modulated by a magnetic field optical signal, which resistant to noise in optical channels. However, for monitoring of modifications of frequency the special photodetector or the multiplexer in this case is required.

Such detectors of magnetic field are expedient for using in systems with optical processing methods of the information.

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Summary

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Keywords: magneto-optical sensor, LED, vary-band structure, magnetic field, frequency-modulated light.

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ДАТЧИК МАГНІТНОГО ПОЛЯ НА ОСНОВІ СВІТЛОВИПРОМІНЮЮЧОГО ДІОДА

Резюме

Виявлені нові ефекти зміни спектру випромінювання світлодіода в магнітному полі, які дають можливість використати світлодіод, як оптоелектронний датчик магнітного поля. Розглядаються фізичні явища, які відбуваються у світлодіодах під дією магнітного поля. У роботі досліджені нові фізичні механізми для створення оптоелектронного магнитодатчика і процеси, що протікають у світлодіодах під дією магнітного поля. Амплітудно-модульований магнітним полем оптичний сигнал можна отримати, якщо використати звичайний світлодіод з вузькою базою, де можна отримати 50% збільшення енергії випромінювання в магнітному полі. Якщо в якості магниточутливого елементу використати світлодіод з варізонною довгою базою, то магнітне поле зрушуватиме ефективну область рекомбінації на ділянку з іншою шириною забороненої зони, і частота випромінювання світлодіода зміниться. Таким чином, ми отримуємо частотно-модульований магнітним полем оптичний сигнал стійкий до перешкод в оптичних каналах. Такі датчики доцільно використовувати в системах з оптичними методами обробки інформації.

Ключові слова: магнітооптичний сенсор, світлодіод, варізонна структура, магнітне поле, частотно-модульоване світло.

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ДАТЧИК МАГНИТНОГО ПОЛЯ НА ОСНОВЕ СВЕТОИЗЛУЧАЮЩЕГО ДИОДА

Резюме

Обнаружены новые эффекты изменения спектра излучения светодиода в магнитном поле, которые дают возможность использовать светодиод, как оптоэлектронный датчик магнитного поля. Рассматриваются физические явления, которые происходят в светодиодах под действием магнитного поля. В работе исследованы новые физические механизмы для создания оптоэлектронного магнитодатчика и процессы, протекающие в светодиодах под действием магнитного поля. Амплитудно-модулированный магнитным полем оптический сигнал можно получить, если использовать обычный светодиод с узкой базой, где можно получить 50% увеличение энергии излучения в магнитном поле. Если в качестве магниточувствительного элемента использовать светодиод с варизонной длинной базой, то магнитное поле будет сдвигать эффективную область рекомбинации на участок с другой шириной запрещенной зоны, и частота излучения светодиода изменится. Таким образом, мы получаем частотно модулированный магнитным полем оптический сигнал устойчивый к помехам в оптических каналах. Такие датчики целесообразно использовать в системах с оптическими методами обработки информации.

Ключевые слова: магнитооптический сенсор, светодиод, варизонная структура, магнитное