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ARAŞTIRMA MAKALESİ/**RESEARCH ARTICLE**

OPTOELECTRONICS LED - PHOTODIODE PAIRS FOR MOISTURE AND GAS SENSORS IN THE SPECTRAL RANGE 1.8 - 4.8 μm

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ABSTRACT

Optoelectronic light-emitting diode - photodiode pairs based on multi component GaInAsSb and InAsSbP solid solutions have been researched and developed. Such pairs are able to detect absorption bands of water and gases belonging to the spectral range 1.8-4.8 μm (H_2O, CO, CO_2, H_2S, N_2O, CH_4 etc). Two - wavelength models of a new type optical moisture meter and a methane meter was fabricated using the developed LED's and higheffi- ciency photodiodes.

Key words: Optoelectronic light-emitting diode - photodiode pairs, optical moisture meter, methane meter.

1.8 - 4.8 mm SPEKTRAL BÖLGESİNDE NEM VE GAZ SENSÖRLERİ İÇİN OPTOELEKTRONİK LED-FOTODİYOT ÇİFTLERİ

ÖZ

GaInAsSb ve InAsSbP çok bileşenli katı çözeltiler üzerindeki optoelektronik LED - fotodiyod çiftleri araştırıldı ve geliştirildi. Bu tür çiftler, 1,8-4,8 μm spektral aralığına (H_2O, CO, CO_2, H_2S, N_2O, CH_4 vb.) ait gazlar ve suya ait absorpsiyon bandlarının gözlenmesini mümkün kılmaktadır. Yeni tip bir optik nem ölçer ve metan ölçerin iki dalga boyu modelleri geliştirilen LED ve yüksek verimli fotodiyotlar kullanılarak üretildi.

Anahtar Kelimeler: Optoeletronik LED - fotodiyot çiftleri, optik nem ölçer, metan ölçer.

1. INTRODUCTION

In recent years a great attention is paid to research and develop sensors for purposes of ecology and environmental control, in particularly, optical sensors. The important components of the devices are sources and photo detectors operating in the mid - IR spectral range 1.8 - 5 mm to which belong basic absorption bands of water and many industrial gases (See Table 1). However up-to-date water and gas sensors based on optical principle have a number of disadvantages. Such sensors have a bulb as an amission source, mechanical disk modulator with filters fixed on it to seperate the measuring and reference operating wavelength [Riken-Keiki CO.LTD, Booklet, 1985]. As a detector in these devices Ir-photo resistor is employed in the most cases, which is not very fast and then it needs often thermoelectric cooling. Besides such model of sensor is bulky, sensitive to electromagnetic interference and so on. At the same time, using semiconductor optoelectronic pairs LED - PD permit to create a qualitative new generation of optoelectronic sensors for the analysis of various liquids and gas mixture components

Table 1. Absorption bands of some gases and liquids in the spectral range 1.6 - 4.8 mm.

1.6 – 4.8 μm.

Substance		Maximum of absorption band, μm			
Water	H_2O	1.94	2.67		3.1
Methane	CH_2	1.65	2.32		3.32
Acetone	CH_3COCH_3		3.4		4.6
Ammonia	NH_3		2.94		
Nitrous oxide	N_2O		2.9	3.9	4.5
Carbon dioxide	CO_2		2.65		4.27
Carbon monoxide	CO		2.34		4.7
Sulfur dioxide	SO_2				4.1
Hydrogen fluoride	HF	1.29	2.45	2.58	

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We report the results of research and development of IR - light-emitting diodes and photodiodes which can be apprteciated for creating spectral-matched optoelectronic pairs of 1.8-4.8 μm spectral range.

2. OPTOELECTRONIC LED-PD PAIRS FOR THE 1.8-2.5 μm SPECTRAL RANGE

LED's and photodiodes for the 1.8-2.5 μm spectral range have been fabricated by LPE technology and based on GaInAsSb multicomponent alloys lattice matched to GaSb substrate. Changing the composition of the solid solution ($0 \leq x \leq 0.24$) the band gap of $Ga_{1-x}In_xAs_ySb_{1-y}$ can be chosen in the range of 0.8-05 eV which corresponds to the wavelength region of 1.8-2.5 μm [DeWinter J.C. and et.al., 1985].

Fig. 1 shows the emission spectra of some of GaInAsSb / GaSb LED's at room temperature. TheLED's have a high quantum efficiency (1-4 %) and can be used both in pulse and cw regime [Andaspaeva A.and et.al., 1988]. The output optical power is P=20-50 mW at operating currents 0.3-3 A, and P= 0.5-1 mW (I = 10-20 mA) in cw operating.

In most of applications these LED's are used with a combination with small parabolic reflector to narrow optical beam to 0°8′ ÷ 0°10′. The main performances of GaInAsSb LED's are presented in Table-2.

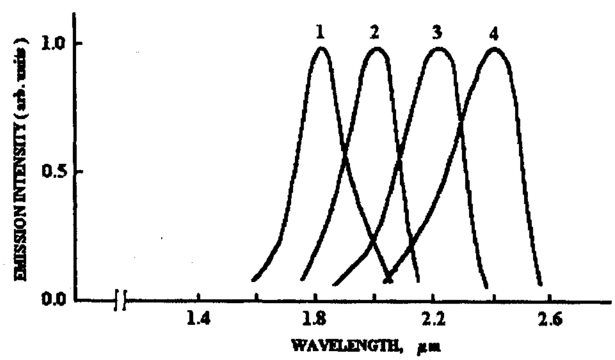


Figure 1. Spectra of emission intensity of GaInAsSb light-emit ting diodes at room temperature (See Table 2).

Table 2: Performances of GaInAsSb LED's (See Fig. 1)

	Maximum of emission band, μm	half-width of emission band, μm	external quantum yield, %	decay time of emission pulse, ns
1.	1.82	0.18	1.7	50
2.	2.01	0.15	4.3	20
3.	2.18	0.21	5.0	13
4.	2.37	0.27	.7	8

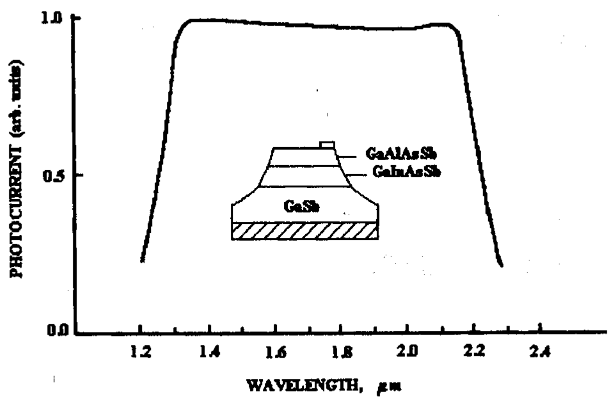


Figure2. Spectral response of GaInAsSb/GaInAsSb photodiode at room temperature.

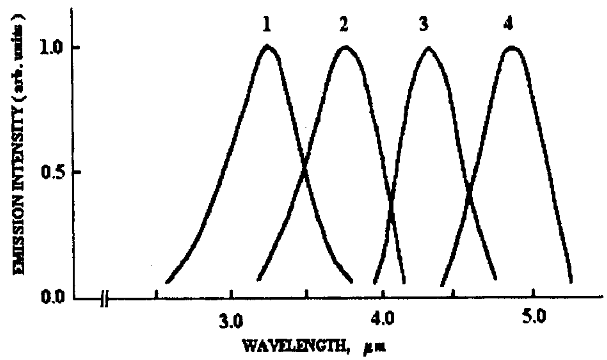


Figure3. Spectra of emission intensity of GaInAsSb/GaInAsSb light-emitting diodes.

To detect the emission of the LED's we fabricated hetero-photodiodes with GaInAsSb as active layer and GaAlAsSb as widebandgap "window" layer [Andreev I.A. and et.al., 1989]. Sensitivity of GaInAsSb / GaAlAsSb photodiodes is about R = 1 A/Wt, and low dark current less than 0.1 μA was obtained at V = 0.5-1 V. The spectral characteristics of typical diode is shown in Fig. 2. The GaInAsSb / GaAlAsSb photodiode has a wide range of sensitivity from 1.3 to 2.4 μm. It allows to use one photodiode to detect emitting photon energy of several LED's with different maximum wavelength of emission. Changing the alloy composition we can move spectral characteristic of LED's and PD's in desirable region of spectrum (See Fig.1). It will be noticed that an important advantage of the developed LED's and PD's have similar temperature dependence of the spectral characteristics because LED's and PD's are made from the same material. The temperature coefficient of band gap dependence is $\Delta E_g/\Delta T = 3.5 \times 10^{-4}$ eV / K. This permits to use spectral-matched optoelectronic LED-PD pair in the wide temperature range from 4.2 K to 320 K.

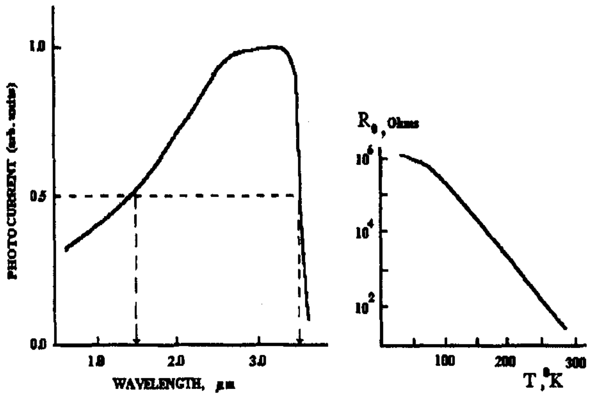


Figure 4. Spectral response of GaInAsSb/InAs photodiode at room temperature (a) and temperature dependence of the differential resistivity $R_0 = \Delta V/\Delta I$.

3. OPTOELECTRONIC LED-PHOTODIODE PAIRS FOR THE 3.0-4.8 μm SPECTRAL RANGE

This spectral range can be covered by using of InAsSbP and InGaAsSb solid solutions lattice matched to InAs and GaSb [Baranov A.I. and et.al., 1990, Andreev I.A. and et.al., 1990]. Light-emitting diodes and photodiodes were grown by LPE [Baranov A.I. and et.al., 1990]. The spectral characteristics of optical power of some In AsSbP/InAs LED's are presented in Fig.3. The efficiency of these longwave-length LED's is less than of GaInAsSb LED's and about 0.01-0.03 %. Operating interval is 3,5 - 4,7 μm, optical power under pulse operation reaches P = 3-10 μW, and in cw operation it was is 15-200 μW. To registrate an emission of these LED's we have developed uncooled photodiode based on InAsSbP / InAs heterostructure (spectral response is in the 1.6-3.6 mm range, R= 1.2 A/Wt at λ=3 μm) with the impedance R=(0.6-1) kOhm at room temperature (See Fig. 4).

The longwavelength photodiodes operating from 1.6 to 4.8 μm have been fabricated on the base of narrow-band gap InGaAsSb alloy (E_g=0.27 eV at T=300 K) [Afrailov M.A. and et.al., 1990]. The spectral response of typical photodiodes InGaAsSb / GaSb is shown in Fig.5. Some absorption bands of H_2O λ = 1.94 μm; 2.7 μm, CO_2 λ =4.27 μm and CO λ = 4.7 μm are indicated in this figure also.

LED-photodiode pairs are also very promising to analyze other gases such as H_2S (λ = 3.9 μm), methane (λ = 3.32 μm) etc. It is interesting to note that there are some weaker absorption lines (overtones) at λ = 2.32 mm - 2.34 μm, 1.65 μm for such gases as methane, propane etc.. It allows to use the optoelectronic pairs based on GaInAsSb for registration these gases. Taking into account the better efficiency of the LED and PD's of the shorter wavelength spectral range we can expect the higher performance of the registration systems using these devices.

We used some optoelectronic LED - PD pairs based on GaInAsSb to develop a new type small-dimension dual-wavelength optical moisture meter. To measure moisture content in paper we chose LED's with maximum emission wavelength λ_{meas} = 1.94 μm which is selectively absorbed by water in paper and λ_{ref} = 2.2 μm which can not been absorbed in paper. As a photodiode was chosen GaInAsSb / GaAlAsSb PD with a broad spectral characteristic. The output signal calibrated in moisture percentage is indicated by digital display. Optical moisture meter allows to measure moisture content in paper of 0.05-2 mm thick with accuracy less than 1% in the range of 0-35 % [Baranov A.N. and et.al., 1989].

In the frame of this work we made also a model of new type optical methane meter using operating wavelength λ = 2.32 - 2.34 μm with LED-PD pair based on GaInAsSb alloy.

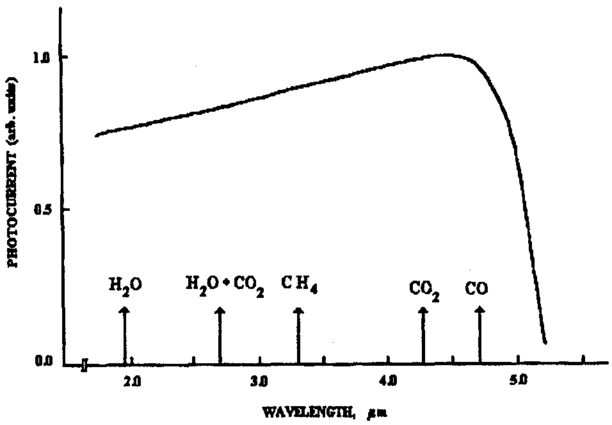


Figure 5. Spectral response of GaInAsSb/GaSb photodiode at room temperature.

The optical moisture and gas sensors based on the spectral - matched semiconductor LED - PD pairs have the following advantages over other known ones:

- the possibility of their combination with fiber optics which allows to use sensors in remote measurements, particularly, in aggressive media, influenced by higher and lower temperatures, etc.
- the high wavelength selectivity can be achieved by the application laser diodes [Baranov A.N. and et.al., 1988] as a source instead LED's and high reproductively of measruements,
- small-dimensions and weight, the autonomous of power-supply,
- high-speed operation (less than 10^{-8} s) permits to automate some technological processes with the use of computer, etc.

4. CONCLUSION

In conclusion, the optoelectronic LED- PD pairs based on multi component GaInAsSb and InAsSbP alloys have been researched and develop for the wide spectral range 1.8 - 4.8 μm. These pairs are very promising for fabricating new type optical sensors for ecology, environmental monitoring, Ir - spectroscopy, automatic control of technological processes, and some other tasks.

REFERENCES

Riken-Keiki Co.Ltd. Booklet, (1985).

DeWinter J.C., Pollack M.A. and et.al., (1985). *J. Electr. Mater.*, 4, 6, 729-747.

Andaspaeva A., Baranov A.N. and et.al., (1988). *Sov. Tech. Phys. Lett.*, .14, .9, 845-849.

Andreev I.A., Afrailov M.A., Baranov A.I., Mikhailova M.P. and et.al., (1989). *Sov. Tech. Phys. Lett.* 15, 7, 715-719.

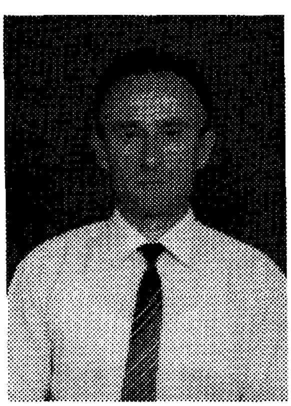
Baranov A.I., Imenkov A.I. and et. al., (1990). *Sov.Tech.Phys. Lett.*, 16, 16, 567-569.

Andeev I.A., Afrailov M.A., Baranov A.N., Mikhailova M.P. and et, al., (1990). *Sov. Tech. Phys.Lett.* 16, 4, 27-32.

Afrailov M.A., Dmitriev A.P., Baranov A.N., Mikhailova M.P. and et.al., (1990). *Sov. Phys. Semicond.* 24, 8., 876-882.

Baranov A.N., Yakovlev Yu.P., Imenkov A.N., Mikhailova M.P. and et.al., (1989). *Bumazhnaya Promyshlennost*, 9, 20-22.

Baranov A.N., Danilova T.N., Dzhurtanov B.E. and et.al., (1988). *Sov. Tech. Phys. Lett* 14, 9, 727-729.



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