Nondispersive Analyzers Based on MID IR LEDs for Fiber Optic Coal Mine Net

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SUMMARY

This report presents data on new IR LEDs based on III-V solid solutions emitting in the 2.5-4.7 μm region at room temperature. Two monitors are considered employing these LEDs as a light source: with spherical mirror and multipass optical system.

INTRODUCTION

Infrared absorption measurements is a useful tool for gas detection procedure due to reliability of data, based on selectivity of absorption, zero-control and linearity of scale. These measurements are usually carried out in the 3-5 μm spectral range, where water vapor absorption can be neglected.

Conventional filament lamps are most commonly used light sources in optical density measurements. Recent researches on uncooled LEDs with λ=3-5 μm based on A^3B^5 narrow band alloys showed, however, considerable advantages over filament lamps[1,2]. The remarkable features are long lifetime, good optical efficiency, possibility of using electronic modulation and small size. The latter is very essential when using LED in devices containing dispersive optical elements, for example, in grating spectrophotometers[3,4].

The intensity of light reaching the detector is related to the gas concentration by Beer's law:

$$I=I_0 \exp(-\alpha \cdot c \cdot b)$$

where I/I_0 is the transmittance of the gas, α is the absorption coefficient for the gas, b is the optical pathlength through the gas and c is the gas concentration. In practice pressure, temperature variations and absorption of other gases should be taken into account in gas detection unit design.

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A.F.Ioffe Physico-Technical Institute has developed a number of infrared LEDs the 2.5-4.7 μm region based on III-V heterostructures having narrow optical bandwidth (0.3-0.5 μm) which can replace the thermal source and chopper assembly of the conventional monitors, yielding a reliable , low power consumption and portable instrument.This report presents data on nondispersive analyzers with key part made from LEDs having maximum at 3.3 μm (C_nH_m absorption band), 4.3 μm (CO_2 absorption band), 4.7 μm (CO absorption band) and PbSe photoresistor.

EXPERIMENT

To obtain high crystalline quality of p-n $In_{1-x}Ga_xAs$ structures for 2.6-3.8 μm LEDs, LPE growth at elevated temperatures (600-680° C) has been used. During the growth most of the misfit was accommodated through relaxation processes involving substrate dissolution and recrystallisation of InGaAs. $In_{1-x}Ga_xAs$ layers had nearly homogeneous composition in the growth direction for thicknesses up to 150 μm.

P-n junction was formed during the growth by doping the melt with Mn. Electron concentration in n-InGaAs was ~ 10^{17} cm^{-3}, hole concentration in p-type layers was in the 10^{16}-10^{18} cm^{-3} range depending on doping procedure. Fig. 1 presents typical emission spectra of LEDs and spectral response of PbSe detector used for methane detection .

P-n mesas 0.5x0.5 mm^2 and PbSe having 2.6x2.6 mm^2 active area size were mounted on thermoelectric cooler; LEDs fed with 1-5 A pulses were as fast as ~10 ns, having efficiency not less than 0.03% and maximum

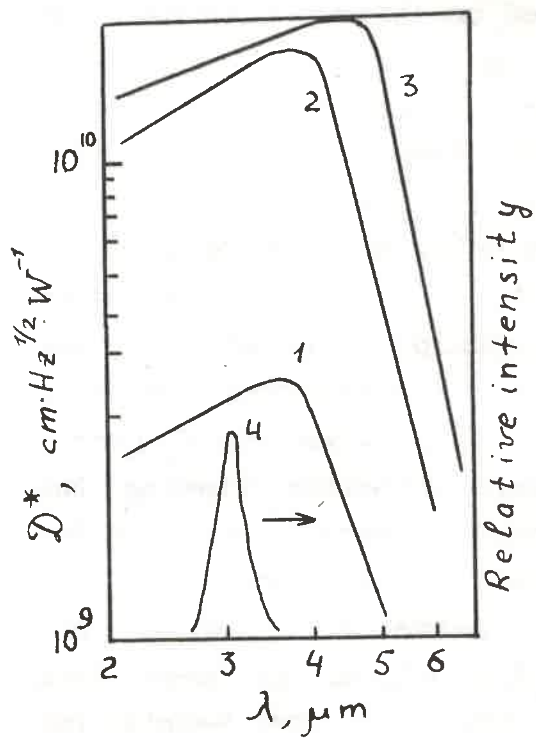

Fig.1 Spectral response of photo detector(1,2,3) and LED emission spectra(4). Temperature,K: 1,4 - 295, 2 - 195, 3 - 77.

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emitted power of 4 mW. Photodetector had 3 -5 μs response time and $D^{*}_{\lambda max}=2\cdot10^{9}$ cm $Hz^{1/2}W^{-1}$ Typical current pulse duration was 30 μs with I = 2 A amplitude.

The emission light was focused onto the photodetector by Al-covered concave mirror with R = 70 mm and D = 50 mm. Mirror was isolated from the gas by quartz window optical path being 100 mm. To compensate for LED intensity changes caused by power variations and for signal fluctuations due to changes in detector bias,reference detector mounted on thermocooler near LED has been employed. Thermocooler, LED and detectors were isolated from a gas by sapphire window; typical operating temperature being 5 $\pm$ 0.1 ^{o}C .

Fig.2 illustrates relationship between gas monitor signal and methane concentration .The signal from a reference detector viewing the LED output directly, was divided in these experiments into the sample detector signal. The resulting signal as seen from Fig.2 deviates from Beer's law because the intensity transmitted through the gas is the sum of strongly absorbed wavelengths and neighbouring weakly absorbed wavelengths. Signal-to-noise ratio (SNR) at zero methane concentration was ≈ 400 with averaging of 400 pulses.

The monitor is planned to be used as methane sensor of coal mine net. Signal processing will be done by a unit which contains a microprocessor , A/D convertor, an interface to communicate with a PC using a serial port and optical module to trasnfer electrical code into optical signal λ=1.3 μm for fiber optical coal mine link.The measured concentrations will be visualized in a computer screen on the surface.Sensor power consumption estimated to be less than 7 W.

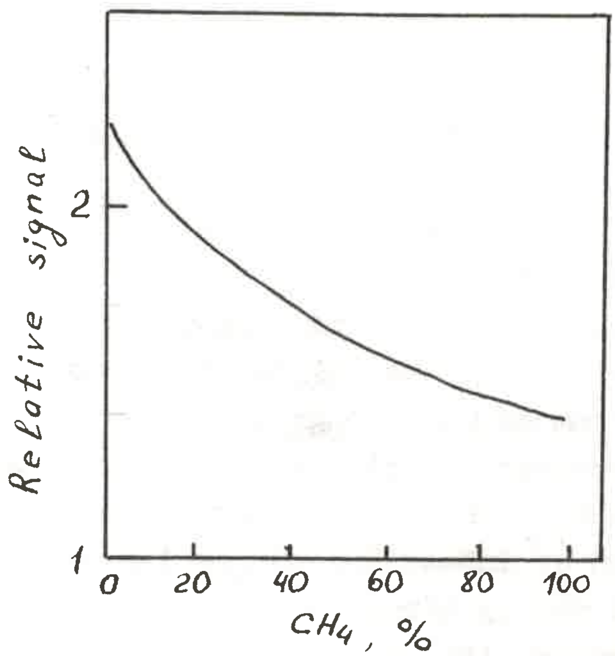

Fig.2 Concentration dependence of monitor signal at t=20^{o}C

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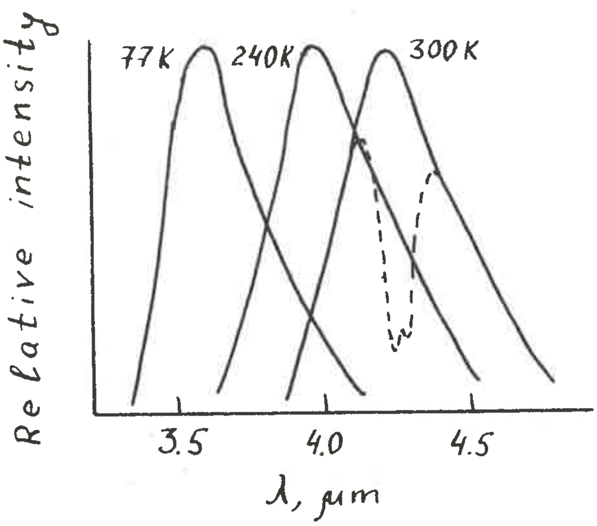

Fig.3 Electroluminescence spectra of LED with $InAs_{0.94}Sb_{0.06}$ active layer at different temperatures. Dotted line - CO_2 absorption.

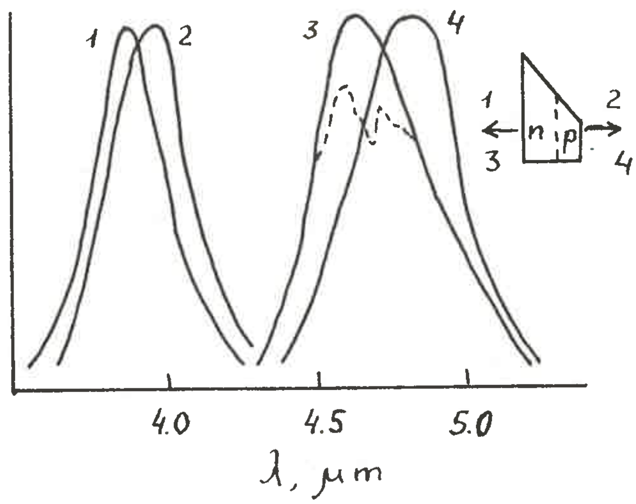

Fig.4 Electroluminescence spectra of LED with $InAs_{0.9}Sb_{0.1}$ active layer at 77 K(1,2) and 300 K(3,4). Dotted line - absorption of CO.

One of the promising material for semiconductor optoelectronics in the spectral range 4.3 - - 4.7 μm is the $InAs_{1-x-y}Sb_xP_y$ solid solution system[1,2].

The growth conditions were chosen to minimize the difference between the lattice constants of the film and the substrate at the heterojunction at 680-720° C and to arrange a smooth increase in the lattice constant along the growth direction. P-n junction was formed by zinc diffusion during the growth of graded band-gap p-InAs SbP layer onto undoped n-InAsSbP film. In some cases InAs substrate was removed by chemical etching. Fig. 3 shows EL spectra of InAsSbP LEDs at 77(a), 240(b) and 300 K measured with a monochromator purged with pure N_2(solid line) or the light passing 50 cm in atmosphere(dotted line). LEDs enriched with antimony have peak positions around 4.7 μm, which is the maximum of carbon oxide absorption (Fig.4). In the latter case two types of LEDs were investigated:1)p-type layer contacts holder and photons propagate through broad-gap n-InAs SbP; 2)n-type layer contacts holder with light propagating through narrow gap p-InAsSbP.LED of type 1 was 3-5 times "brighter" than type 2. As shown in fig.3,4 temperature shift of EL spectra is ~55 meV,which nearly

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equals $\Delta h\nu$ obtained for InAs p-n junctions and ΔE_g of InAs for ΔT= =300-77 K [5].

The basic idea in optical design has been to use multipass optical cell described in [6]. The cell contained 5 convex mirrors all having radius of 500 mm. It was posiible to obtain optical path as long as 16 m at a distance between opposite mirrors of 500 mm. In our experiments we used the simple image configuration providing optical path of 2m length.Light from uncooled LED with λ_{max}=4.7 µm passed through the LiF lens with f=8 mm,D=9 mm and input slit.The output light was focused by another LiF lens onto PbSe detector with 2.6 x 2.6 mm^2 sensitive area mounted on 2 stage thermoelectric cooler.SNR of the monitor at current pulses of 5A(τ=30 µs,f=500 Hz)and averaging of 500 pulses was one decade. Detector temperature was -40°C.

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