STIMULATED EMISSION FROM INAS (GaAs) MONOLAYERS STACKS EMBEDDED IN $Al_{0.33}Ga_{0.67}As$ ACTIVE REGION

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Summary Our study is focused on the optical and electronic properties of InAs (GaAs) monolayers embedded in $Al_{0.33}Ga_{0.67}As$ barrier layers investigated by temperature dependencies of electroluminescence spectra. The experimental results obtained from low temperature electroluminescence measurements of InAs (GaAs) / $Al_{0.33}Ga_{0.67}As$ revealed the excellent emission spectra in the visible range 630-690 nm. The stimulated emission from these structures across their cleavage planes has been observed at low temperatures what is highly interesting for potential device applications.

Abstrakt Štúdia je zameraná na optické a elektronické vlastnosti InAs (GaAs) monovrstiev v kombinácii s $Al_{0.33}Ga_{0.67}As$ bariérovými vrstvami. Tieto štruktúry boli vyšetrované meraním elektroluminiscenčných spektier v závislosti od teploty. Experimentálne výsledky získané z elektroluminiscenčných meraní pri nízkych teplotách na štruktúrach InAs (GaAs) / $Al_{0.33}Ga_{0.67}As$ odhalili vynikajúce emisné spektrum v rozsahu viditeľného žiarenia 630-690 nm. Pri nízkych teplotách bola zo štiepanej hrany týchto štruktúr pozorovaná stimulovaná emisia, čo môže byť veľmi zaujímavé pre potenciálne aplikácie v oblasti prvkov.

1. INTRODUCTION

Considerable attention has been recently devoted to monolayer (ML) and submonolayer InAs/GaAs heterostructures. The efficient emission from single monolayers of InAs in GaAs has been observed in superlattices and multiple quantum well structures grown by metal-organic vapor-phase epitaxy (MOVPE) [1,2,3]. Such structures show very intense photoluminescence [1] and electroluminescence properties with extremely high quantum efficiencies, which make them attractive for applications in laser devices [2]. These structures emit in the near-infrared, i.e., slightly below energy band gap of GaAs [3].

When replacing the GaAs barrier layer by $Al_xGa_{1-x}As$ material the emission of excitons bound to the InAs monolayers shifts to higher photon energies with increasing of Al mole fraction [4] (cf. Fig. 1).

In this paper we present electroluminescence (EL) data to study under these conditions the emission properties of spatially well-separated InAs and GaAs monolayers embedded in $Al_xGa_{1-x}As$ (x=0.33). We show that these InAs (GaAs) / $Al_{0.33}Ga_{0.67}As$ structures might be a real perspective for light emitting devices in the red and orange range of spectrum.

Our investigations focused on EL measurements of InAs (GaAs) / $Al_{0.33}Ga_{0.67}As$ structures grown by MOVPE as a function of temperature. Electronic properties of the structures were investigated by measuring the current-voltage characteristics. To get information on the layer perfection high-resolution transmission electron microscopy investigations have been performed.

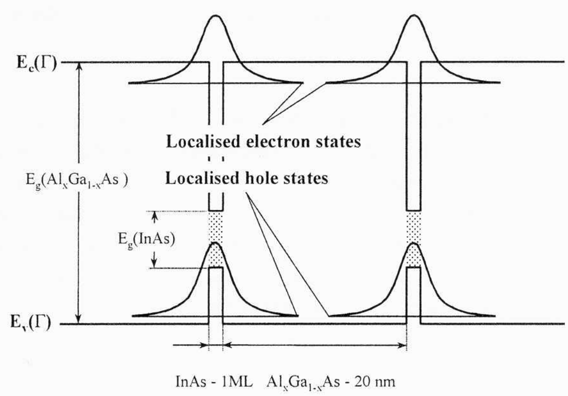

Fig. 1. The localized electron and hole states in InAs / $Al_xGa_{1-x}As$ structures.

2. EXPERIMENTAL

The sample growth has been carried out by low-pressure MOVPE in a commercial AIXTRON AIX-200 reactor equipped with a rotating substrate holder and standard precursors TMAl, TMGa, TMIn, DetZn, AsH_3 and Si_2H_6 with vapor pressure values p(tot)=50mbar and f(tot)=7slm on (001) oriented n-type GaAs substrates. The substrate temperature during MOVPE process was kept at 700°C to achieve perfect abrupt interfaces.

The structures consist of a 450 nm n-doped GaAs buffer layer followed by an 1300 nm n-doped $Al_{0.45}Ga_{0.55}As$ confinement layer, the active region and 550 nm p-doped $Al_{0.45}Ga_{0.55}As$ (cf. Fig. 2). The structure was covered by 10 nm GaAs layer. Three sets of samples with the different active region arrangement were prepared (Table I). The active region contains 10 spatially well-separated InAs (GaAs) monolayers buried in thick (20 nm) $Al_{0.33}Ga_{0.67}As$ barriers. For the comparing of optical properties the base structure with bulk $Al_{0.33}Ga_{0.67}As$ active region (without monolayers stacks) has been prepared.

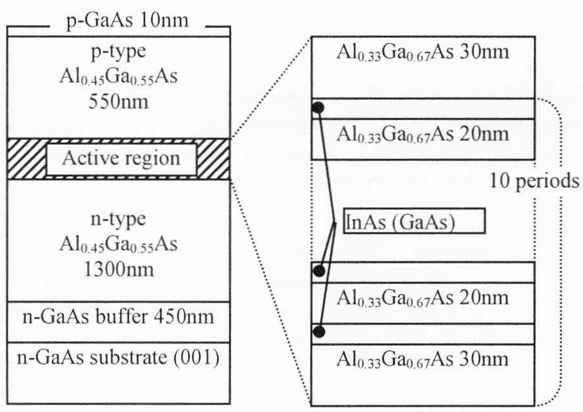

Fig. 2. The structure layer arrangement with detail of active region.

For the experimental emission study the gain guided metal stripe lasers have been fabricated. The stripes width of 5 μm in SiO_2 mask and AuBe/Ti/Au p-contact layer has been deposited. The device fabrication has been completed by thinning of the wafer to 150 μm thickness and evaporation of bottom AuGe/Au n-contact. The samples have been cleaved perpendicular to metal stripes to have bars with varying length.

Table I. The active region characterization of prepared structures.

	Active region
SME 7/1	$Al_{0.33}Ga_{0.67}As$
SME 7/2	InAs / $Al_{0.33}Ga_{0.67}As$
SME 7/3	GaAs / $Al_{0.33}Ga_{0.67}As$

The electronic properties of the structures have been determined from current-voltage measurements at forward bias. To measure low-temperature electroluminescence spectra as a function of temperature the diodes were put into closed cycle He-cryostat. For recording the EL spectra a monochromator of type SPM2 and Si-photodetector have been employed. The EL intensity vs. driving current has been measured by conventional LOCK-IN technique. Laser mode emission spectra were recorded using high-resolution double grating monochromator.

3. EXPERIMENTAL RESULTS

The current-voltage measurements at forward bias confirmed the p-n junction diffusion potential of app. 1V (cf. Fig. 3). The current flow shows limitation due to high series resistance of confinement layers and intrinsic active region in the range of 1.5V-2.5V.

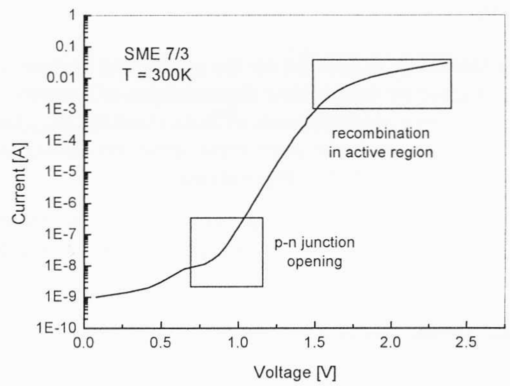

Fig. 3. Current-voltage characteristic of SME 7/3 structure measured at room temperature.

The current flow increasing through the active region has considerable influence on emission intensity. The room temperature EL spectra were measured at driving currents 10 mA (cf. Fig. 4).

The EL spectrum of SME 7/1 structure (with bulk $Al_{0.33}Ga_{0.67}As$ material in active region) demonstrates luminescence contribution at the energy 1.895 eV in correspondence with band-to-band recombination in $Al_{0.33}Ga_{0.67}As$ ternary. It agrees well with room temperature calculated data (1.897 eV) according [5]:

$$E_g^{\Gamma}(x) = 1.425 + 1.36x + 0.22x^2,$$

where x is Al mole fraction in $Al_xGa_{1-x}As$ material. The dominant recombination channel of SME 7/2 (with InAs ML in active region) structures at the energy 1.825 eV is related to the excitons bound to InAs ML. The weak shoulder at the energy 1.895 eV originates from band-to-band recombination in $Al_{0.33}Ga_{0.67}As$ ternary in active region. This is in agreement with the calculated data of band-to-band recombination in $Al_{0.33}Ga_{0.67}As$ (1.897 eV) and corresponds well with energy of dominant transition in SME 7/1 structures. Evident maximum for SME 7/3 structures (with GaAs ML in active region) observed at the energy 1.880 eV could be attributed to transitions related to GaAs ML. The band-to-band recombination related to the $Al_{0.33}Ga_{0.67}As$ barrier material in EL spectra is suppressed because of the small energy separation of excitons related to GaAs monolayer and $Al_{0.33}Ga_{0.67}As$ band gap.

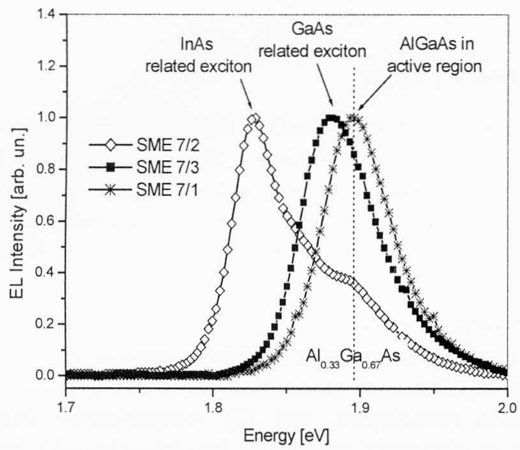

Fig. 4. Normalized room temperature EL spectra for SME 7/1,2,3 structures.

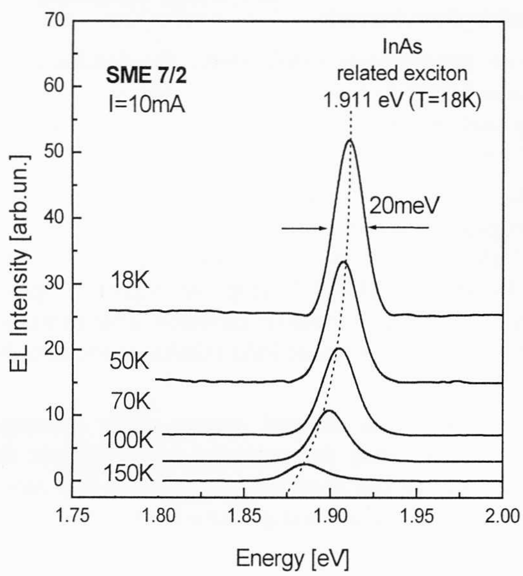

Fig. 5. Temperature dependence of EL spectra of SME 7/2 structure.

When going to low temperatures the EL intensity increases due to the effective exciton binding to monolayers and the EL spectra show the blue shift (cf. Fig.5). At T=18 K SME 7/2 structures show maximum related to the InAs excitonic transitions at the energy 1.911 eV.

Normalized temperature dependence of EL spectra of SME 7/2 structures demonstrate decrease of line width as is shown in Fig.6. At temperature 18 K the line width of this emission amounts to only 20 meV. The $Al_{0.33}Ga_{0.67}As$ band-to-band emission decreases with the decrease of temperature and for temperatures lower than 150 K is entirely disappeared. The same optical properties have been observed in SME 7/3 structures.

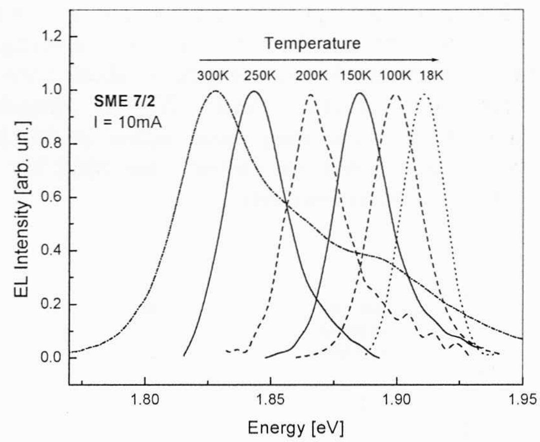

Fig. 6. Normalized EL spectra in temperature dependence (18 K- 300 K) of the structure SME 7/2.

The maximum related to the GaAs excitonic transitions in SME 7/3 structures was recorded at the energy 1.964 eV. The temperature dependence of the optical transition energies for SME 7/1 structures reflects nearly the $E_g(T)$-relation of $Al_{0.33}Ga_{0.67}As$ (cf. fig. 7), which has been calculated according to [6]:

$$E_g^{\Gamma}(T) = 1.520 - \frac{5.405 \cdot 10^{-4} T^2}{(T + 204)} ,$$

where T is temperature. In the same dependence the energy of InAs (GaAs)-related luminescence of SME 7/2 (SME 7/3) structures reflects the $E_g(T)$-relation of $Al_{0.33}Ga_{0.67}As$ lowered by the exciton binding energy of localized excitons in InAs (GaAs) ML.

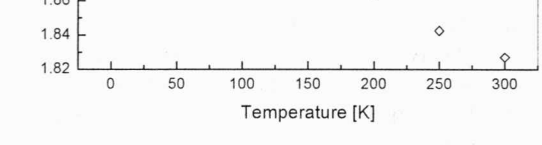

Fig. 7. Energy of excitonic transitions as a function of temperature for SME 7/1-3 structures (symbols) in comparing with the calculated band-to-band recombination in $Al_{0.33}Ga_{0.67}As$ ternary (solid line).

For temperatures ranging from 18 K to 100 K our stripe laser SME 7/2 and SME 7/3 structures show stimulated emission across their cleavage planes.

In fig. 8 a laser mode spectrum measured at T = 18 K is plotted. The stimulated emission for investigated structures occurs at photon energies of about 1.991 eV (622.8 nm) for structure SME 7/1 as quenching superluminescence and sharp laser action at 1.913 eV (648.19 nm) and 1.963 (631.69 nm) for SME 7/2 and SME 7/3 structures, respectively.

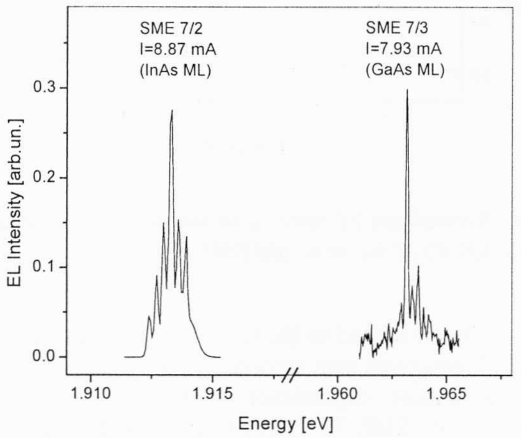

Fig. 8. Laser activity across the cleavage plane of samples SME 7/2 and SME 7/3.

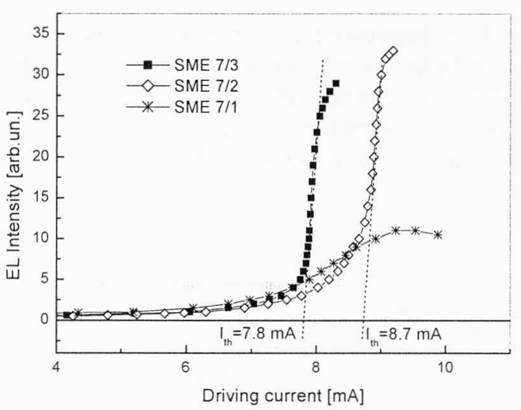

Fig. 9. The EL intensity vs. driving current for structure SME 7/1-3 recorded at T=18 K.

The dependence of EL intensity vs. driving current documents the typical laser enhancement of EL intensity in the region of threshold current densities for SME 7/2 and SME 7/3 structures (cf. Fig.9). From the recorded dependence the extremely low threshold current and current density was estimated to be I_{th}=8.7 mA (J_{th}=332 A/cm^2) for SME 7/2 and I_{th}=7.8 mA (J_{th}=350 A/cm^2) for SME 7/3 structures. (Note, the parameters of metal stripe were determined to be 437 μm x 6 μm (SME 7/2) 371 μm x 6 μm (SME 7/3)).

In SME 7/1 structures (without monolayers in active region) we suppose the ineffective exciton binding, however, the shallow increase of EL intensity with driving current still remains an open question. For the temperatures above 100K the stimulated emission disappears due to the thermal dissociation of InAs (GaAs) monolayer-bound excitons [1].

4. CONCLUSION

In summary, we have studied the optical and electronic properties of monolayers structures with InAs (GaAs) / $Al_{0.33}Ga_{0.67}As$ in active region grown by MOVPE. Optical properties were investigated by EL spectra in wide range of temperatures (18 K-300 K) taken from the cleavage plane of stripe laser arrangements.

In the room temperature EL spectra two optical transitions were observed in structure with InAs monolayers in active region: (1) dominant recombination of excitons bound to the InAs monolayers, and (2) recombination channel which is obviously related to the $Al_{0.33}Ga_{0.67}As$ barrier material. In structure with GaAs monolayers in active region prevail only (1) recombination channel and the recombination related to the $Al_{0.33}Ga_{0.67}As$ barrier material is weak because of the small energy separation of both recombination channels.

At low temperatures (18K-100K) the luminescence of excitons bound to InAs (GaAs) monolayer becomes very sharp and intense; its peak energy reflects nearly the $E_g(T)$-relation of the $Al_{0.33}Ga_{0.67}As$ band gap.

In the low temperature range stimulated emission of investigated structures occurs at photon energies of about 1.913 eV (648.19 nm) for SME 7/2 and 1.963 eV (631.69 nm) for SME 7/3, resp. At higher temperatures (above 100K) the stimulated emission disappears due to the thermal dissociation of InAs (GaAs) monolayer-bound excitons [1].

In our opinion the material system under investigation might be interesting for potential optoelectronic device applications. To our knowledge, this is the first report on the InAs based red and orange stimulated emission.

Acknowledgement

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