Available online at www.sciencedirect.com

ScienceDirect

Physics Procedia 3 (2010) 1189–1193

Physics Procedia

www.elsevier.com/locate/procedia

14th International Conference on Narrow Gap Semiconductors and Systems

Intense interface luminescence in type II narrow-gap InAs-based heterostructures at room temperature

Konstantin Moiseev[a,*], Eduard Ivanov[a], Vyacheslav Romanov[a], Maya Mikhailova[a], Yury Yakovlev[a], Eduard Hulicius[b], Alica Hospodková[b], Jiri Pangrác[b], Tomislav Šimeček[b]

[a]*Ioffe Institute, Russian Academy of Sciences, 26 Politekhnicheskaya street, St Petersburg 194021, Russia*
[b]*Institute of Physics, AS CR, v. v. i., Cukrovarnická 10, Prague 6, 162 53, Czech Republic*

Abstract

Positive and negative luminescence was observed in a type II broken-gap p-InAs/p-GaAsSb heterostructure in the mid-infrared spectral range 3-5 μm at room temperature. Interface-related radiative recombination was provided by Mn acceptor states on InAs surface. I-V characteristics behavior was discussed using the tunneling-assisted current transport mechanism through surface states. Redistribution between the interband ($h\nu_1$=0.36 eV) and interface ($h\nu_2$=0.31 eV) emission bands in electroluminescent spectra at reverse bias was found in dependence on Fermi level position pinning by surface states at the type II broken-gap heterointerface.

Keywords: MOVPE; GaSb; InAs; surface states; negative luminescence; interface electroluminescence

---

1. Introduction

Type II heterostructures in the GaSb-InAs solid solution system have been intensively studied in recent years as promising candidates for the design of optoelectronic devices operating in the mid-infrared spectral range 2-5 μm [1,2]. Advantage of this ternary system is that the GaAsSb epilayers can be grown lattice-matched on two different substrates (InP and InAs) and these solid solutions can form type II staggered GaAsSb/InP and broken-gap GaAsSb/InAs heterojunctions. [3,4]. Among the narrow-gap heterostructures, the GaAsSb solid solutions can be used as a wide-gap window in photodiodes and/or a semimetal injector in laser structures [5]. Type II broken-gap heterojunctions in the InAs-GaSb system demonstrated unusual features in transport and luminescence due to their specific energy band diagram. The most remarkable property is existence of 2D-electron channel on the InAs side of the type II broken-gap p-InAs/p-GaInAsSb heterointerface [2]. To produce the electron channel is necessary to locate Fermi level in the InAs conduction band. Then, presence of n-type inversion layer on the p-type material resulted in a formation of the p-n homojunction with a large space-charge region. If such p-n junction is run in reverse bias, carriers are extracted from p- and n-region, respectively, and their reduced concentrations can lead to

---

* Corresponding author. Tel.: +7-812-292-7929; fax: +7-812-297-0006.
E-mail address: mkd@iropt2.ioffe.rssi.ru.

doi:10.1016/j.phpro.2010.01.161

appearance of a negative luminescence [6]. Recently, the both positive and negative luminescence were observed in the type II asymmetric p-InAs/p-GaSb heterostructures with the deep quantum well AlSb/InAsSb/AlSb at the interface grown by MOVPE [7]. Here, we report study of the first observation of interface luminescence and suppression of negative luminescence in the type II broken-gap p-InAs/p-GaAsSb heterojunction at T=300 K due to control of Fermi level position by acceptor surface states at the heteroboundary.

2. Experimental details

The structures under study were grown on InAs(100) oriented substrates doped with Mn in a horizontal reactor of AIXTRON 200 machine with a RF heated graphite susceptor by low-pressure MOVPE described elsewhere [8]. Tris(tertiarybutyl)aluminium (TtBAl), triethylgallium (TEGa), tertiarybutylarsin (tBAsH$_2$), and triethylantimony (TESb) were used as precursors. During the growth in-situ measurements of an epilayer sequence were performed using EpiRAS 200 TT (LayTec) equipment in the Reflectance Anisotropy Spectroscopy time resolved mode. The epitaxial structure A consisted of the unintentionally doped 0.4-μm-thick p-GaAs$_{0.06}$Sb layer deposed on p-InAs substrate doped with Mn (Fig.1,a). The sample B contained additional oxide layer inserted into p-InAs/p-GaAs$_{0.06}$Sb heterojunction (Fig.1,b) due to the surface of the p-InAs<Mn> substrate was treated in dry O$_2$-plasma environment before the growing [9]. In contrary to that, the sample A was grown on the p-InAs substrate with the working surface to be prepared using wet chemical procedure. Round mesa-structures were performed using photolithography alignment system and selective wet chemical etching with a mesa diameter of 300 μm and a contact area of 50 μm. I-V characteristics of the processed structures were examined under steady-state conditions in the temperature range 77-300 K. Electroluminescent spectra were recorded using the set-up equipped by MDR-2 0.5-m monochromator and Stanford S580 lock-in amplifier. The emission signal was detected by liquid nitrogen cooled InSb detector (Judson Ltd). Spontaneous emission was studied under quasi-state regime with pulse duration of 2.5 ms and repetition rate of 32 kHz.

3. Results and discussion

Recently, calculation of the composition dependence of the GaAsSb energy gap was proposed [4]. It was established that the GaAs$_x$Sb$_{1-x}$/InAs heterostructure is a type II broken-gap heterojunction for the composition range x<0.15. Large asymmetric band-offsets at the type II interface (ΔE_C>0.6 eV and ΔE_V>0.35 eV at 300 K) can lead to formation of high potential barriers for electrons and holes (see Fig.1,a). Following that, the top of the valence band of the GaAs$_{0.06}$Sb$_{0.94}$ epitaxial layer is lying higher in energy than the bottom of the InAs conduction band and the energy band overlap can reach of ΔE=100 meV at the interface at T=300 K.

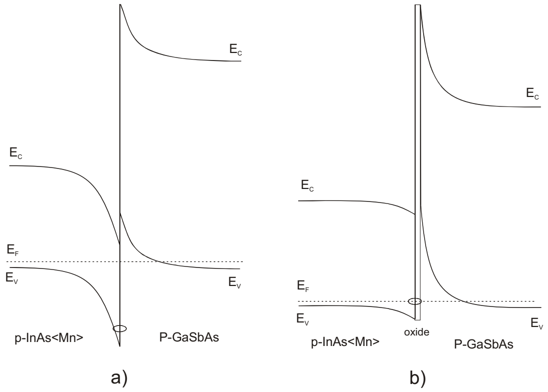

Fig.1. Schematic energy band diagrams at 300 K for type II heterostructures: a) – p-InAs/p-GaAsSb, b)– p-InAs/oxide/p-GaAsSb. Surface states of Mn at the heterointerface are pointed by circles.

I-V characteristics of the sample A measured at room temperature is slightly rectifying with a small cutoff in the reverse branch (Fig.2). The forward branch exhibited a small N-shape feature similar to that was described by the contribution of acceptor surface states in GaAs bulk doped with Mn [10]. As it was shown in [11], the position of common Fermi level of a heterojunction can be controlled be surface states localized on the heterointerface. It is also known that impurity Mn atoms form acceptor states on the InAs open surface [12]. Using plasma oxidation of the working surface of the InAs substrate we believe to provide pinning of common Fermi level through Mn surface states (see Fig.1,b). According to the schematic energy band diagram no effective depletion region has been formed on both sides of the p-InAs/GaAsSb heteroboundary. The I-V characteristic for the sample B is quite linear that confirms our suggestion.

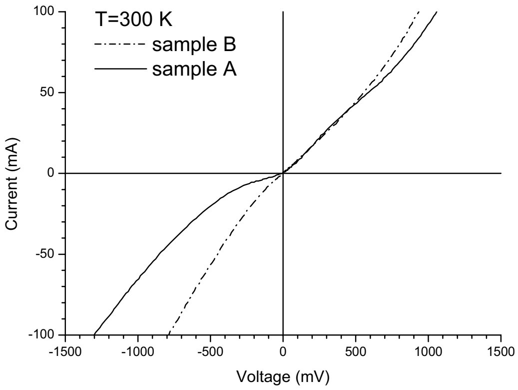

Fig.2. I-V characteristics of the type II p-InAs/p-GaAsSb heterostructures measured at 300 K.

The sample A exhibited intense electroluminescence in the mid-infrared spectral range 0.25-0.50 eV at T=300 K (Fig.3, solid line). Positive luminescence (PL) spectra obtained at forward external bias contained a single emission band with photon energy at maximum $h\nu_l$=0.36 eV. We consider the forward bias when a positive potential is applied to the p-InAs substrate whereas a negative one is applied to the p-GaAsSb epilayer. Asymmetric shape of the emission band with sharp low-energy edge was observed. Half-width of this peak (FWHM) was found to be of 55 meV. The PL observed can be associated with interband radiative recombination transitions occurred on the InAs side of the heterostructure, because the energy gaps of the semiconductors forming this heterostructure are 0.36 eV and 0.7 eV at T=300 K for InAs and $GaAs_{0.06}Sb_{0.94}$, respectively [4]. At reverse bias, when the negative potential was applied to the p-InAs and the positive one was applied to the p-GaAsSb, the sample A demonstrated negative luminescence (NL) in the spectral region 0.33-0.5 eV at T=300 K (Fig.4, solid line). NL spectrum contained the pronounced emission band at $h\nu_l$=0.36 eV with the similar asymmetric shape as for PL one, but its intensity was less by 4 times. PL and NL spectra occurred in the same range of photon energy above 0.33 eV. However in the NL spectrum, a change of the sign of the NL signal at photon energies below 0.33 eV was found, and an additional emission band of PL at $h\nu_2$=0.31 eV was observed. That additional peak can be associated with radiative transitions caused by influence of the heterointerface. As a result, the electroluminescence spectrum at reverse bias contained two emission peaks with opposite phases.

Variation of the energy bands bending at the heterointerface is exhibited in luminescent properties of the type II p-InAs/p-GaAsSb heterostructure. The sample B demonstrated positive electroluminescence at both forward ("+" on p-InAs) and reverse ("-" on p-InAs) bias at T=300 K (dotted lines in Fig.3 and 4). Therefore, we can see from figures suppression of NL at $h\nu_l$=0.36 eV and enhancement of the interface PL at $h\nu_2$=0.31 eV in the type II p-InAs/p-GaAsSb heterostructure with the processed heteroboundary at the reverse bias. In the sample A, due to the conduction band of p-InAs bent down near the interface, the ionization of Mn impurity centers at the surface is occurred. That prevents effective interface radiative recombination through these states under reverse bias. In contrast to the sample A, in the sample B Fermi level pinning on the Mn surface states at the heterointerface was made owing to the surface oxidation. Strong accumulation and effective confinement of the charge carriers near the Mn surface states at the heterointerface result in interface radiative transitions assisted by tunneling-resonance current flow across the heterostructure. The obtained results show that using the surface states in the energy gap of the narrow-gap semiconductors we can tune the effective wavelength of luminescence from middle to far infrared.

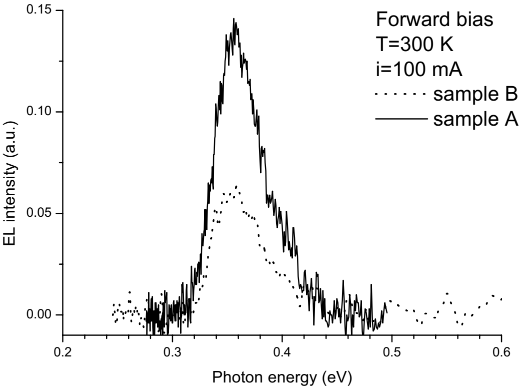

Fig.3. EL spectra in the type II p-InAs/p-GaAsSb heterostructures obtained at forward bias at 300 K.

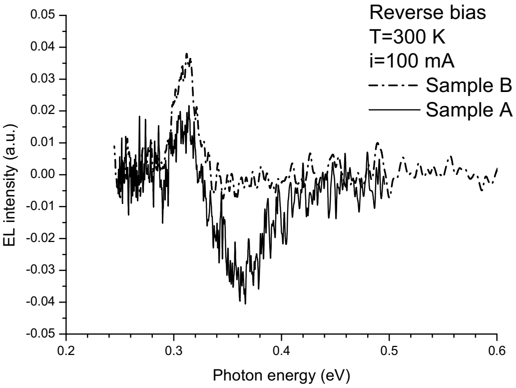

Fig.4. EL spectra in the type II p-InAs/p-GaAsSb heterostructures obtained at reverse bias at 300 K.

4. Conclusions

Two types of the narrow-gap heterostructures were grown on InAs(100) oriented substrates doped with Mn by low-pressure MOVPE using different surface treatment modes of the substrate. Positive and negative luminescence was observed in a type II broken-gap p-InAs/p-GaAsSb heterostructure in mid-infrared spectral range 3-5 µm at room temperature. It was found that formation of Mn surface states by plasma oxidation at the p-InAs/p-GaAsSb heteroboundary resulted in Fermi level pinning and changing of electroluminescent spectra with variation of external bias polarity. Both PL and NL spectra contained single pronounced emission band at $h\nu_1$=0.36 eV with half-width of 55 meV. However, the NL spectrum demonstrated a change of a sign of the signal phase at photon energies below 0.33 eV and the additional emission band at $h\nu_2$=0.31 eV was found. That additional PL peak can be associated with radiative transitions caused by influence of the heterointerface. Control of the effective luminescence wavelength from middle to far infrared spectral range was demonstrated.

Acknowledgements

This work was in part supported by the RBRF grants (09-02-00063 and 08-02-01277), programs of Presidium RAS and the Division of Physic Sciences of RAS, Grant Agency of the AS CR project A100100719 and project AV0Z 10100521.

References

[1]. M.P. Mikhailova and A.N.Titkov, Semicond. Sci. Technol., 9 (1994) 1279.
[2]. M.P. Mikhailova, K.D. Moiseev and Yu.P. Yakovlev, Semicond. Sci. Technol., 19 (2004) R109.
[3]. M. Peter, N. Herres, F. Fuchs, K. Wikler, K.-H. Bachem, J. Wagner, Appl. Phys. Lett. 74 (1999) 410.
[4]. K.D. Moiseev, V.V. Romanov, T.I. Voronina, T.S. Lagunova, M.P. Mikhailova, and Yu.P. Yakovlev, J. Cryst. Growth, 310 (2008) 4846.
[5]. A.A. Allerman, R.M. Biefeld and S.R. Kurtz, Appl. Phys. Lett., 69 (1996) 465.
[6]. T. Ashley, C.T. Elliott, N.T. Gordon, R.S. Hall, A.D. Johnson, G.J. Pryce, Infr. Phys. Technol., 36 (1995) 1037.
[7]. M.P. Mikhailova, E.V. Ivanov, K.D. Moiseev, Yu.P. Yakovlev, E. Hulicius, A. Hospodkova, J. Pangrac, T. Šimeček, Semicond., 44 (2010) to be published
[8]. D. Kindl, J. Toušková, E. Hulicius, J. Pangrác, T. Šimeček, V. Jurka, P. Hubík, J.J. Mareš and J. Krištofik, J. Appl. Phys., 95 (2004) 1811.
[9]. K. Aoki, S. Uekusa and H. Katsumata, Jpn. J. Appl. Phys., 41 (2002) 5762.
[10]. A.M. Yakunin, A.Yu. Silov, P.M. Coenraad, J.H. Wolter, W. Van Roy, J. De Boeck, J.-M. Tang and M.E. Flatte, Phys. Rev. B, 92 (2004) 216806.
[11]. G. Margaritondo, Rep. Prog. Phys., 62 (1992) 765.
[12]. F. Marczinowski, J. Weibe, J.-M. Tang, M.E. Flatte, F. Meier, M. Morgenstern and R. Weiserdanger, Phys. Rev. Lett., 99 (2007) 157202.