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Optical studies of InAs/InAsSb/InAsSbP heterostructures

M.S. Ruzhevich [1] ✉, I.D. Kirilenko [1], I.V. Chumanov [2], D.D. Firsov [2],
O.S. Komkov [2], K.D. Mynbaev [1, 3], V.V. Romanov [3], K.D. Moiseev [3]

[1] ITMO University, St. Petersburg, Russia;
[2] St. Petersburg Electrotechnical University "LETI", St. Petersburg, Russia;
[3] Ioffe Institute, St. Petersburg, Russia
✉ max.ruzhevich@niuitmo.ru

Abstract. Fourier-transform infrared photoluminescence and photoreflectance were used to study the optical properties of InAs/InAsSbP and InAs/InAsSb/InAsSbP heterostructures. A strong dependence of chemical composition and optical quality of the top InAsSbP barrier layers on the composition of the material on which the layer was grown has been established.

Keywords: heterostructures, InAsSbP, photoluminescence, photoreflectance

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Материалы конференции
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Оптические исследования гетероструктур InAs/InAsSb/InAsSbP

М.С. Ружевич [1] ✉, Я.Д. Кириленко [1], И.В. Чуманов [2], Д.Д. Фирсов [2],
О.С. Комков [2], К.Д. Мынбаев [1, 3], В.В. Романов [3], К.Д. Моисеев [3]

[1] Университет ИТМО, Санкт-Петербург, Россия;
[2] Санкт-Петербургский государственный электротехнический университет «ЛЭТИ» имени В.И. Ульянова (Ленина), Санкт-Петербург, Россия;
[3] Физико-технический институт им. А.Ф. Иоффе, Санкт-Петербург, Россия
✉ max.ruzhevich@niuitmo.ru

Аннотация. Методами инфракрасной фурье-спектроскопии фотолюминесценции и фотоотражения исследованы оптические свойства гетероструктур InAs/InAsSbP и InAs/InAsSb/InAsSbP. Обнаружена сильная зависимость химического состава и оптического качества верхних барьерных слоев InAsSbP от состава материала, на котором были выращены эти слои.

Ключевые слова: гетероструктуры, InAsSbP, фотолюминесценция, фотоотражение

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Introduction

InAsSb is an indispensable material for the fabrication of optoelectronic devices that cover the mid-wavelength infrared (MWIR) spectral range (2–6 μm). MWIR devices are widely used in, e.g., environmental monitoring, defense applications, industry, and medical diagnostics [1]. Using $InAs_{1-y}Sb_y$ in the active layer of a semiconductor heterostructure (HS), one can cover a 3.4–11.0 μm range. Increasing *y*, which is necessary for extending the working range of the HSs towards longer wavelengths, however, leads to a strong lattice mismatch between the InAsSb epitaxial layer and the substrate (typically made of InAs), as well as in technological challenges in deposition of InAsSbP on InAsSb using metal-organic vapor-phase epitaxy (MOVPE) [2]. These factors can result in a number of competing channels of radiative recombination in the HSs, which, in fact, may be useful in the design of multi-color LEDs [3]. Electroluminescence (EL) and electrical studies used for characterization of HSs do not always give sufficient information on their actual construction and its difference from the original design, inherent to lattice-mismatched systems. This information, however, can be obtained by studying optical properties of HS constituents, with the advantage of optical methods being non-destructive (see, e.g., [4]). In this paper, we present the results of the studies of InAs/(InAsSb)/InAsSbP HSs performed with Fourier-transform infrared (FTIR) photoluminescence (PL) and photoreflectance (PR).

Materials and Methods

The studied HSs were grown by MOVPE on undoped InAs(001) substrates. The deposition of undoped InAsSb active layer and/or zinc-doped InAsSbP layers was performed in a horizontal reactor under atmospheric pressure with the growth details reported elsewhere [2]. The thickness of the $InAs_{0.88}Sb_{0.12}$ layer was ~3 μm, and that of the $InAsSb_{0.22}P_{0.47}$ layers ~1.2 μm.

Optical studies were performed using the setup described in [5] and based on a Bruker Vertex 80 FTIR spectrometer with a cooled InSb or HgCdTe photodetector. PL and PR studies were carried out in a T = 11–300 K range under excitation with an 809 nm cw laser diode modulated with 2.5 kHz frequency, and providing power density up to 4.0 W/cm^2. During the measurements the HSs were placed in a Janis CCS-150 closed-cycle helium cryostat.

Results and Discussion

PL spectra of the InAs/InAsSbP HS (Fig. 1, *a*) contained a strong asymmetrical band with its peak at ~0.52 eV (T = 11 K) obviously related to the PL from the InAsSbP layer. The low-energy shoulder of the band could be related to PL from acceptor states in the layer (possibly, arising due to the introduction of Zn) and to the signal coming from the underlying InAs substrate (bandgap E_g = 0.41 eV at T = 11 K). The intensity of the band was gradually decreasing with T increasing, while the full-width at half-maximum (FWHM ~ 30 meV at T =11 K) of the main peak was increasing.

The PL spectra of InAs/InAsSb/InAsSbP HS (Fig. 1, *b*) contained an almost symmetrical peak from the InAsSbP layer (~0.42 eV at T = 11 K) and a peak related to the InAsSb layer (~0.27 eV at T =11 K). The FWHMs of the PL peaks related to InAsSbP layers in the two HSs were similar. The peak from the InAsSb layer had a FWHM of ~25 meV at T =11 K. Its energy differed by ~ 20 meV from that of the EL peak of the HS as presented in [6], which confirmed the interface origin of the EL in these HSs, as was suggested earlier.

Fig. 2, *a* shows PR spectra of the InAs/InAsSbP HS. The spectra had an oscillating shape and, most probably, represented a superimposition of the Fabry-Perot interference and the differential signal from the interband transitions in the InAsSbP layer (marked as 'E_g'). For the InAs/InAsSb/InAsSbP HS, PR signal was not detected, possibly indicating lower structural quality of the InAsSbP layer, which in this case was grown on lattice-mismatched InAsSb. Measured under identical conditions, the PL signal from InAsSbP in the InAs/InAsSb/InAsSbP HS was also weaker than that from the similar layer in the InAs/InAsSbP HS.

The temperature dependences of the energy of the PL and PR peaks are shown in Fig. 2, *b*. For the InAs/InAsSbP HS, the PL peak related to the InAsSbP layer did not change its energy in the T = 11–120 K range; at higher T, its energy was decreasing, approaching the Varshni law.

a) *b*)

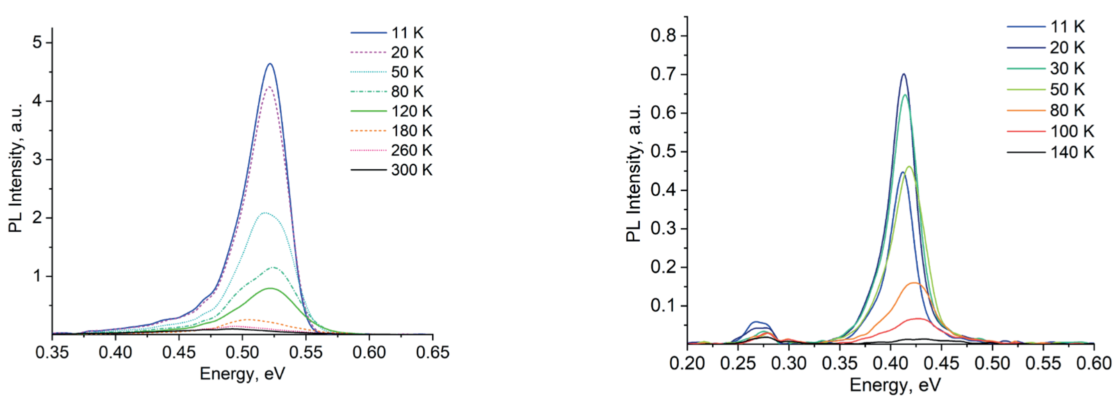

Fig. 1. Variable-temperature PL spectra of InAs/InAsSbP (*a*) and InAs/InAsSb/InAsSbP (*b*) heterostructures

The positions of both the PL and PR peaks within the whole T = 11–300 K range did not correspond to the E_g calculated according to the expected composition of the layer. For InAs/InAsSb/InAsSbP HS, the PL peak of the InAsSbP layer in T = 11–200 K range showed some blue-shift with temperature increasing, and at higher T also followed the Varshni law. Its position again did not correspond to the calculated E_g, and was indicative of greater InSb content as compared to that in the InAsSbP layer in the InAs/InAsSbP HS.

a) *b*)

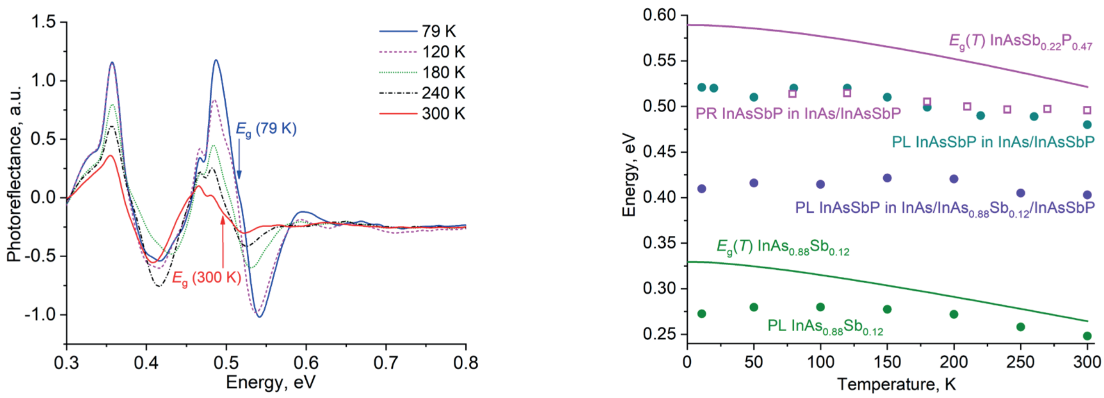

Fig. 2. Variable-temperature PR spectra of InAsSbP/InAs HS (*a*), and temperature dependences of the energy of PL and PR peaks (symbols) with corresponding $E_g(T)$ dependences (lines) calculated according to the Varshni law [7] with parameters $\alpha = 3.3 \cdot 10^{-4}$ eV/K, β = 120 K for InAsSbP (*b*)

Conclusion

The results of the optical studies of InAs/InAsSbP and InAs/InAsSb/InAsSbP heterostructures performed with FTIR photoluminescence and photoreflectance methods allowed for a non-destructive study of the properties of the layers constituting the structures. For InAs/InAsSb/InAsSbP HS, a weakening of the optical response was detected, indicating lower structural quality of the InAsSbP material. In the PL spectra, a signal was observed from both the InAs(Sb) and InAsSbP, and for the latter, the position of the PL peak depended on the composition of the underlying material. This meant that during the growth of InAsSbP layer, its chemical composition got adjusted to the "substrate", which affected the optical properties of the HS. In the InAs/InAsSbP HS, the presence of defect states was detected, possibly associated with introduction of Zn.

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THE AUTHORS

RUZHEVICH Maxim S.
max.ruzhevich@niuitmo.ru
ORCID: 0000-0002-4513-6345

KIRILENKO Iaroslav D.
idkirilenko@itmo.ru
ORCID: 0009-0007-1056-5100

CHUMANOV Ivan V.
chumanov2000@yandex.ru
ORCID: 0009-0009-2564-6100

FIRSOV Dmitrii D.
ddfirsov@gmail.com
ORCID: 0000-0001-7608-9580

KOMKOV Oleg S.
oskomkov@yahoo.com
ORCID: 0000-0002-8999-1175

MYNBAEV Karim D.
mynkad@mail.ioffe.ru
ORCID: 0000-0002-9853-8874

ROMANOV Vyacheslav V.
romanovvv@mail.ioffe.ru
ORCID: 0000-0002-9989-3843

MOISEEV Konstantin D.
mkd@iropt2.mail.ioffe.ru
ORCID: 0000-0002-6306-0129

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