St. Petersburg Polytechnic University Journal. Physics and Mathematics. 2024. Vol. 17. No. 3.1
Научно-технические ведомости СПбГПУ. Физико-математические науки. 17 (3.1) 2024

Conference materials
UDC 535.37
DOI: https://doi.org/10.18721/JPM.173.147

Study of planar microcavity structure with $In_{0.63}Ga_{0.37}As$ quantum dots and non-absorbing $Al_{0.2}Ga_{0.8}As/Al_{0.9}Ga_{0.1}As$ mirrors

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Abstract. The planar microcavity structure based on non-absorbing $Al_{0.2}Ga_{0.8}As/Al_{0.9}Ga_{0.1}As$ mirrors was fully fabricated by molecular-beam epitaxy. Usage of $In_{0.63}Ga_{0.37}As$ quantum dots reveals room temperature emission near 1110 nm with emission bandwidth of about 80 meV. The determined spectral mismatch between peak position of gain region and reflectivity spectrum dip was about 115 meV at 290 K. The shift of the reflectance dip position along the whole wafer surface was less than 15 meV. The determined by defect inspection root mean square surface roughness was less than 1.3 nm for studied 8 μm thick planar microcavity structure.

Keywords: molecular-beam epitaxy, planar microcavity, gallium arsenide, InGaAs, Stransky-Krastanow growth mode

Funding: The authors from Ioffe Institute acknowledge support in part by the grant of the Russian Science Foundation No. 22-19-00221, https://rscf.ru/project/22-19-00221/ for the structure design, MBE epitaxy, transmission electron microscopy analysis and the study of photoluminescence spectra. The authors from HSE University acknowledge support in part by the Basic Research Program at the HSE University for support in the photoluminescence spectra analysis. The authors from ITMO University acknowledge support in part by the Ministry of Science and Higher Education of the Russian Federation, project no. 2019-1442 (project reference number FSER-2020-0013) for the analysis of surface defect and reflection spectra of a planar microcavity structure.

Citation: Babichev A.V., Papylev D.S., Komarov S.D., Kryzhanovskaya N.V., Blokhin S.A., Nevedomsky V.N., Gladyshev A.G., Karachinsky L.Ya., Novikov I.I., Egorov A.Yu., Study of planar microcavity structure with $In_{0.63}Ga_{0.37}As$ quantum dots and non-absorbing $Al_{0.2}Ga_{0.8}As/Al_{0.9}Ga_{0.1}As$ mirrors, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 17 (3.1) (2024) 233–237. DOI: https://doi.org/10.18721/JPM.173.147

Материалы конференции
УДК 535.37
DOI: https://doi.org/10.18721/JPM.173.147

Исследование планарной структуры микрорезонатора с квантовыми точками $In_{0.63}Ga_{0.37}As$ и непоглощающими зеркалами $Al_{0.2}Ga_{0.8}As/Al_{0.9}Ga_{0.1}As$

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Аннотация. Планарная структура вертикального микрорезонатора с непоглощающими распределенными брэгговскими отражателями $Al_{0.2}Ga_{0.8}As/Al_{0.9}Ga_{0.1}As$ была изготовлена методом молекулярно-пучковой эпитаксии. Квантовые точки, сформированные по механизму Странски-Крастанова из слоя $In_{0.63}Ga_{0.37}As$ демонстрируют фотолюминесценцию при комнатной температуре вблизи 1110 нм, с характерной полушириной пика около 80 мэВ. Величина спектрального рассогласования между положением пика фотолюминесценции активной области и провалом в спектре отражения составило около 115 мэВ при температуре 290 K. Сдвиг положения резонансной длины волны в спектре отражения при смещении от центра к краю пластины не превысил 15 мэВ. Оценочная величина шероховатости поверхности планарной структуры вертикального микрорезонатора толщиной 8 мкм не превысила 1.3 нм.

Ключевые слова: молекулярно-пучковая эпитаксия, планарный вертикальный микрорезонатор, арсенид галлия, InGaAs, механизм Странски-Крастанова

Финансирование: Авторы из ФТИ им. А.Ф. Иоффе выражают благодарность за частичную поддержку проекту РНФ № 22-19-00221, https://rscf.ru/project/22-19-00221/ в части разработки структуры, эпитаксии методом молекулярно-пучковой эпитаксии, анализ методом просвечивающей электронной микроскопии и исследование спектров фотолюминесценции. Авторы из НИУ ВШЭ благодарят за поддержку Программу фундаментальных исследований НИУ ВШЭ за поддержку в части анализа спектров фотолюминесценции. Авторы из Университета ИТМО выражают благодарность за поддержку Министерство науки и высшего образования Российской Федерации, проект тематики научных исследований № 2019-1442 (код научной темы FSER-2020-0013) в части анализа карт поверхностных дефектов и спектров отражения гетероструктуры вертикального микрорезонатора.

Ссылка при цитировании: Бабичев А.В., Папылев Д.С., Комаров С.Д., Крыжановская Н.В., Блохин С.А., Неведомский В.Н., Гладышев А.Г., Карачинский Л.Я., Новиков И.И., Егоров А.Ю. Исследование планарной структуры микрорезонатора с квантовыми точками $In_{0.63}Ga_{0.37}As$ и непоглощающими зеркалами $Al_{0.2}Ga_{0.8}As/Al_{0.9}Ga_{0.1}As$ // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2024. Т. 17. № 3.1. С. 233–237. DOI: https://doi.org/10.18721/JPM.173.147

Introduction

The realization of optical reservoir computing (RC) based on micropillar lasers with optical pumping requires a high spectral uniformity and low threshold excitation powers in lasers array.

Recently, spectral uniformity about 190 μeV for 8×8 micropillar arrays and low threshold excitation power (about 1 mW for 5 μm diameter pillar) have been reported for microcavities with absorbing GaAs/$Al_{0.9}Ga_{0.1}As$ mirrors [1]. The maximal lasing temperature (~130 K) was limited by strong absorption of distributed Bragg reflector GaAs layers at excitation wavelength [2]. In opposite, the ultra-low threshold excitation power (about 30 μW for 5 μm pillar [3]) were reported for new microcavities with non-absorbing $Al_{0.2}Ga_{0.8}As/Al_{0.9}Ga_{0.1}As$ mirrors. Moreover, gain to cavity detuning, GCD (spectral mismatch between gain region maxima and microcavity reflectance dip position) strongly effect on the threshold excitation power versus temperature behavior as well [2, 4].

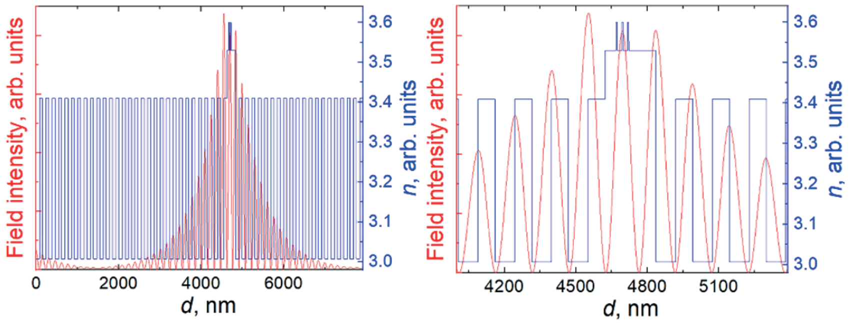

Fig. 1. Optical field intensity versus distance from the substrate. Right panel demonstrates the enlarged image of left panel

This paper is devoted to studies of the optical characteristics of planar microcavity structure with InGaAs/GaAs quantum dots (QDs) and non-absorbing $Al_{0.2}Ga_{0.8}As/Al_{0.9}Ga_{0.1}As$ mirrors.

Materials and Methods

The microcavity as well as QDs test heterostructure were grown by molecular-beam epitaxy. The one lambda thick microcavity was formed by non-absorbing (at 700–820 nm range of exciting laser wavelength) bottom and top mirrors consisted of 30 and 20 pairs of $Al_{0.2}Ga_{0.8}As/Al_{0.9}Ga_{0.1}As$ respectively. The gain region was positioned in E-field maxima and consisted of 3-fold stacked QDs layers separated by 20 nm thick GaAs barriers (cf. Fig. 1). The QDs were formed from $In_{0.63}Ga_{0.37}As$ layer by the Stransky-Krastanow growth mode. The thickness of $In_{0.63}Ga_{0.37}As$ layer was equaled to 2.6 monolayers. The QDs test structure includes the same three-stacked QDs layers that were applied as the gain region of microcavity structure.

The photoluminescence (PL) studies were carried out in the 77–290 K temperature range. The optical pumping of QDs test heterostructure was made by a Nd:YAG laser (with 532 nm wavelength excitation) with low CW excitation power density (54 mW/cm^2) aimed to compare with previously published results for structure grown by metal-organic chemical vapor deposition, MOCVD [5]. The reflection spectrum maps of the planar microcavity structure were analyzed by a VerteX PM2000 mapper system (Nanometrics Inc.). The transmission electron microscopy (TEM) studies were conducted using a JEM2100F electron microscope (Jeol Ltd.) at accelerating voltage of 200 kV. Surfscan defect inspection system (KLA Tencor Corp.) was used to measure the normal (with sizes in the range of 0.6–10 μm^2) and oval (with sizes in the range of 10–250 μm^2) defects distribution over the entire substrate surface.

Results and Discussion

The inhomogeneous broadening determined at 77 K for PL spectrum at 54 mW/cm^2 was about 99 meV. Temperature rise reveals to fall of the PL spectrum full width at half maximum (FWHM), with minimum value about 60 meV at 180 K. Room temperature (at 290 K) value of inhomogeneous broadening was 83 meV that is close to the previously mentioned value for MOCVD-grown single layer QDs (~80 meV [5]). Peak position of PL spectrum measured at 77 K was near 1030 nm. Rise of the temperature up to 290 K yields to shift of ground state emission to 1110 nm. This value is just above the previously mentioned for MOCVD structure (1014 nm [5]), due to the difference in QDs composition. To clarify the GCD the high-resolution reflectance spectrum was measured. The dip position of reflectance spectrum was located at 993 nm that results GCD about 117 nm (~114 meV). Previously, the PL peak and reflectance dip position was 1100 nm and 1050 nm, respectively that yields GCD of about 50 nm (~54 meV) [5]. Using the value of FWHM of the reflectance spectra the quality-factor of planar microcavity structure was determined, which was ~1450. Aimed to clarify the spectral inhomogeneity of reflectance dip position over the whole wafer surface the map of reflectance spectra was measured. The change in the position of the reflection dip with a radial shift of approximately 25 mm from the center was about 3 meV, which is about 9 times less than for MOCVD-grown planar microcavity structure [1].

The images obtained by transmission electron microscopy are presented in Fig. 3. In general, "inverse Christmas tree" growth mode was realized due to indium segregation that cause dislocation formation in oversized QDs [6]. Moreover, due to different size of QDs in stacked layers increase the inhomogeneous broadening was observed for this gain region. Aimed to realize the uniform QDs, anticorrelation growth mode may be applied [7]. Herein, we have realized the QD seeding, but without change of size for QDs located in different layers (cf. Fig. 3). As a result, the effect of increasing the inhomogeneous broadening due to the dispersion of QD sizes in different layers did not appear. The STEM image (Fig. 3) demonstrates that the DBR layers have good planarity and a constant period, and there are no defects in the area of the DBR/gain region boundaries.

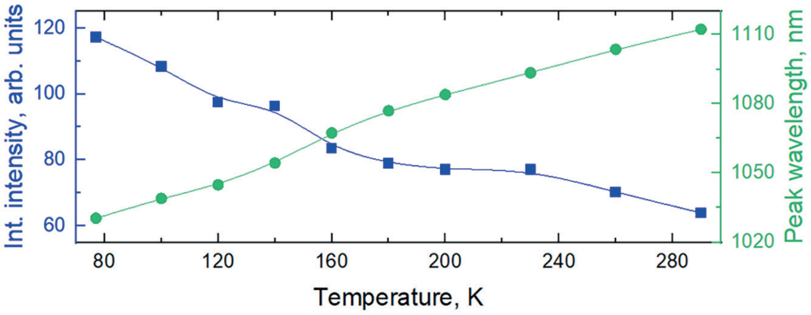

Fig. 2. Integrated intensity (left Y axis) and peak position of PL spectra (right Y axis) versus temperature behaviors for test structure with $In_{0.63}Ga_{0.37}As$ QDs

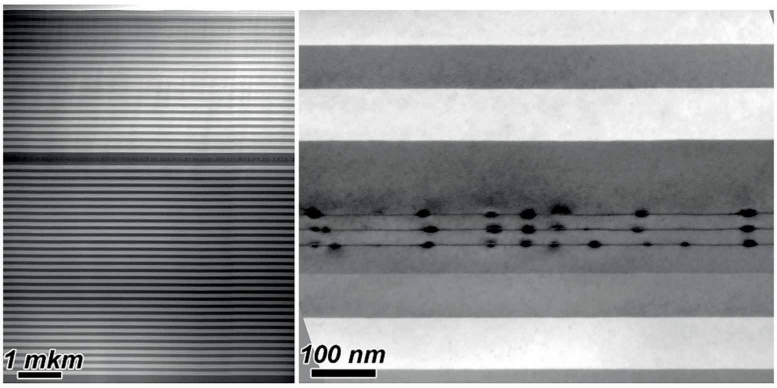

Fig. 3. STEM (left panel) and TEM (right panel) images of the microcavity heterostructure

The defects distribution over the entire substrate surface was analyzed as well. The density of normal and oval defects was 179 and 194 per cm^2, respectively. The average haze values were 412 and 388 ppm for normal and oval defects. As a result, the estimated root mean square (RMS) roughness of the surface was less than 1.3 nm.

Conclusion

MBE-grown $In_{0.63}Ga_{0.37}As$ quantum dots gain region were embedded in the one lambda length cavity based on 30 and 20 pairs $Al_{0.2}Ga_{0.8}As/Al_{0.9}Ga_{0.1}As$ DBR. The estimated from reflectance measurements quality-factor of this planar cavity was about 1450. The evaluated zero gain to cavity detuning was near the 230 K temperature. The small shift of reflectance dip value along radius position reveals perspective of MBE-grown micropillar structure usage for fabrication of micropillars laser arrays with ultra-high spectral homogeneity.

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Received 08.07.2024. Approved after reviewing 23.07.2024. Accepted 24.07.2024.