JOURNAL OF CRYSTAL GROWTH

ELSEVIER

Journal of Crystal Growth 201/202 (1999) 1143–1145

1.75 μm emission from self-organized InAs quantum dots on GaAs

V.M. Ustinov[a,*], A.Yu. Egorov[a], A.E. Zhukov[a], A.R. Kovsh[a], N.N. Ledentsov[a], M.V. Maximov[a], B.V. Volovik[a], A.F. Tsatsul'nikov[a], P.S. Kop'ev[a], Zh.I. Alferov[a], I.P. Soshnikov[b,1], N. Zakharov[b], P. Werner[b], D. Bimberg[c]

[a] *A.F. Ioffe Physico-Technical Institute, Russian Academy of Sciences 26 Politekhnicheskaya, 194021 St. Petersburg, Russia*

[b] *Max-Planck-Institut für Mikrostrukturphysik, Weinberg 2, 06120 Halle/Saale, Germany*

[c] *Institut fur Festkorperphysik, Technische Universitat Berlin, Hardenbergstr. 36, D-10623 Berlin, Germany*

Abstract

Photoluminescence (PL) of self-organized InAs quantum dots (QDs) grown by conventional solid source molecular beam epitaxy (MBE) on a GaAs substrate was studied as a function of the deposition temperature. We have found that decreasing the growth temperature below the 480–500°C range leads to the appearance and increase in intensity of a long wavelength band in addition to the usual 1 μm line in a low-temperature PL spectrum. At the deposition temperature of 300°C this line dominates in the room temperature (RT) PL spectrum and its peak position is 1.75 μm. TEM studies have shown that the origin of this line are agglomerates of QDs which are formed in two preferential chain- and cluster-like shapes. © 1999 Elsevier Science B.V. All rights reserved.

PACS: 68.35.Bs; 68.65. + g; 81.05.Ea; 81.15.Hi

Keywords: Molecular beam epitaxy; Quantum dots; Transmission electron microscopy; Photoluminescence

InAs self-organized quantum dots (QD) have been shown to extend the light emission range for semiconductor heterostructures on a GaAs substrate toward long wavelengths as compared to quantum wells (QW). 1.3 μm emission has been reported for the (In, Ga)As QDs [1], whereas the long wavelength limit for the InGaAs/GaAs QWs is around 1.1 μm [2]. Lasing at 1.3 μm has recently been reported for a quantum dot structure [3], and further shifting the long wavelength limit for the GaAs-based optical devices is an important problem in current semiconductor technology. This will allow for the extension of the application range of the GaAs-based optoelectronic devices to the fiber communications area. In the present work, we report on the 1.75 μm emission registered at room

* Corresponding author. Tel.: + 7-812-2479132; fax: + 7-812-2478640; e-mail: vmust@beam.ioffe.rssi.ru.

[1] On leave from A.F. Ioffe Physico-Technical Institute, St. Petersburg, Russia.

PII: S0022-0248(99)00004-4

temperature (RT) for the InAs quantum dots on a GaAs substrate.

The structures were grown by conventional solid source molecular beam epitaxy (MBE) in a wide range of the QD deposition temperatures, 300–500°C. Effective InAs thickness, III/V ratio, and growth rate were kept constant in all growth runs. The effective thickness of InAs deposited was 3 monolayers (ML). QDs were inserted into the middle of the 0.2 μm GaAs layer sandwiched between two short-period AlAs/GaAs superlattices. Photoluminescence (PL) was excited by the Ar^+ laser and registered by Ge photodiode. Spectra were taken in a continuous flow liquid He cryostat in the 10–300 K temperature range. TEM was studied with the JEM4000 high-resolution transmission electron microscope using an acceleration voltage of 400 kV. Plan view specimens were prepared using standard techniques. The samples were mechanically thinned and polished. Ion milling was performed with the 4 keV Ar^+ ions at an incident angle of 13°.

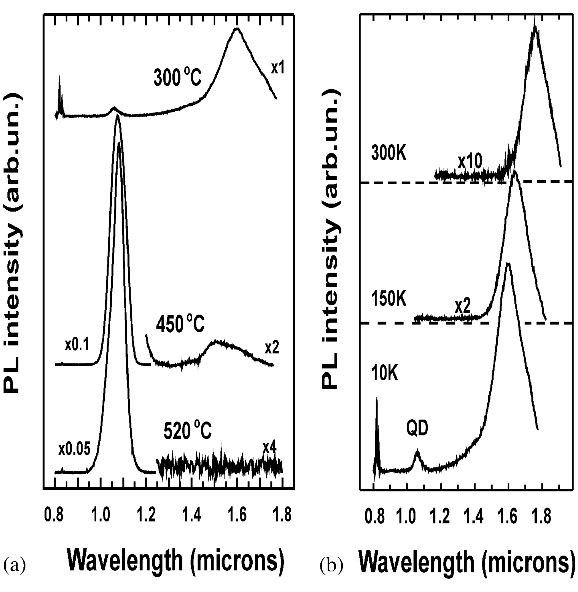

Fig. 1. Photoluminescence spectra of InAs quantum dot structures grown at various deposition temperatures (a) and temperature dependence of PL for the structure grown at 300°C (b).

Fig. 1a shows the evolution of the low-temperature PL spectrum as a function of the growth temperature. Only usual 1 μm line is present in the spectrum of the structure grown at 500°C. When the growth temperature is decreased the additional band appears at 1.5–1.6 μm. Further decreasing the growth temperature leads to the redistribution of the PL intensity between the 1 and 1.6 μm lines. The PL spectrum of the sample grown at 300°C shows only a weak feature at 1 and 1.6 μm line dominates in the spectrum. This line regularly shifts with the temperature of observation and at room temperature its maximum is at 1.75 μm, Fig. 1b. We note that we observed no regular shift of the peak position of the long wavelength line with the decrease in the growth temperature, it remains essentially the same. This fact allows us to assume that some new objects in addition to the well-known quantum dots are responsible for this new emission line.

To find out the origin of the long wavelength line, we performed the extensive transmission electron microscopy (TEM) study of the structures obtained. The results of this study will be published elsewhere. For the present short communication in Fig. 2 we only show the TEM image of the sample grown at 300°C when the long wavelength line is most strongly pronounced and which is typical for the structures grown at low temperatures. In addition to the usual quantum dots one can see a lot of new objects. These objects are agglomerates or laterally associated complexes of quantum dots. These agglomerates are of two preferential shapes, chain-like (Fig. 2b) and symmetrical (Fig. 2c) clusters. Since the size of these agglomerates is apparently larger than that of the usual quantum dots the energy of optical transition in these objects should be less than that in quantum dots. Therefore, we attribute the origin of the new long wavelength PL line to the agglomerates of quantum dots revealed in the TEM images. Further work is required to understand the effect of growth regimes on the formation of these agglomerates and to improve the emission intensity.

In conclusion, we have demonstrated the 1.75 μm room temperature photoluminescence from the InAs self-organized quantum dots grown by MBE on a GaAs substrate. The origin of the

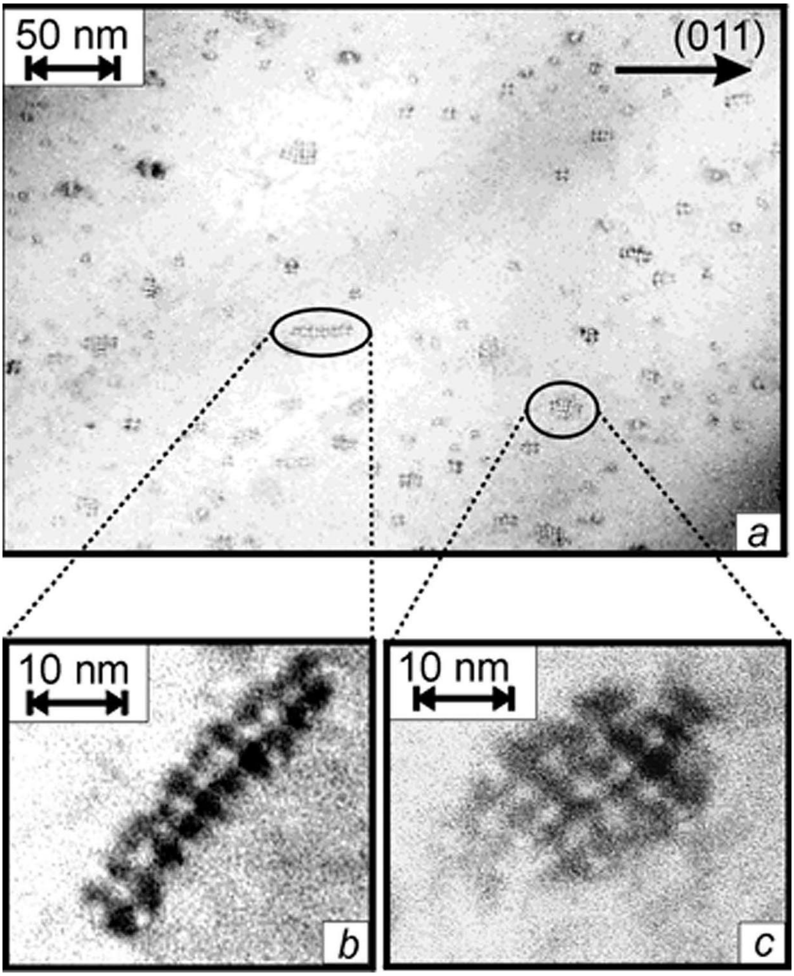

Fig. 2. Transmission electron microscopy image of InAs quantum dot structure deposited at 300°C (a) and TEM images of chain-like (b) and symmetrically shaped (c) agglomerates of quantum dots.

new long wavelength line is attributed to the agglomerates of quantum dots formed at low deposition temperatures. The emission wavelength is much longer than reported previously for the structures grown on GaAs and opens a possibility for the application of the GaAs-based devices in practically important optical range.

References

[1] R.P. Mirin, J.P. Ibbetson, K. Nishi, A.C. Gossard, J.E. Bowers, Appl. Phys. Lett. 67 (1995) 3795.

[2] S.L. Yellen, R.G. Waters, P.K. York, K.J. Beernink, J.J. Coleman, Electron. Lett. 27 (1991) 552.

[3] D.L. Huffaker, G. Park, Z. Zhou, O.B. Shchekin, D.G. Deppe, Appl. Phys. Lett. 73 (1998) 2564.