

Droplet hetero-epitaxy of InAs quantum dots on InP nanopyramids formed by selective-area flow rate modulation epitaxy

R. Oga, S. Yamamoto, I. Ohzawa, Y. Fujiwara and Y. Takeda
Department of Materials Science and Engineering, Graduate School of Engineering
Nagoya University, Nagoya 464-8603, Japan
oga@mercury.numse.nagoya-u.ac.jp

We have grown InAs quantum dots (QDs) by droplet hetero-epitaxy on InP nanopyramids and investigated their luminescence properties. The nanopyramids with improved size control are formed successfully by selective-area flow rate modulation epitaxy (FME). In photoluminescence (PL) measurements at 4.2 K, characteristic luminescence due to InAs quantum structures is observed clearly, depending slightly on TMIn supply time during InAs growth.

In recent years, a variety of fabrication techniques have been developed for the purpose of the realization of device-quality semiconductor QD structures. Among them, self-assembling formation methods that utilize the Stranski-Krastanow (S-K) mode have been proved to be suitable for achieving high-density QDs with high optical quality. However, the uniformity and arrangement of the QDs are still far from those required for the realization of high performance optoelectronic devices. Selective-area growth has an advantage that structures with controlled sizes can be fabricated in specific positions. In this contribution, we report on the formation of InP nanopyramids with improved size control by selective-area FME, and droplet hetero-epitaxy of InAs quantum structures on the nanopyramids. Luminescence properties of the structures are also reported.

Selective area growth was carried out on masked S-doped (001) InP substrates with a 10 nm thick SiO₂ layer, which were patterned by electron beam lithography and wet chemical etching. Circular openings of 160 nm in diameter were periodically defined along the [110] and [1-10] directions with a period of 400 nm. The growth was performed at 76 Torr with a susceptor temperature of 620 °C. The formation of nanopyramids was carried out by alternate growth of In and P. The growth cycle consisted of a four-step gas injection sequence with a duration of 1s for each step. TBP flow rate was modulated from 1.19×10^{-6} mol/s to 3.38×10^{-6} mol/s, while TMIn flow rate was fixed at 1.68×10^{-8} mol/s. For InAs growth by droplet hetero-epitaxy, TMIn and TBAs were supplied at 1.68×10^{-8} mol/s and 3.35×10^{-6} mol/s, respectively. The supply time was varied from 1s to 4s. It was followed by FME growth of an InP cap layer.

Figure 1(a) shows a photograph of InP nanopyramids grown by FME. Four {111} facets of pyramidal structures are formed. Distribution of bottom size of the nanopyramids in the samples grown by conventional OMVPE and FME are shown in Fig. 1(b) and (c). The standard deviation in the sample grown by conventional OMVPE is 2188 nm². In FME, on the other hand, it is 1201 nm². This result clearly indicates that FME is useful for the formation of the nanopyramids with improved size control.

Figure 2 shows PL spectra in InP nanopyramid samples without (a) and with InAs (b~d). All the samples exhibit a sharp emission line at 875 nm, accompanied with a broad band near InP bandgap energy. The sharp line is due to bound excitons in InP nanopyramids. The broad band comes from the S-doped substrate. In the samples with InAs, characteristic luminescence is observed successfully, depending slightly on the TMIn supply time during the droplet hetero-epitaxial growth of InAs. Peak positions of the luminescence are 950 nm, 1080 nm and 1160 nm in the sample of 1s (Fig. 2(b)). In the sample of 2s (Fig. 2(c)), the spectral shape is basically the same as that in the sample of 1s. In the sample of 4s (Fig. 2(d)), the three peaks shift slightly to the longer wavelength region. The mapping of PL intensities of the peaks reveals that the two longer-wavelength bands originate from the nanopyramids and the 950 nm band from an unpatterned area surrounding the region. Based on these observations, the 950 nm band can be assigned due to an InAs quantum well formed on the unpatterned area, and the longer-wavelength bands due to InAs QDs on the nanopyramids. It should be noted here that InAs QDs are formed even for the TMIn supply time of 1s and that the size of the QDs remains almost constant against the increasing TMIn supply time.

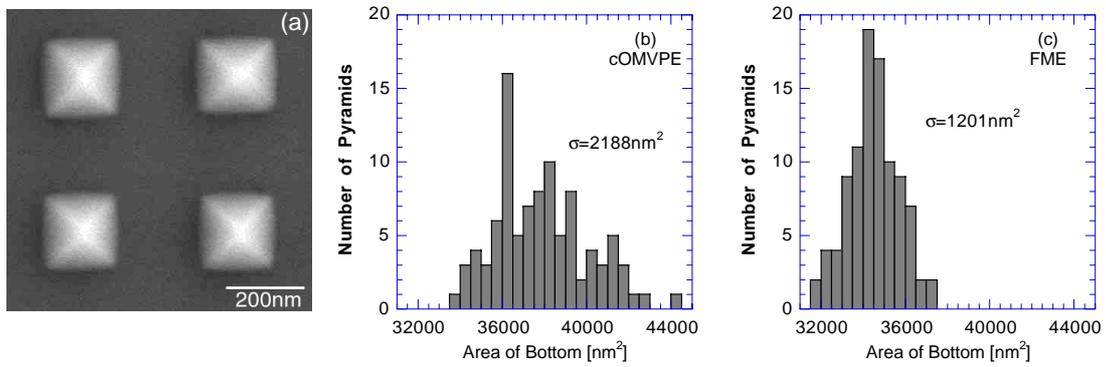


Figure 1 (a) SEM photograph of InP nanopillars grown by FME. Distribution of bottom size of the nanopillars; (b) conventional OMVPE and (c) FME.

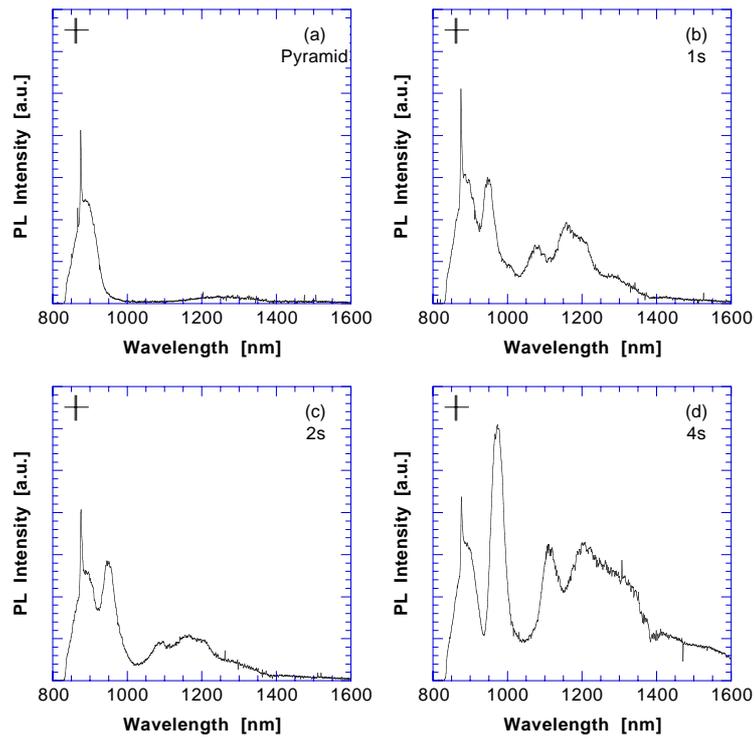


Figure 2 4.2K PL spectra in the nanopillar samples. (a) pillars without InAs, and (b)-(d) pillars with InAs grown with different TMIn supply times; (b) 1s, (c) 2s, and (d) 4s.