High Growth Temperature Studies of InAlAs/InGaAs Superlattices for High Performance QCL Applications

Jiun-Yun Li and Fow-Sen Choa

***Abstract*— High growth temperature studies of InGaAs/InAlAs superlattice were conducted to help to obtain high quality materials. Results show that at high temperature the window of stable growth condition shrinks and the amount of hetero-interfacial defects can be controlled by the length of the growth interruption period.**

***Index Terms*— Semiconductor lasers, semiconductor materials, superlattices**

I. Introduction

Since the invention of quantum cascade lasers (QCLs), the design of active region and waveguide structures have been improved for enhancing the laser performances such as output power, wall-plug efficiency, and maximum operation temperature. Most InGaAs/InAlAs lattice-matched QCLs are prepared by molecular beam epitaxy (MBE). It has the advantages of providing abrupt hetero-interfaces and the disadvantages of requiring a long growth time compared with using the metal organic chemical vapor deposition (MOCVD) technique. Furthermore, since the MBE growth temperature is much lower than that of the MOCVD, it is likely that the long term device reliability may become an issue in the future. So far, only few groups have successfully grown QCLs using MOCVD [1]-[3], and much less information was disclosed about the material aspects. In this work, we study the growth of InGaAs/InAlAs superlattice by MOCVD with different growth temperatures and V/III ratios. Furthermore, the impact of interruption time between alternating layers are studied by using room-temperature photoluminescence (PL).

II. Experiment

In general, high material growth temperature is preferable due to the reduction of impurity such as carbon or oxygen [4], [5]. However, for InGaAs, if the temperature is too high, the photoluminescence (PL) and morphology will deteriorate[6]. On the other hand for InAlAs, high temperature can help Al atoms move to the desired sites due to higher surface mobility, and thus will improve the material quality [7]. Furthermore, the V/III ratio also affects the morphology of InGaAs and InAlAs. When the V/III ratio increases, the morphology of InGaAs can be improved. However for InAlAs, the V/III ratio cannot be too high. There exists a growth window for the InGaAs/InAlAs system. In our study, we first focused on the quality of bulk InGaAs and InAlAs. We then grew superlattices and measured their x-ray and PL. The group III precursors used are trimethylindium (TMI), trimethylgallium (TMG), and trimethylaluminum (TMA). The group V precursors used are arsine and phosphine.

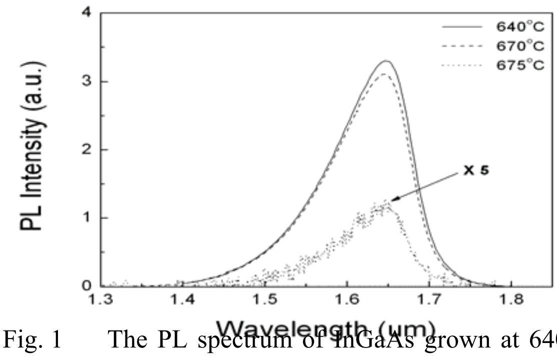

Fig. 1 The PL spectrum of InGaAs grown at 640, 670, 675^{o}C with V/III ~ 45.

III. Results

First, we study the high temperature growths of bulk ternary materials. Fig. 1 illustrates the PL intensity of InGaAs at three temperatures 640, 670, and 675^{o}C with V/III ratio of 45. The PL intensity decreases when the growth temperature is increased from 640 to 675^{o}C. If the temperature is increased to above 690^{o}C, no PL signal can be observed and surface morphology become bad. To remedy it, we increase the V/III ratio from 45 to 130. The maximum temperature without surface decomposition can be extended to 685^{o}C as shown in Fig. 2.

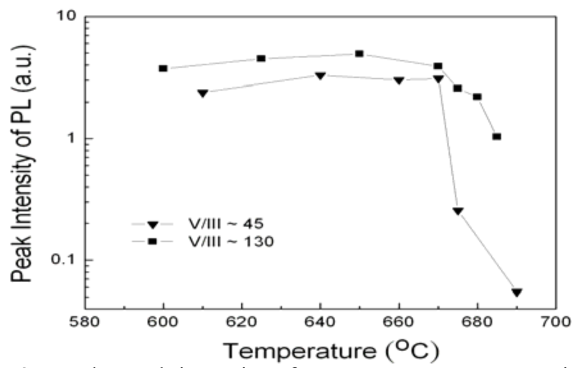

Fig. 2 The peak intensity of PL versus temperature with V/III ~ 45 and ~130.

For QCLs, high growth temperature can provide materials with low defects and achieve better device performance. Since the InGaAs material has a

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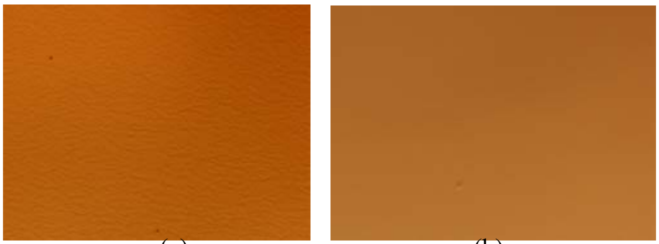
growth-temperature upper limit we need to reduce the InAlAs material growth temperature to match the two materials.

Fig. 3 (a) and (b) show the surface morphologies of InAlAs materials grown at 640 °C and 680 °C. The material grown at 680 °C apparently has a much smoother surface. Fine surface features can be observed for sample grown at 640°C. By keeping a V/III ratios below 150, excellent morphology of InAlAs materials were obtained even at lower temperature 660°C. This temperature is close to the maximum value we can grow good quality InGaAs. In fact, we expect we can push it higher to around 675°C. We believe that interface defects play a very important role to determine the scattering loss of electrons and optical absorption loss of photons.



(a) (b)

Fig. 3 Optical image of InAlAs grown at (a) 640°C; (b) 680°C Fine surface feature can be observed for the sample (a).

After the growth parameters of bulk InGaAs and InAlAs were determined, we grew superlattices to probe the effect of interface between quantum wells and barriers. The superlattice structure has 15 repeat units and each is composed of 4 layers: 10 nm InAlAs/3.2 nm InGaAs/2nm InAlAs/2.2 nm InGaAs. The core is sandwiched by two 150nm InGaAs buffer layers and then capped by a thin InP layer.

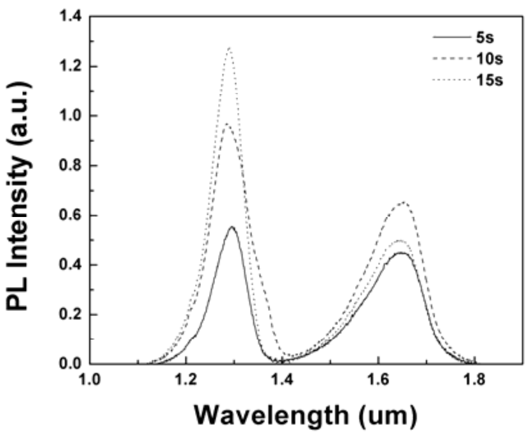


Fig. 4 PL spectra of MQWs with different interruption time

The PL spectrum is shown in Fig. 4 with an emission wavelength at 1.28 and 1.64 μm. The former is emitted from the superlattice and the later are related to emissions from the top InGaAs.

Here as the interruption and purging time increases from 5 second to 15 second, the PL intensity increases accordingly. The PL intensity represents carrier lifetime in the superlatttice. It reflects the crystal quality. We expect that the higher the PL intensity, the less the number of hetero-interface defects [8]. Furthermore, we grew a sample with no interruption between layers. The obtained PL intensity is the strongest among all samples. The emission wavelength also shifted to a shorter wavelength ~ 1.249 μm. It can be easily understood that the InGaAs layer actually becomes the InGaAlAs quaternary layer [9] due to the unclean switching process. There are much less interfacial defects generated since the switching only involves the Ga and Al flows, which is always matched.

IV. Conclusion

High growth temperature studies of the InGaAs and InAlAs and their superlattice were conducted to help to obtain high quality materials. The stable growth region becomes smaller when the growth is done at higher temperature. At high temperature the amount of hetero-interfacial defects can be reduced by increasing the growth interruption period.

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