CHAPTER V

CONCLUSIONS

$In_xGa_{1-x}As/GaAs$ cross-hatch virtual substrate (VS) is used as a template for the formation of laterally-aligned InAs QDs. The cross-hatch appearance on the surface of low-mismatched, single layer of $In_{0.15}Ga_{0.85}As$ due to the generation of misfit and threading dislocations is studied by AFM and TEM. The width and height of surface undulations along the [1-10] direction are greater than those along the [110] direction due to asymmetries of misfit dislocations. The strain of the InGaAs layers is studied by HRXRD measurements on samples with different InGaAs thicknesses and In compositions. It is found that the InGaAs layer relaxes more as the thickness and the In composition increase.

The InGaAs/GaAs VS is then used as a template on which QDs are grown. The orderliness of the QDs depends mainly on the surface undulations of the VS and partly on the growth interruption (GI) time. At *low* level of strain relaxation, the surface of the VS shows small, well-separated cross hatches. Growth of QDs on this VS thus results in laterally ordered QDs on the cross hatches. At *medium* level of strain relaxation, the surface of the VS shows larger (higher peak-to-valley distance), partially-merged cross hatches. Growth of QDs on this VS thus results in ordered QDs on the cross hatches (small group of QDs). At *high* level of strain relaxation, the surface of the VS shows largest (highest peak-to-valley distance), fully-merged cross hatches. Growth of QDs on this VS also results in ordered QDs on the cross hatches (but with increased groupings of QDs). In all cases, the formation of QDs reflects the variation in surface heights (thus strain energy) of the underlying VS.

The structural properties of QDs capped with partial GaAs layer are studied for large QDs, grown on conventional GaAs substrate, and small QDs, grown on cross-hatch VS. While nano holes are clearly seen in the middle of the large QDs, none exists in the case of small QDs. This can be explained by the effect of strain energy of the underlying layers. Since the surface undulations along the [1-10] and [110] are different, the structural changes of cross hatch patterns along these directions are not the same during the capping process. While the cross-hatch patterns along the [1-10] direction are *more* prominent, they are *less* prominent along [110] direction. Hence, the regrowth of QDs on the VS capped partially with GaAs layer results in QDs chain along the [1-10] direction.

There are some still unresolved issues which need further investigation. One issue is that PL emission peak is not observed for the QDs on cross hatch VS at room temperature (RT). This may be attributed to asymmetry of strain between the InGaAs underlying and GaAs capping layers since the strain completely determines the formation of nanostructures. RT PL emission peak at 1.3μm has been observed for the QDs embedded in lower confinement and upper confinement $In_xGa_{1-x}As$ layers with the same In composition (Seravalli et al., 2003). Therefore QD-dot strain engineering is needed in order to get appropriate strain for QDs by tuning the lower and upper layers of QDs. This means that these two layers must be pseudomorphic with each other. It is worthy to note that PL emission peak also depends on In composition for underlying InGaAs layer. The energy difference between the ground state of the QDs and potential barrier is lower for larger In composition layer. Due to lower barrier, thermal emission of carriers is higher than absorption. Therefore, RT luminescence emission decreases for the large composition in underlying InGaAs layer. Moreover, higher lattice mismatch between the $In_xGa_{1-x}As$ layer and GaAs substrate favours the nonradiative defects. This may also decreases the RT luminescence efficiency.

Another unresolved issue is that the evolution of QDs on cross hatch during capping process is not fully understood yet. One possible approach to overcome this problem is that large QDs on the VS should be created first. Then, various thicknesses of GaAs capping layers are grown on top of QDs in order to see the nanohole in the middle of QDs. The large QD may be obtained when the QDs are grown at higher temperature (more than 500°C). At higher growth temperature, In desorption increases and the time taken for QDs formation is longer than before. This means that the growth rate decreases while growth temperature increases. Consequently, In adatoms have a higher chance to be incorporated to the pre-existing island during the longer formation time since their diffusion length increases. But higher growth temperature more than 510°C, QDs may hardly form due to the thermal desorption. Another possible way is that the strain between the lower and upper confining layers of QDs has to be adjusted. In this case, QDs on VS have to be capped with $In_xGa_{1-x}As$ layers instead of being capped with GaAs layers. Then, the effect of cap layer on the shape evolution of QDs can be investigated by varying the In composition and the thickness of $In_xGa_{1-x}As$ capping layer.