CHAPTER 6
Conclusions

A study on spectral response of GaAs/GaAlAs staircase bandgap photodiodes has been done in this research. We have designed two types of staircase bandgap photodiodes comparing to the one of constant bandgap: (1) type A staircase bandgap photodiode, which the bangap energy of active layer is converged from that of $Ga_{0.6}Al_{0.4}As$ (P^+) window layer to that of GaAs (n^+) substrate and (2) type B staircase bandgap photodiode, which the bangap energy of active layer is diverged from that of GaAs (n^-) underneath $Ga_{0.6}Al_{0.4}As$ (P^+) window layer to that of $Ga_{0.6}Al_{0.4}As$ (N^-) layer near to the GaAs (n^+) substrate. The calculated generation rate and spectral response as well as the energy band diagram according to Anderson's Model lead to the conclusions as follows:

- The optimal thickness of $Ga_{0.6}Al_{0.4}As$ (P^+) window layer and GaAs (n^-) layer of constant bandgap photodiode are 2 μm and 6 μm respectively.
- The carrier generation of constant bandgap photodiode occurs near the junction where the high surface recombination exists.
- The constant bandgap photodiode does not have any band edge gradient within the active region and therefore no quasi electric field was produced. For this reason, the quantum efficiency can not be enhanced.
- Type A staircase bandgap photodiode has the advantages over the constant bandgap: (1) the carrier generation occurs far distance from the junction which electrons can drift toward the n-side very nearly and (2) there are several band edge gradients in active region which the quasi electric field can be produced, especially for electrons. Consequently, the electron multiplication can be gained.
- Type B staircase bandgap photodiode has the only advantage over the constant bandgap that is the band edge gradients in active region, especially for valence band. Hence the quasi electric field for holes can be mainly produced and the hole multiplication can be gained.
- The quasi electric field for electrons and holes in both types of photodiode can be separately adjusted by even doping aspect or the thickness control of the $Ga_{1-x}Al_xAs$ (N^-) staircase bandgap active layer. This will greatly benefit for the SAM APD to minimize the excess avalanche noise.
- From the theoretical point of view, the $Ga_{1-x}Al_xAs$ (N^-) staircase bandgap active layer would not prefer to absorb photons but produce quasi electric field whereas the GaAs (n^-) dominates the optical absorption. The $Ga_{1-x}Al_xAs$ (N^-) active layer is so called "multiplication region" and the GaAs (n^-) active layer is so called "absorption region" in the structure of SAM APD.

Afterward, we have fabricated three structures, namely Structure I, Structure II and Structure III. All structures are type A staircase bandgap photodiode. Structure I and II were grown by LPE while structure III was grown by MBE. Especially for structure III, the pn-junction is formed by Zn diffusion. The experimental results base upon the IV characteristic and spectral response could be concluded as follows:

- The cut in voltage of these structures is about 1-1.6 V, which is corresponding to the typical value of GaAlAs diodes while the breakdown voltage is around 2-5 V, which is not as high as it should be. In fact, the calculated value should be around 10 V or larger depending upon the doping density and the width of active region. [6], [12]

- The experimental spectral responses of these structures are almost consistent with the theoretical one except (1) the short wavelength responses expand more broader due to the diffusion current (2) the spectral response between 650 and 800 nm in case of structure I, and between 650 and 870 nm in case of structure II and III are fluctuated because of the recombinations around each interface of active layer

- The cutoff wavelength of structure I spectral response is 800 nm which is agreed with the cutoff wavelength of $Ga_{0.9}Al_{0.1}As$. In case of structure II and III, it is 870 nm which is corresponding to that of GaAs.

- In case of pn-junction formed by Zn diffusion, the short wavelength spectral response in between 400 and 750 nm depends upon the junction depth, which is controlled by the heating temperature as well as the diffusion time. The deeper the junction is, the lower the spectral response at short wavelengths can exhibit. By examining their energy band diagrams, the optimal pn metallurgical junction should be at location 3 or 4 to obtain the higher breakdown voltage and to benefit the most from the quasi-electric field.

The suggestion for further work is that the GaAs/GaAlAs staircase bandgap photodiode should be grown by MBE rather than LPE because the MBE itself is more precisely in process of thickness and doping control. Moreover, the surface morphology of MBE's epitaxial layer is more perfect than that of LPE. For this reason, the quasi electric field can really be adjusted and also the energy band discontinuity in active layer can be graded to suppress the recombinations. Therefore, the low noise avalanche photodiodes can be realized.