


三五族磊晶材料整合於矽基板上做為 高速電子元件跟光電元件應用的研究

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摘要



本論文成功利用矽鍺磊晶結構當作三五族材料跟矽基板之間的緩衝層，解決砷化鎵和矽基板之間晶格匹配和熱膨脹差異的問題，在本論文中結合矽離子的佈植和不同組成矽鍺磊晶層兩種方法，以成長低缺陷砷化鎵磊晶在矽基板上，矽離子佈植可以增加點缺陷，侷限住差排的移動與表面應力的釋放，不同組成的矽鍺磊晶層，藉由介面應力場的阻擋，可以將差排侷限在緩衝層之中，降低差排密度，結合這兩種技術設計，亦可將緩衝層厚度降至 1.0 μm 以下，低緩衝層厚度，可避免熱應力在薄膜間造成裂痕，這種成長技術成功的將三五族高速元件跟發光元件應用在矽基板上。

在高速電子元件方面，我們成功的將砷化鋁鎵/砷化銻鎵通道的高速電子遷移率電晶體元件結構(AlGaAs/InGaAs channel HEMT) 透過矽鍺緩衝層，長在矽基

版上面，其電子遷移率為 $3,550\text{cm}^2/\text{Vs}$ ，當在此晶片上製作完成 HEMT 元件後，在直流特性方面，當汲-源極電壓 (V_{DS}) 1.5V 時，在最大飽和電流 (I_{dss}) 可以達到 $150\text{mA}/\text{mm}$ ，轉導值 (g_m) 可以達到 $155\text{mS}/\text{mm}$ ，在偏壓為時 14.2V ，漏電電流為 $5\mu\text{A}$ 。

在超高速電子元件磊晶方面，我們成功的透過我們開發的矽鍺緩衝層，將砷化銦通道的高速電晶體長在矽基板上面，其電子遷移率為 $27,300\text{cm}^2/\text{v}\cdot\text{s}$ 。方法是利用超高真空化學氣象沈積法成長矽鍺緩衝層，再利用分子束磊晶法成長銻化鋁鎵、銻化鋁等材料去調變與矽鍺緩衝層 7% 晶格差異，利用這種磊晶結構設計，最後可以在矽基板上得到高品質砷化銦通道的高電子遷移率的電晶體。

在光電材料方面，我們利用有機金屬氣相沈積法，將自組性砷化銦鎵量子點成長在矽鍺緩衝層上面，利用穿透性電子顯微鏡跟原子力電子顯微鏡觀察到在 450°C 時，砷化銦量子點密度可以達到 $1 \times 10^{11}\text{cm}^{-2}$ ，而 PL 之光譜波長為 110nm ，這種材料研發可以應用在近紅外波長等光電元件上。

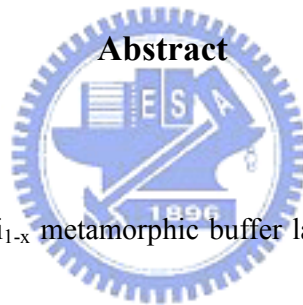
The Study of III-V Epitaxial Material on Si Substrates for High-Speed Electronic and Optoelectronic Applications

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Abstract

In this dissertation, $\text{Ge}_x\text{Si}_{1-x}$ metamorphic buffer layers were used for the growth of the III-V material on the Si substrate. Using Ge/ $\text{Ge}_x\text{Si}_{1-x}$ metamorphic structure as the buffer layer, the thermal expansion mismatch and the lattice mismatch problems of the interface between GaAs and Si was solved. The use of Si^+ pre-ion-implantation combined with a $\text{Ge}_x\text{Si}_{1-x}$ metamorphic buffer structure for the growth of the Ge layer on Si substrate was proposed. Enhanced strain relaxation of the $\text{Ge}_x\text{Si}_{1-x}$ metamorphic buffer layer on Si substrate was achieved due to the introduction of point-defects by heavy dose Si^+ ion-implantation. Because of both strain relaxation enhancement and the interface-blocking of the dislocations in the $\text{Ge}_x\text{Si}_{1-x}$ metamorphic buffer structure,

the total thickness of the buffer layer was only 1 μ m. The thinner buffer structures are preferred for the growth of the GaAs layers on Si substrate due to the large thermal expansion difference between these two materials.

We demonstrated epitaxial growth of AlGaAs/InGaAs HEMT grown on Si substrate with Ge/Ge_xSi_{1-x} buffer is demonstrated for the first time in this study. The electron mobility in the In_{0.18}Ga_{0.82}As channel of the HEMT structure grown was 3,550cm²/Vs. After process, the HEMT device demonstrated a transconductance of 155 mS/mm and a saturation current of 150 mA/mm when the drain-source voltage (V_{DS}) was 1.5V. After isolation etched, the HEMT structure demonstrated a leakage current of 0.016 μ A/ μ m when the bias voltage was up to 14.2V.

A high mobility InAs channel MHEMT structure was also grown on Si substrate with 6° off angle toward to [110]. The Hall measurement shows that the electron mobility of the InAs MHEMT grown on Si was 27,300 cm²/v-s. A novel Ge/Ge_xSi_{1-x} buffer layers were used as the buffer and were grown by using UHV/CVD method. The AlGaSb/AlSb/GaAs layers were grown by MBE process to accommodate the lattice strain induced by the large lattice mismatch of 7 % between the AlGaSb/InAs HEMT structure and the Ge layer.

Self-assembled In_{0.22}Ga_{0.78}As quantum dots (QDs) on Si substrate by metal organic vapor phase (MOVPE) with Ge/SiGe as buffer layer grown were investigated.

Transmission electron microscopy (TEM) and atomic force microscopy (AFM) images were used to observe the size and space distribution of the $\text{In}_{0.22}\text{Ga}_{0.78}\text{As}$ QDs grown on the $\text{GaAs}/\text{Ge}/\text{Ge}_x\text{Si}_{1-x}/\text{Si}$ layer structure. The influence of the growth temperature on the QDs size and density distribution was investigated. For QDs grown at 450°C , the density of the $\text{In}_{0.22}\text{Ga}_{0.78}\text{As}$ dots was estimated to be $1 \times 10^{11} \text{ cm}^{-2}$, the average size of $\text{In}_{0.22}\text{Ga}_{0.78}\text{As}$ QDs were 20nm and PL spectrum was 110nm.

