分子束磊晶法於砷化鎵基板成長 1.3 微米半導體雷射

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摘要

本論文研製之方法是利用固態源分子束磊晶技術法在砷化鎵的基板上成長發光波長介於 1.3µm~1.55µm 應用於光纖通訊的磊晶層發光材料並製作元件並分析其元件特性。研究的材料包含 InAs 的量子點與 InGaAsN 的量子井發光層。

第二章為砷化銦（InAs）量子點的材料研究，改變不同銦原子的成長速率得到發光波長的改變及量子點密度的變化並且同時利用變化不同的材料及結構的改變，變化量子點的能階及應力;如以 InGaAs, InAlAs and AlAs 覆蓋於砷化銦（InAs）量子點上。利用不同材料的晶格結構及應力的不同，此法可以將發光層的波長拉長及減少量子點大小的不均勻性更可以將發光層的基態與激發態距離拉遠，並且利用多層結構提高材料增益而製作出高效率的雷射元件。在砷化銦（InAs）的材料研究分析上對單層的量子點的材料，改變厚度使其從完美的晶格排列結構至超過臨界厚度所產生過大的應力引起晶格鬆弛的行為變化以光性及電性的量測方式最深入的研究探討。

第三章是針對量子點的磊晶技術進一步發展至元件的製作及量測。在此章節中利用上述磊晶及結構方式製作高效率的雷射元件，其起始電流為 26mA,發光波長為 1.31 微米的邊射型雷射元件。面射型雷射的部分利用了上下導電的布拉格反射鏡面（DBRs）並以多層量子點結構做為發光層的電激發量子點面射型雷射，元件成功產生電激發光並且是目前世界上少數成功發表之一，也是相當令人振奮的成果。第四章的部分成長含氮原子的材料，我們利用 Epi unibulb radio-frequency(rf) plasma 作為氮的材料源。利用低溫成長的方式抑制了材料本身所產生的相分離現象。以成長

GaAsN 厚膜為基礎改變成長速率，成長溫度及氮含量從這些磊晶的條件下尋求出最佳化的磊晶條件並應用於成長氮化銦鎵（InGaAsN）的量子井材料，在氮化銦鎵（InGaAsN）量子井的研究上我們改變了不同長晶速率，銦及氮的含量比及變化材料的屏障層及活化溫度並將發光強度及發光波長做一系列的最佳化。於電性上的研究中也同時清楚的看到不同長晶速率的量子井結構中，低的長晶速率所產生相分離的情況所形成的晶格缺陷也在電性量測中被解析出來。

第五章我們製作了以氮化銦鎵（InGaAsN）做為發光層的邊射型及面射型的元件，同時以邊射型的雷射特性結果來驗證氮化銦鎵（InGaAsN）發光層的磊晶品質已達到高功率的元件特性水準，在面射型雷射的元件上我們改變了不同寬度的氧化侷限層在電激發光的結果中同時顯現出多模及單模的元件特性結果。

GaAs-based 1.3μm lasers grown by MBE

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Abstract

The main purpose of this dissertation is to investigate quantum dot (QDs) growth mechanism and to optimize the material quality of GaAs based compound semiconductor telecommunications laser applications. Our final goal is to demonstrate high performance vertical cavity surface emitting lasers (VCSELs) at 1.3μm. The other main focus are on the two laser active media InAs quantum dot and InGaAsN quantum well which emit light in the wavelength range in the widely used in the optical communications.

In chapter 2, the Molecular Beam Epitaxy (MBE) technique is used to study the InAs QDs growth. Growth conditions such as V/III ratio, indium growth rate, and QDs combination layer were characterized by optical and electrical measurements. Our study on the material growth mechanism was aimed to find out the optimum QDs growth condition, for high quantum dots density and better light emitting material quality. The carrier transportation and relaxation from relaxed QDs were also investigated.

Chapter 3 deals with characterization of VCSEL. To realize both fully doped InAs/GaAs QDs, InGaAsN/GaAs QW VCSELs at 1.3μm is a challenging task since several problems must be overcome. To demonstrate the successful operation of these two devices is indeed a major break through in this work. We succeeded in solving such issues as semiconductor DBR reflectivity, detuning ranging, resistance of device, nitrogen solubility, and plasma damage in the course of this study. In addition, an oxide confined structure, incorporated in the VCSEL design, provides significantly better optical and electronical confinement and thus remarkably improve laser threshold current and efficiency. Therefore, several record-breaking lasers have been made. (1) Single

mode lasing at 1.31 μm with full width at half maximum of 45^0. (2) A threshold current of 26 mA equivalent an current density of 173 A/cm^2. (3) External differential efficiency of 45% (0.43 W/A). (4) A characteristic temperature 85K indicating the J_{th} temperature stability with 20-60^{0}C range has been derived experimentally. (5)The single transverse mode and room temperature continuous wave threshold current below 1 mA are achieved.

Chapter 4 demonstrates the optimal growth conditions of GaAsN and InGaAsN compound semiconductor alloys by RF plasma-assisted MBE. GaAsN and InGaAsN are two new dilute nitride alloys promising for a wide range of optoelectronic devices. RF plasma-assisted MBE technique is often applied to yield the high growth rate of these two alloys. In general RF plasma is easily affected by many control parameters. The parameters-forward and reflected RF powers, injected nitrogen flow rate, mixed As/N materials, ion defection plate, and the aperture size and holes are critical to compound semiconductor growth. Significant efforts have been made on the investigation of these factors. In addition, in order to grow high quality GaAsN and InGaAsN, the phase segregation problem can be suppressed by setting the substrate temperature, total growth rate, and nitrogen composition. Post annealing was applied to improve the material quality following low temperature growth. As a result, the PL intensity can increase by a factor of two orders of magnitude.

Chapter 5 focuses on the InGaAsN/GaAs laser device characterization and design. A single mode laser operation with the J_{th}=22mA, different efficiency of 62%, and an output power more than 210mW. This power value is the highest value ever reports for single mode 1.3μm GaAs based laser. A monolithic intra cavity contacted VCSEL with an InGaAsN/GaAs QWs active region, emitting light at 1304 nm, was fabricated by low-temperature growth MBE. The output power for this lasers with 18μm oxided aperture size, an achieve more than 10 mW with an initial slope efficiency of 0.20 W/A under pulse operation, while under CW operation of 7μm oxide aperture has been demonstrated the output power exceeds 1 mW with an initial slope efficiency of 0.15 W/A.

Furthermore, a RT-CW single mode output power of 0.75 mW with an initial slope efficiency of 0.17 W/A and a side mode suppression ratio of 40 dB was achieved. This work successfully demonstrated low temperature MBE growth of high-quality InGaAsN/GaAs intra-cavity contacted VCSEL at 1.304μm.