國 立 交 通 大 學

電 子 物 理 研 究 所

博 士 論 文

Ⅲ-族氮化物表層缺陷研究

Investigation of interfacial defects
in Ⅲ-nitride

研 究 生：黃國欽

指導教授：黃凱風

中華民國　九十八年六月

Ⅲ-族氮化物表層缺陷研究

Investigation of interfacial defects
in Ⅲ-nitride

研 究 生：黃國欽　　Student: Kuo-Chin Huang

指導教授：黃凱風　　Advisor: Kai Feng Huang

國 立 交 通 大 學

電 子 物 理 研 究 所

博 士 論 文

A Dissertation
Submitted to Institute of Electrophysics
College of Science
National Chiao Tung University
in partial fulfillment of the Requirements
for the Degree of
Doctor of Philosophy
in Electrophysics
June 2009
Hsinchu, Taiwan, Republic of China

中 華 民 國　九十八年六月

Ⅲ-族氮化物表層缺陷研究

黃國欽[1] 黃凱風[2]

國立交通大學電子物理所

摘要

在本論文中，我們研究表面缺陷特性以氮化鎵材料為主並藉由蕭特基元件在不同表面處理的條件下探討電流轉換機制及缺陷密度，並利用特徵電阻(Specific contact resistance)、理想因子(Ideality factor)及特性參數(characteristic energy)作分析。另外為了研究表面缺陷對元件的光電性影響，光檢測器的製作與元件特性經由不同表面處理及熱穩定性也將在論文中一一探討。其中元件在沒有經由電漿式耦合蝕刻(ICP)的條件下，電流轉換機制由熱激發式(Thermionic emission；TE)來主導，另一方面，當元件經由電漿式耦合蝕刻(ICP)的處理後 ，其電流轉換機制將由熱激發式轉而變成場發式 (Field emission；FE)來主導，其原因主要是由於元件使用電漿式耦合蝕刻(ICP)後會在元件表面產生表面缺陷而改變其電流轉換機制 ，而這些由電漿式耦合蝕刻(ICP)產生的表面缺陷可以經由在高溫 600℃氮氣或 500℃氫氣下減少並使電流的轉換機制由場發式轉而變成熱激發式，以改善元件的特性。

另外我們使用了電容 對頻率(Capacitance-frequency；C-f)的方

法去分析元件經由電漿式耦合蝕刻(ICP)後所產生的表面缺陷形式，約可分為 s-type、m-type 及 f-type。其中 s-type 的表面缺陷主要是來自於元件經由電漿式耦合蝕刻(ICP)處理後所產生的缺陷並可藉由在高溫 600℃氮氣或 500℃氫氣下減少，另外 m-type 及 f-type 的表面缺陷是來自於元件本身的磊晶成長缺陷並亦可利用在 高溫氮氣或氫氣下降低缺陷密度。

另一方面光檢測器利用電漿式耦合蝕刻 (ICP)後所產生的表面缺陷及高溫處理後，將可產生較高的光響應及內部增益，其中光檢測器光響應藉由在氮氣高溫合金 400℃、500℃及 600℃下各別為 3.95A/W、0.72A/W 及 1.85A/W 與內部增益在氮氣高溫合金 400℃、500℃及 600℃下各別為 195、36 及 84。較高的光響應及內部增益主要是由於光檢測器利用電漿式耦合蝕刻(ICP)後所產生的表面缺陷及高溫處理後在其元件的材料特性中，有較多的電洞或電子被補捉，當元件操作在高電場及照光下 將藉由這些電洞或電子被補捉與增加碰撞機率產生更多的光電子。

1) 作者

2) 指導教授

Investigation of interfacial defects in Ⅲ-nitride

Kuo-Chin Huang[1] Kai Feng Huang[2]

Abstract

The interfacial defects properties of GaN-based Schottky diodes have been investigated and fabricated by utilized current voltage temperature (*I-V-T*) and capacitance-frequency (*C-f*) methods. Surface states effects of metal-semiconductor-metal (MSM) photodetectors (PDs) and p-i-n PDs is applied high reverse electrical field in illumination to confirm the relationship between ICP-induced defects and optoelectric devices characteristics in this dissertation. The current transport mechanisms are analyzed in terms of specific contact resistance (ρ_c), characteristic energy (E_{00}) and ideality factor (η) under different annealing temperatures. The current transport mechanisms of non-treated *n*-type GaN was TE and was FE based on the finding that the sample by using ICP etching processes. However, the current transport mechanisms can be changed from FE to TE by annealing at 600℃ in N_2 ambient or 500℃ in H_2 ambient, that is, the current transport mechanism dominates TE or between TE and FE. These results showed that the ICP damages were reduced to a low level and the Schottky diodes characteristics recovered by annealing 600℃ in N_2 ambient or 500℃ in H_2 ambient. In this dissertation, we have found that the current transport mechanisms are directly

dependent on the surface treated conditions, and annealing processes are an effective step in eliminating these defects, and characterize ICP-induced defects such as *s*-type, *m*-type and *f*-type interfacial defects by capacitance-frequency (*C-f*) methods. The *s*-type interfacial defects can be reduced by annealing temperature increasing to 600℃ in N_2 ambient or 500℃ in H_2 ambient. The *m*-type interfacial defects can be recovered to non-treated *n*-type GaN by annealing at high temperature in N_2 ambient or in H_2 ambient. In *f*-type interfacial defects, annealing in N_2 ambient is more effective than that in H_2 ambient. The interfacial defects of the Schottky diode with ICP induced defect is dominant *s*-type, and non-treated sample is dominant *f*-type. The interfacial defects is *f*-type indicating the ICP induced defects nearly recovered to non-treated sample, this is the defects result from epitaxial growth such as dislocation or the others.
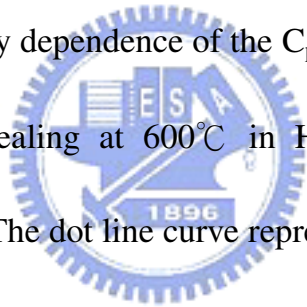
On the other hand, the higher responsivity and internal gain for metal semiconductor metal photodetectors (MSM-PDs) with different surface treatment have been fabricated. The responsivity of MSM-PDs with annealing at 400℃, 500℃ and 600℃ in N_2 ambient by applying reverse bias -1Volt is 3.95A/W, 0.72A/W and 1.85A/W, respectively. The internal gain of MSM-PDs with annealing at 400℃, 500℃ and 600℃ in N_2 ambient at a photon energy of 3.35eV by applying reverse bias -1Volt is 195, 36 and 84, respectively. The higher responsivity and internal gain characteristics for MSM-PDs with ICP etching process and annealing in N_2 ambient at different temperatures are clearly observed. This result may attribute to interfacial
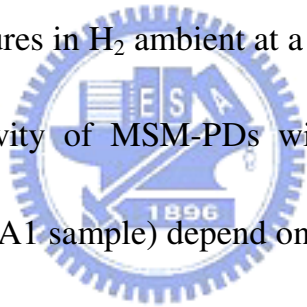
states such as holes traps what capture or emit electrons or hole as applied high reverse electrical field and illumination. The persistent photoconductivity effects (PPC) in MSM-PDs with interfacial states by annealing treatment have been studied to confirm the ICP-induced defects exist. Photocurrent gradually increased and the dark current decreased with measured time is observed. These results may also attribute to the presence of holes trap or acceptor-type trap states.

1) Author, Department of Electrophysics, National Chiao Tung University

2) Advisor, Department of Electrophysics, National Chiao Tung University

誌謝

（Acknowledgements）

的包容，讓我可以學以致用在工作上，將工作與學習融為一體，並能從中獲得對物理原理的探討與知識，並感謝這七年來一路陪我走過來的璨圓光電同事們，謝謝你們平時的相處與鼓勵，豐富了我的生命與生活，有你們的日子裡讓我感受到朋友的真諦。

感謝口試委員藍文厚教授、陳振芳教授、陳永富教授、簡奉任董事長、林文仁博士及李晉東博士對本論文的指導與建議。

最後感謝我的父母親及家人們平時對我的包容與關心，從高中時期到今日在外求學總是聚少離多 ，隨著時間的增長離家越遠回家越少，在此我想告訴我的爸爸媽媽：你們辛苦了，雖然我花了不少時間才完成學業，但我把你們沒有讀的書與夢想完成了。另外在修讀博士期間，特別感謝李卓燕多年來的鼓勵與支持，在課業之餘充實我的精神生活與陶冶心靈，豐富了我的生命與生活，為我的人生寫下值得回憶的樂章。

Contents

Table captions

Figure captions