國立交通大學

材料科學與工程學研究所
碩士論文

光輔助化學蝕刻對氮化鎵材料的研究

The study of photoenhanced chemical etching for GaN materials

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中華民國九十三年七月

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碩 士 論 文

A Dissertation

Submitted to Department of Materials Science and Engeneering
College of Engineering
National Chiao Tung University
In Partial Fulfill of the Requirements
For the Degree of
Master of Science
In Materials Science and Engineering
2004
HsinChu, Taiwan, Republic of China

中華民國九十三年八月

Contents

致 謝

在經過了兩年碩士生涯的訓練，讓我學習到如何的獨立研究、與人討論交流、解決所遭遇的問題…，首先要感謝的是張翼老師讓我有這學習的機會，豐富的實驗資源與完整的實驗儀器，提供我充分學習的機會，衷心感謝!

創業惟艱，這實驗能有一個初步的結果，最要感謝的是黃瑞乾學長，給予我實驗上需要的最大幫忙，也是我腦力激盪的一位好夥伴!沒有他，就沒有今天的成果!還有徐金鈺學長，也常常給我一些製程上的觀念，讓我對整體的概念有更清楚的輪廓。張家達學弟每星期不辭辛勞地為我簽 SEM 的儀器使用時段，也是這實驗能完成的大功臣。

此外，我要謝謝梁坊旭先生、詹前璋先生、張晃崇學長、李晃銘學長、褚立新學長、謝炎彰學長、邵宜暄同學、呂宗育同學、葉協鑫同學…，他們對這實驗的完成也都功不可沒!還有許許多多對我有幫助的同學、朋友，這裡沒能提到你們，不過我會牢記在心的!謝謝你們大家。

最後，感激我的父母、哥哥、堂哥、女朋友，在最艱難的時刻，因為有你們的支持，讓我能咬緊牙根的持續下去!

8.23.2004

光輔助化學蝕刻對氮化鎵材料的研究

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摘 要

這實驗主要在研究光輔助化學蝕刻對氮化鎵材料的蝕刻情形和利用光輔助化學蝕刻來製作氮化鋁鎵/氮化鎵高電子遷移率場校電晶體。經過測試後，最佳蝕刻條件是:KOH 莫爾濃度 0.015M、汞燈強度 30~50mW/cm^2、鈦金屬蝕刻保護罩(Ti)、溶液有攪拌。N 型參雜和未參雜的氮化鎵蝕刻速率分別是 70nm 和 35nm。本實驗嘗試用氮化鎵歐姆接觸金屬來當成蝕刻保護罩，且用新的機制來解釋於實驗中所發現的現象。我們也用所測得的蝕刻條件進行氮化鋁鎵/氮化鎵高電子遷移率場校電晶體的製作。利用光輔助化學蝕刻進行元件絕緣步驟的氮化鋁鎵/氮化鎵高電子遷移率場校電晶體的 DC 直流特性為:轉導值 115mS/mm、飽和電流 510mA/mm;同樣的製程條件，利用偶合電漿乾式蝕刻來進行元件絕緣步驟的場校電晶體，有比較低的 DC 直流特性:轉導值 110mS/mm、飽和電流 460mA/mm

The study of photoenhanced chemical etching for GaN materials

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Abstract

This research focuses on the photoenhanced chemical etching of GaN and fabrication of AlGaN/GaN HEMTs using photoenhanced chemical etching process. The etching conditions were: KOH solution concentration 0.015M, light intensity 30~50mW/cm^2, Ti was used as etching mask, solution was stirred. The etching rates for n^+-GaN (10^{18}/cm^3) and n^--GaN (10^{17}/cm^3) were 70nm and 35nm respectively. In this work, we use ohmic contact as an etching mask and a new mechanism was used to explain the etching phenomena observed. The photoenhanced chemical etching was applied to the fabrication of AlGaN/GaN HEMTs with optimized etching conditions. The AlGaN/GaN HEMT device fabricated with PEC process for mesa isolation showed following DC performance: transconductance 115mS/mm, saturation current 510mA/mm. The same devices fabricated with dry eching for isolation had lower transconductance and saturation current, 110mS/mm and 460mA/mm respectively.

Chapter 1
Introduction

Because of the excellent physical and chemical properties, such as high band gap (3.4eV), high breakdown field (5×10^6V/cm), high electron saturation drift velocity (3×10^7cm/s)…etc, GaN based Ⅲ-Ⅳ nitrides become important materials for applications in the optoelectronic devices and high power electronic devices, such as light emitting diodes (LEDs), laser diodes (LDs), heterostructure field-effect transistor (HFETs)… etc.

The fundamental step in realization of any devices is the transfer of patterns to the surface of semiconductor by etching. For optical and high frequency applications, patterning of the semiconductor on micrometer and submicrometer scales is required. The most convenient etching of GaN has been accomplished by dry etching methods, including reactive ion etching (RIE) , inductively coupled plasma (ICP) RIE, electron cyclotron resonance (ECR) RIE、low energy electron enhanced etching (LE4).

For the applications of high power and high frequency electronic devices, the ion damage due to the strong bombardment of physical component induced by dry etching method would degrade the device performance. The wet etching method is a complement to dry etching by providing low etching damage, low cost, complexity, and selective etching of different materials. Due to the strong chemical stability of GaN

materials, the etching rate is only several tens of angstroms per minutes for GaN film using wet chemical etchant.[1] The etching rate of GaN in different chemical solution is listed in Table 1.

Chemical	Temperature (°C)	Etch rate (μm/min)	Etching planes observed
Acetic acid (CH_3COOH)	30	<0.001	None
Hydrochloric acid (HCl)	50	<0.001	None
Nitric acid (HNO_3)	81	<0.001	None
Phosphoric acid (H_3PO_4)	108–195	0.013–3.2	$\{10\bar{1}\bar{2}\}$,$\{10\bar{1}3\}$
Sulphuric acid (H_2SO_4)	93	<0.001	None
Potassium hydroxide (KOH), molten	150–247	0.003–2.3	$\{10\bar{1}0\}$,$\{10\bar{1}\bar{1}\}$
50% KOH in H_2O	83	<0.001	None
10%–50% KOH in ethylene glycol (CH_2OHCH_2OH)	90–182	0.0015–1.3	$\{10\bar{1}0\}$
50% NaOH in H_2O	100	<0.001	None
20% NaOH in ethylene glycol	178	0.67–1.0	None

Table 1. The etching condition for different chemical solution.

Due to the specific chemical stability, it is difficult to etch GaN film by general wet etching method at the room temperature. Photoenhanced chemical etching on GaN has recently identified as a method of greatly improving the chemical reactivity of GaN at the room temperature. The developed wet etching process based on PEC reactions in KOH solution have been published.[2,3] J.Skriniarova et al.[4] reported the results of GaN etched in KOH, NaOH, and AZ400K etching solutions with an external

bias. Etching rate as high as approximately 400nm/cm^2 by using KOH solution have been published.[5]

The photoenhanced chemical etching technique holds promise as a method for low-damage processing of GaN-based electric and optoelectronic devices. However, previous demonstrations of this technique would result in significant levels of roughness on the etched GaN surface. It is shown that smooth etching occurs for low solution concentration and high illumination intensity under a diffusion limited etching process. The surface roughness of 1.5nm and 50nm/min etching rate are obtained using KOH solution and Hg arc lamp.[6]

As mentioned above, PEC etching has the advantages of low etching damage and smooth surface, so we hope to develop the PEC etching technique on GaN HEMT. However there are no etching recipes of PEC etching for us, we need to get PEC etching recipes, and finally apply the PEC etching on the GaN power transistor.

Chapter 2
Fundamentals

2.1 The reaction formula for PEC etching

The photoenhanced chemical etching for GaN materials is departed into two main sub-reactions, as the oxidation reaction and dissolution reaction[7]. Due to the strong chemical stability, it is difficult to etch GaN with KOH solution at room temperature, so the GaN film must be excited by the Hg arc illumination to generate electron-hole pairs at the sample surface.

$$\mathbf{GaN + photon \rightarrow GaN + e^- + p^+}$$

Then, the p^+ and GaN material would interact with OH^- in the solution, and produce Ga_2O_3.

$$\mathbf{2GaN + 6p^+ + 6OH^- \rightarrow Ga_2O_3 + N_2 + 3H_2O}$$

After the oxidation step, the Ga_2O_3 would react with OH^- and dissolve in the KOH solution.

$$\mathbf{Ga_2O_3 + 6OH^- \rightarrow 2GaO_3^{3-} + 3H_2O}$$

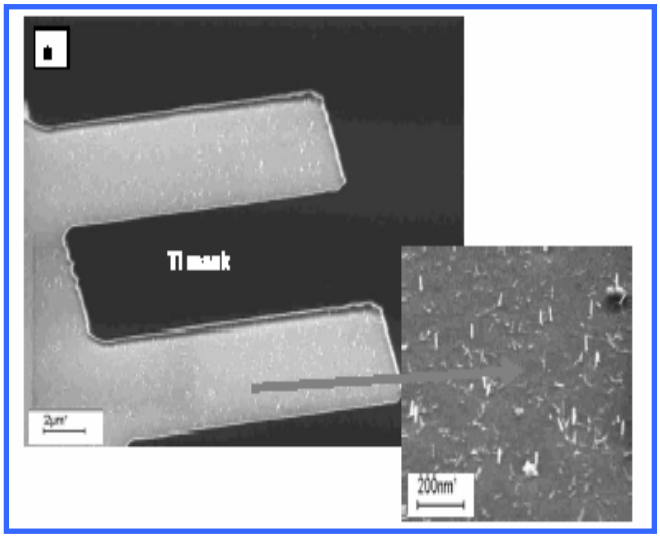
When high light intensity and low solution concentration are used, and the oxidation rate and the dissolution rate reach a steady state, the smooth etched surface would be obtained. It is so called diffusion limited process.[6]

2.2 selective etching of defects and perfect crystal of GaN film

Because of the limitation of epilayer growth techniques, amounts of crystal defects exist in the GaN bulk, including vacancy, dislocation, and impurity, in the order of $10^8/cm^2$. Due to the different physical and chemical properties, the selective etching occurs at dislocation[8]. At dislocation, it has the fast electron-hole pair recombination rate than normal crystal, so there is a low etching rate by the lack of p^+. With the increasing of the UV light intensity, the instant generation amounts of electron-hole pairs would increase, and lower the recombination effect at the dislocations. The smooth etching surface could be obtained by the lower of the selective etching effect.

In accordance of the literatures, it shows that the etching peaks are mostly Ga_2O_3 after PEC etching, so peaks can be removed by hot KOH treatment[9,10]. Figure 2.1 show the etched surface before hot KOH treatment and after hot KOH treatment.

(a)



(b)

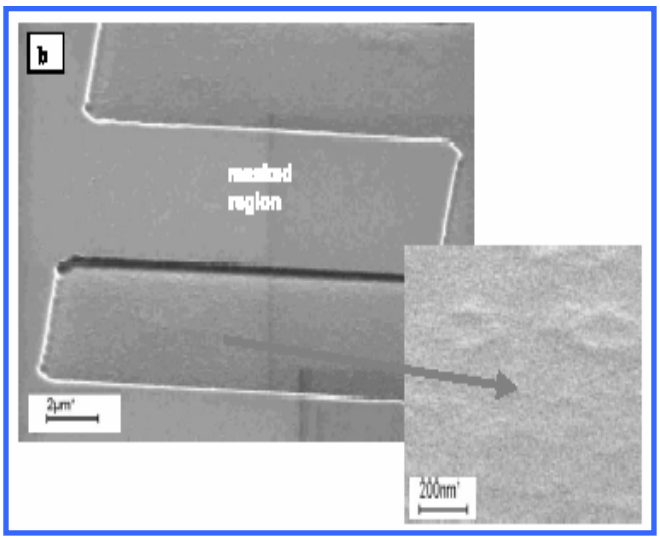


Figure 2.1 the etched surface (a) before (b) after hot KOH treatment

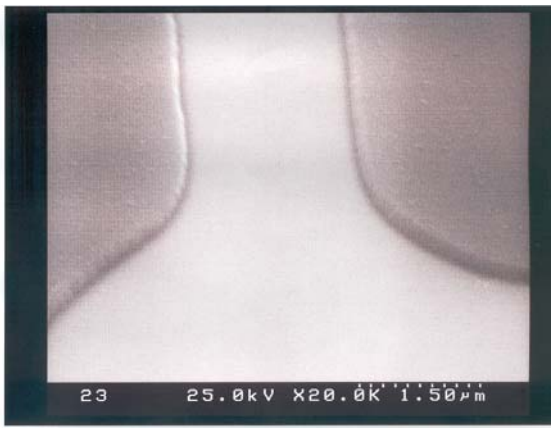
Chapter 3
Experimental

3.1 The etch conditions for PEC etching

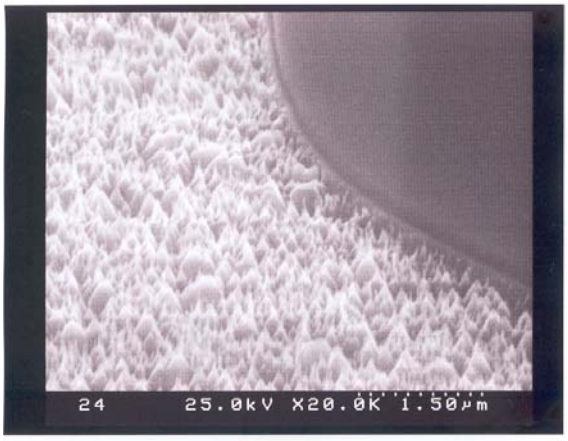
To optimize the etching conditions for solution concentration and light intensity would be carried out first. For light intensity, we applied three different illumination powers, 200W, 300W, and 400W respectively. The etching results were showed in Figure 3.1. Throughout this test, we chose the 400W as the illumination power, because the etching peaks for 400W were finest than 200W and 300W, and the peaks can be removed clearly by hot KOH treatment. The optimized light intensity condition using in the experiment was shown in Figure 3.2.

Besides of light intensity, the recipes of KOH solution concentration were also optimized. In the beginning, we used KOH concentration in the range of 1M to 0.001M, but we found that 1M was rough etching and 0.001M was no etching. Finally the most proper conditions were decided between 0.01M and 0.05M.

(a)



(b)



(c)

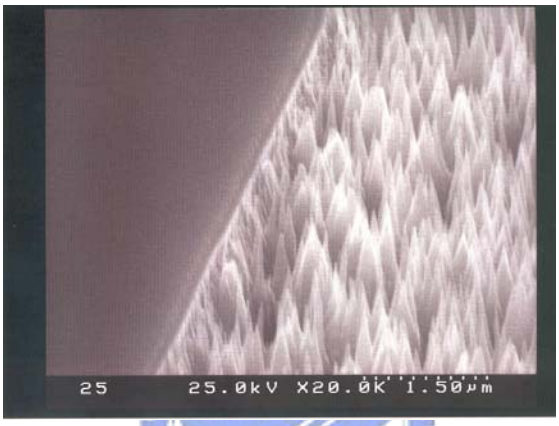


Figure 3.1 The SEM images for n-GaN using Ti mask at different illumination power for 0.015M KOH after 2 hours PEC etching (a)200W (b)300W (c)400W

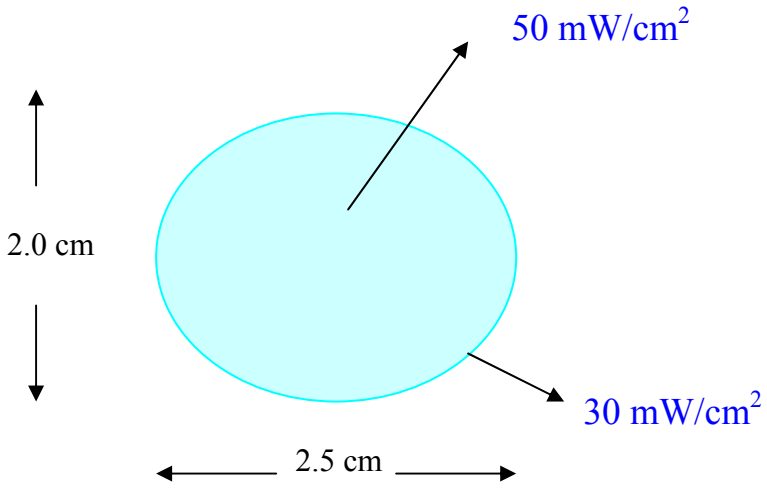


Figure3.2 light intensity condition in the experiment (400W)

In order to improve the convenience of experiments and practicality, we designed the new equipment in Figure 3.3. Both of the parallel light source and the sample carrier increased the efficiency and stability of the PEC etching.

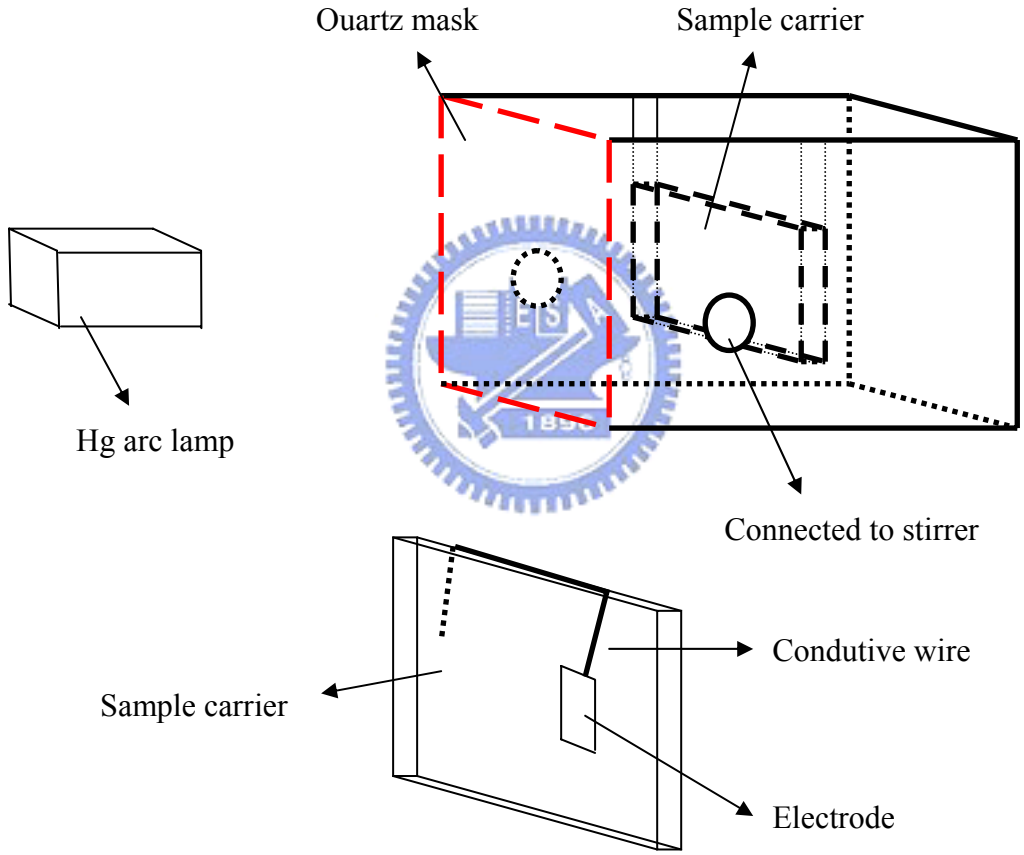
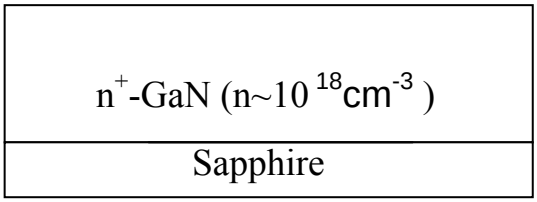


Figure3.3 PEC etching apparatus

3.2 GaN sample

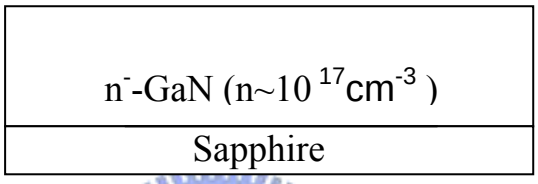
The samples used in the experiment were grown by MOCVD. The epilayer structure and the characteristics were listed below.

n^+-GaN



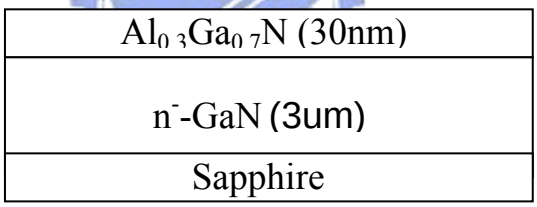
(sample 1)

n^--GaN



(sample 2)

HEMT



(sample 3)

At first, we used n^+-GaN (sample 1) to test, including etching rate and surface roughness. Because there were lots of literatures for PEC etching on n^+-GaN, it was convenient for us to collect the basic etching conditions. Then n^--GaN (sample 2) was the second testing material. Due to the goal for applying PEC etching on HEMT process, it needed to know the etching conditions of single layer, n^--GaN. After the testing of n^+-GaN and n^--GaN, we would apply the PEC etching on HEMT device (sample 3).

3.3 Photoenhanced chemical etching on n^+-GaN , n^--GaN using Ti etching mask

Because the etching conditions for different material were not the same, for the stability and accuracy of the experiment, fist we needed to know the etching rate and roughness related to each layer, and setup the baseline for PEC etching process. The sample of n^--GaN and n^+-GaN were prepared to be etched by photoenhanced chemical etching method in this work. The process flow was shown below.

1. **Initial clean**

   First the sample was immersed in ACE and IPA for each five minutes to remove the surface particles and organic contaminations, then dried by N_2 gas. After that, the sample was immersed into $HCl:H_2O$ = 1:10 for 5minutes to remove the surface oxide, finally rinsed in D.I water and dried by N_2 gas

2. **Lithography**

   After initial clean step, the following step was lithography process. We used AZ5214E lithography process to define the pattern, then the sample was descummed in ICP to remove the remaining organics.

3. **Metal deposition**

   1000Å Ti metal was deposited by E-gun evaporator.

4. Standard lift-off process

Then we used ACE 5min to remove undesired Ti metal by standard lift-off process, and IPA 5min to clean, finally dried in N_2 gas.

5. PEC etching test

The PEC etching conditions are: KOH concentration 0.0075M ~ 0.03 M, Ti etching mask, light intensity 30~50mW/cm^2, stirring solution. (We used 80℃ 1M hot KOH to remove the etched peaks after PEC etching.)

6. Material analysis:

FESEM was used to observe the etched surface, and AFM was used to measure surface roughness.

3.4 Photoenhanced chemical etching on n^+-GaN, n^--GaN using ohmic etching mask

In the general PEC etching, Titanium metal always takes the role as etching mask because of its low reactivity to KOH solution. However the detail mechanism for the etching mask has not been investigated. Based on the reaction formulas in chapter 2.1, we know the hole is the reactant in the PEC etching, so the etching rate can be enhanced by transmitting the extra photo-induced electrons into solution. Because of the reason, we

replaced Ti mask for ohmic mask in order to understand the transmitting mechanism for etching mask. As for stability issue, gold is an inert metal (top layer of ohmic metal). By the replace of the etching mask metal, we can understand the role in the PEC etching clearly. Additionally, by using ohmic etching mask, it has the advantage of flexibility and integrated into the device process. The process flow was shown below.

1. Initial clean

First the sample was immersed in ACE and IPA for each five minutes to remove the surface particles and organic contaminations, then dried by N_2 gas. After that, the sample was immersed into $HCl:H_2O$ = 1:10 for 5minutes to remove the surface oxide, finally rinsed in D.I water and dried by N_2 gas

2. Lithography

After initial clean step, the following step was lithography process. We used AZ5214E lithography process to define the pattern, then the sample was descummed in ICP to remove the remaining organics.

3. Ohmic contact formation & Standard lift-off process

The ohmic metal Ti/Al/Ni/Au (300 Å /1500Å/300 Å/ 2000Å) was deposited by E-gun evaporator. Then the sample was immersed into ACE 5minutes to remove the undesired metal by lift-off process and IPA 5 minutes to clean remaining organics. Finally the ohmic contact was formed by rapid thermal annealing

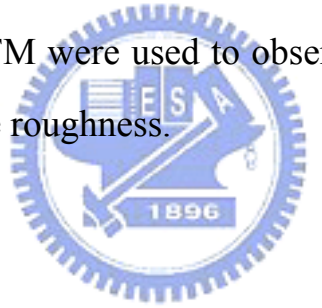
850℃ 50sec

4. PEC etching

In chapter 3.3, we tested the KOH concentration range from 0.0075M to 0.03M, then we found that KOH concentration at 0.015M is best condition, so 0.015M was used here. The etching condition was: KOH concentration 0.015M, ohmic etching mask, light intensity 30~50mW/cm^2, stirring solution. (Hot KOH treatment was also used to modify the etched surface.)

5. Material analysis

FESEM and AFM were used to observe the etched surface and to measure surface roughness.



3.5 Recipe test of Mesa isolation by PEC etching

In the flow of HEMT process, the PEC etching can be applied on the two parts, mesa isolation and gate recess. In this work, we applied PEC etching on device mesa isolation and used Ga-face HEMT to be the device sample. Due to the specific material properties for Ga-face HEMT device, it was difficult to process mesa isolation in one step. The problem was solved by double Ti etching mask. The detail process steps and the obstacles occurring in the experiment were described in the chapter 4.2 “The device fabrication”.

3.6 HEMT process

After the recipes testing, the sample was carried out in HEMT process by photoenhanced chemical etching. The process step was listed below.

1. Mesa isolation

PEC etching and ICP dry etching were used in mesa isolation. The meaning of ICP dry etching was a comparison for PEC etching.

→ PEC etching condition: After wafer initial clean, we used AZ5214E lithography to define the device active region, then deposited 1000Å Ti by E-gun evaporator. We used PEC etching to etch 300Å AlGaN after lift-off process. The following step was to use AZ5214E lithography to define the ohmic pattern, then we deposited 1000Å Ti by E-gun evaporator. After lift-off process, 2000Å GaN was etched by PEC etching. The etching depth was checked by α-step. Finally used HF solution to remove Ti metal on the sample. The etching condition was: KOH concentration 0.015M, double Ti mask, light intensity 30~50mW/cm^2, stirring solution.

→ Dry etching condition: First deposited 2000Å Ni by E-gun evaporator after wafer initial clean, and used FH6400 to define the active region, then used the HNO_3 solution to etch Ni metal. ICP was applied on mesa etching for the depth of 2000Å. The ICP dry etching condition was: ICP/RF power 600/200W, Cl_2/Ar=25/5sccm, 10mtorr, etching time 1min. The etching step is check by α-step. Finally the sample was immersed into HNO_3 to remove the Ni metal

2. Ohmic contact

First we used AZ5214E lithography to define the ohmic pattern, and then used HCl solution to clean surface oxide for good ohmic property. The Ohmic metal Ti/Al/Ni/Au (300Å/1500Å/300Å/2000Å) was deposited by E-gun evaporator, then throughout rapid thermal annealing: 850°C, 50sec

3. T-gate formation

The T-gate was fabricated by lithography with gate length 1um, 2um, 3um. After alignment, we used FHD5 to develop. Then optical microscope was used to check the lithography process. Ni/Au (200Å/3000Å) was the gate metal, deposited by E-gun evaporator. Finally the T-gate was formed by standard lift-off process.

4. Passivation

Passivation was the final device process step. The meaning was to protect the device by depositing a stable layer. The sample here was passivated with 1000 Å Si_3N_4 by PECVD.

3.7 Material analysis

The PEC etching rate is the slope of the plot of etching depth divided by etching time. The etching depth were measured by α-step (TENCOR p-10). Field-emission scanning electronic microscope (FESEM) were used to observe the surface morphology. Atomic force microscope (AFM)

was used to measure the surface roughness after PEC etching. The scanning mode is contact mode. The device DC performances were carried out by HP 4142 measurement system.

Chapter 4
Results and Discussion

4.1 The PEC etching results

After many times testing, the final etching condition were: KOH concentration 0.015M, light intensity 30~50mW/cm^2, stirred solution. After PEC etching, the hot KOH treatment at 80℃ for 1min was applied to improve the surface morphology. The recipe above can be regarded as a standard etching condition in this work.

4.1.1 n+ GaN with different solution concentration, Ti etching mask

Figure 4.1 showed the etching rate of n+ GaN (n~10^{18}) as a function of etching time in different KOH concentrations which were 0.0075M, 0.015M, and 0.03M respectively. From Figure 4.1, the etching rate for n^+-GaN increases with the solution concentration. Increasing KOH concentration means increasing of OH^- content. According to the Le Chatelier's principle, the reaction would occur toward equilibrium state, so the reaction formula (1) would react to right direction to increase the etching rate. The etching rates were about 700Å/min, 1000Å/min, and 1400Å/min for 0.0075M, 0.015M, and 0.03M respectively. Figure 4.2 was the SEM figure of etched surface before and after hot KOH treatment

for 0.0075M KOH concentration. Figure 4.3 was the SEM figure of etched surface before and after hot KOH treatment for 0.015M KOH concentration and Figure 4.4 showed the etching results for 0.03M solution concentration. (hot KOH treatment was a method to remove the surface oxide and the surface whiskers after PEC etching)

Figure 4.5 showed the three-dimension AFM image of the etching roughness after hot KOH treatment for 0.0075M, 0.015M, and 0.03M respectively. The etching roughness for 0.0075M, 0.015M, and 0.03M were respectively 14.567nm, 16.040nm, and 16.119nm after 1M, 1 minute hot KOH treatment.

4.1.2 n^+-GaN with Ti and ohmic etching mask

Figure 4.6 shows the etching rate of Ti and ohmic etching mask for n^+-GaN. The etching rates of Ti and ohmic etching mask were about 700Å and 2000Å respectively. Apparently the etching rate of ohmic etching mask was higher than Ti mask. Because using ohmic etching mask had lower contact resistance than Ti, ohmic metal increased the etching rate by transmitting the photo-induced electrons rapidly into the solution. Figure 4.7 described the transmission mechanism of Ti and ohmic etching mask by energy band diagram. For Ti etching mask, it can be regarded as a shottcky contact for GaN because the energy level of Ti metal is higher than GaN. Because high shottcky barrier disturb the transmission of extra electron, it has low etching rate for PEC etching. For ohmic contact, due to the match of the energy level for ohmic metal and GaN material, photo-induced electrons on the surface can rapidly

transmit throughout ohmic metal by tunneling mechanism. Therefore with these two different transmission mechanism of Ti and ohmic metal on GaN, the etching rate with ohmic mask was higher than that with Ti etching mask.

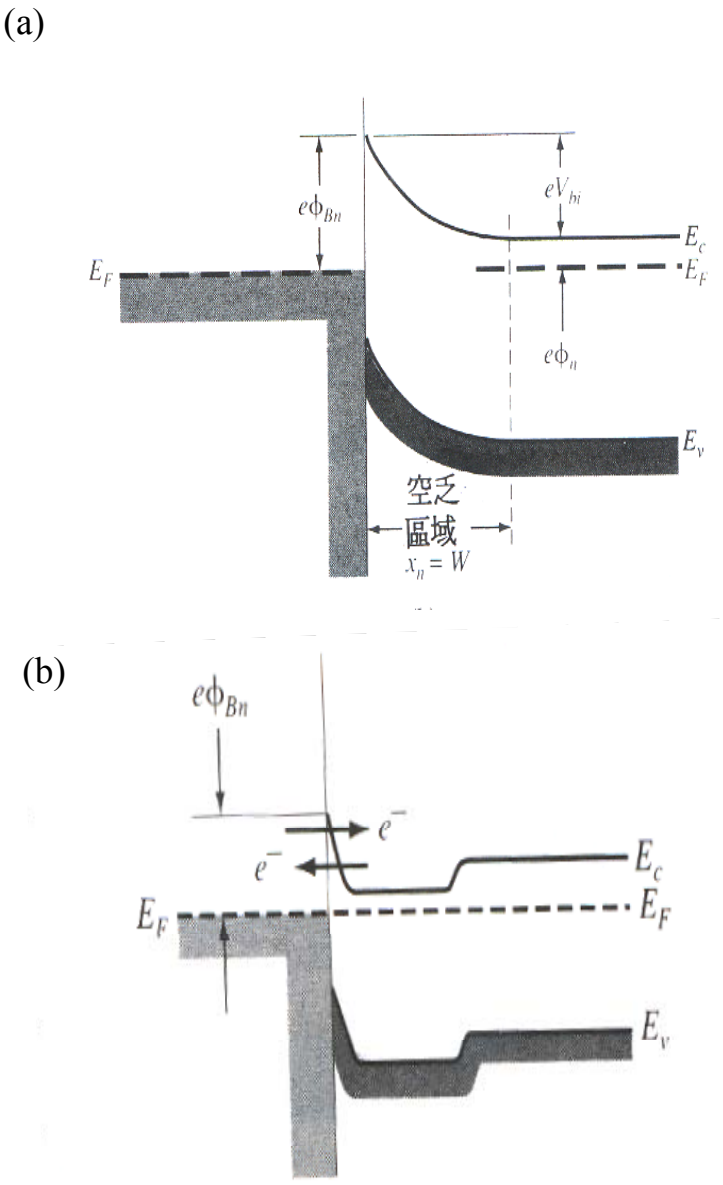


Figure 4.7 the transmission mechanism for (a)Ti mask (b) ohmic mask

For this reason, transmitting the extra electrons into solution makes more holes available to react with GaN and OH^-, and increases the reaction rate. The Figure 4.8 below describes the etching situation.

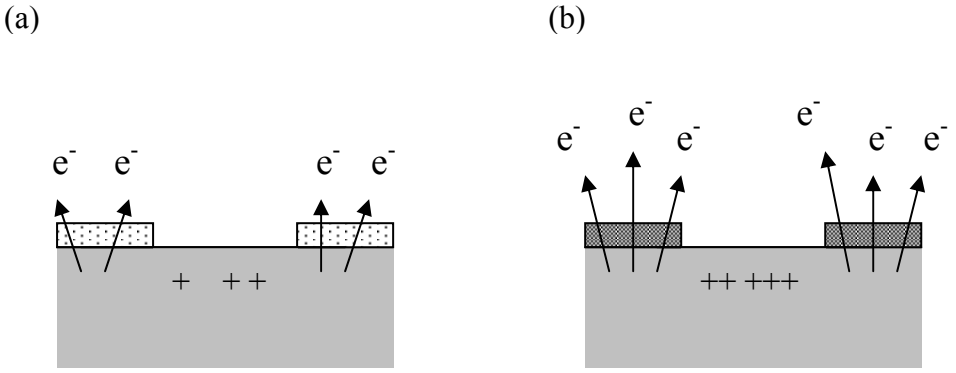


Figure 4.8 the comparison of the ability of transmitting electrons into Solution (a) Ti etching mask, (b) ohmic etching mask

The etching roughness of n^+-GaN with Ti and ohmic mask using 0.015M solution concentration were 16.040 and 15.191nm. The roughness of Ti and ohmic mask were almost the same order. The roughness images were shown in Figure 4.9 and the SEM images of etched surface were shown in Figure 4.10 for ohmic etching mask. From the Figure 4.5 and Figure 4.9, the roughness of n+ GaN with different etching mask were totally in the same order. We believed that the important factor which affects the etching roughness resulted from the intrinsic material properties. In this experiment, we used the same n^+-GaN sample ($n\sim10^{18}/cm^3$) to test, and all process steps were equal except for deposition metal (Ti and ohmic metal). According to the phenomenon observed in the experiment, it demonstrated that the etched surface roughness wss related to the material properties (dopant

concentration).

4.1.3 n^--GaN with Ti and ohmic etching mask

The etching rate of n^--GaN film with Ti and ohmic etching mask were 350 Å and 800Å, shown in Figure 4.11. From the Figure 4.6 and Figure 4.11, it showed that the etching rate of n^--GaN was lower than n^+-GaN apparently, because the conduction rate for n^+-GaN is larger than n^--GaN . Table 4.1 showed the etching rate for n^+-GaN and n^--GaN with Ti and ohmic etching mask respectively. The SEM images of n^--GaN with Ti and ohmic etching mask after PEC etching and hot KOH treatment were shown in Figure 4.12 and Figure 4.13 respectively.

	ohmic etching mask	**Ti etching mask**
n^+-GaN	**~200nm/min**	**~70nm/min**
n^--GaN	**~80nm/min**	**~40nm/min**

Table 4.1 comparisons for n^+-GaN and n^--GaN with Ti and ohmic etching mask respectively.

The roughness of n^--GaN with Ti and ohmic etching mask were 68.327nm and 60.531nm respectively. Figure 4.14 showed the roughness 3-D images of n^--GaN. Apparently the roughness of n^--GaN were bigger than n^+-GaN etched roughness. From the results, we can conclude that the

etched roughness was related to dopant concentration. When the higher the dopant concentration is, the lower the selective etching effect is. In other words, the higher dopant concentration means the smoother etched surface.

4.2 The device fabrication

After GaN bulk etching test, we applied PEC etching on fabrication process of AlGaN/GaN HEMTs. Due to the absence of sample of AlGaN/GaN HEMTs with n^+-GaN capping layer, we only can finish the part of mesa isolation. The meaning of mesa isolation, the first step for HEMTs process, is to define the active region of device and to isolate the devices.By the database of PEC etching, we chose the standard etching recipe (KOH concentration 0.015M, light intensity 30~50mW/cm^2, stirred solution and Ti etching mask) to fabricate mesa isolation. Due to the specific quality of device sample, we faced a lot of obstacles for mesa isolation. The first one was that PEC etching can't etch the second layer (GaN bulk) of device, because the barrier of 2DEG was too high for electron to transmit from GaN buffer into AlGaN. Figure 4.15 was the band diagram.

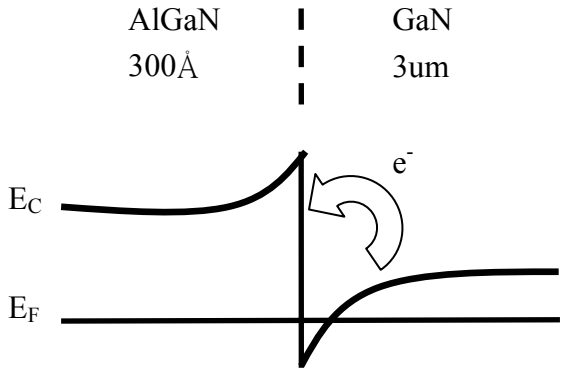


Figure 4.15 band diagram for AlGaN/GaN HEMTs

Figure 4.16 showed the etched surface after 50min, 90min, and 130min PEC etching respectively. From the SEM figures, there was no etching depth for GaN even over 130min PEC etching.

In order to solve the transmission problem, we used the ohmic etching mask to avoid the failure of transmission mechanism of buffer layer. We solved successfully the unetched phenomenon, but there was the second obstacle after using ohmic etching mask. From the Figure 4.17, there was nonuniform etching at the region between devices. We thought it was due to the electron accumulations on the etching mask, resulting in the nonuniform etching near the mask. We tried to minimize the effect of nonuniform etching by using 0.0075M KOH solution, but the method can't solve this problem thoroughly.

Finally we overcame the obstacles by using double Ti etching mask and finished the device mesa isolation successfully. The flow of mesa process was shown in Figure 4.18. We used the first Ti mask to etch the AlGaN, then deposited the second Ti mask to etch the GaN buffer.

After mesa isolation, we finished the ohmic contact, optical gate, and nitride passivation consequently. The performances of DC characteristics were shown in Figure 4.19. The device size was a 100um gatewidth, 2um gatelength, 5um source-drain spacing, and 2um G-D spacing. The I_DSS was 510mA/mm and Gm was 120mS/mm for PEC etching device. Besides of wet etching, we fabricated the second device by dry etching. Figure 4.20 showed the DC characteristics. The device size was the same with that fabricated by PEC etching. The I_DSS was 460mA/mm and Gm is 110ms/mm for ICP dry etching. According to the DC performance in Figure 4.19 and Figure 4.20, we can identify that the double Ti etching

mask solved successfully the process step of device mesa isolation, and the device fabricated by PEC etching had the better characteristics than that by dry etching. We believed the difference of the DC performances between PEC and dry etching resulted from the etching damage existing on etching surface.

Chapter 5
Conclusions

This work studies the PEC etch for GaN materials. The PEC etching was successfully applied to n^+-GaN and n^--GaN and a new etching mechanism was proposed.

The etching rates of n^+-GaN with Ti mask at 0.0075M, 0.015M, and 0.03M KOH concentration were 700Å/min, 1000Å/min, and 1400Å/min respectively. From the data, we know that the higher the KOH concentration is, the faster the etching rate is. The etching rate of n^+-GaN using ohmic etching mask was 2000 Å/min (0.015M KOH concentration). Apparently the etching rate for ohmic mask was higher than that for Ti mask. The roughness was 16.0nm and 15.2nm for Ti and ohmic mask at 0.015M KOH concentration respectively. The etched roughness of the samples were in the same order for the n^+-GaN etched at different etching conditions.

The etching rates of n^--GaN were 350Å/min and 800Å/min for using Ti etching mask and ohmic etching mask respectively and the surface roughnesses were 68.327nm and 60.531nm for Ti and ohmic etching mask respectively. From the comparison for n^+-GaN and n^--GaN, we know that the higher dopant concentration would minimize the selective etching effect, and result in the smooth etching surface.

In this work, we found the transmission mechanism for etching mask in PEC etching, and explained why the etching rate fast of ohmic mask

was. Besides of this, we used double Ti mask to solve successfully the mesa isolation, and the PEC etching was applied to the AlGaN/GaN HEMT process for mesa etch. The results were compared to those AlGaN/GaN processed with conventional ICP dry etch for isolation. From the DC measurement data, the device fabricated by PEC etching had the better characteristics with Gm 115mA/mm and $I_D$ss 510mS/mm; meanwhile the device using dry etching for isolation had Gm 110mA/mm and $I_D$ss 460mS/mm

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"Photoenhanced wet chemical etching of n+-doped GaN."

10.C. Youtesey, L.T. Rommano, I. Adesida. Appl. Phys. Lett. 73 (1998) 6, (Gallium nitride whiskers formed by selective photoenhanced wet etching of dislocation.)

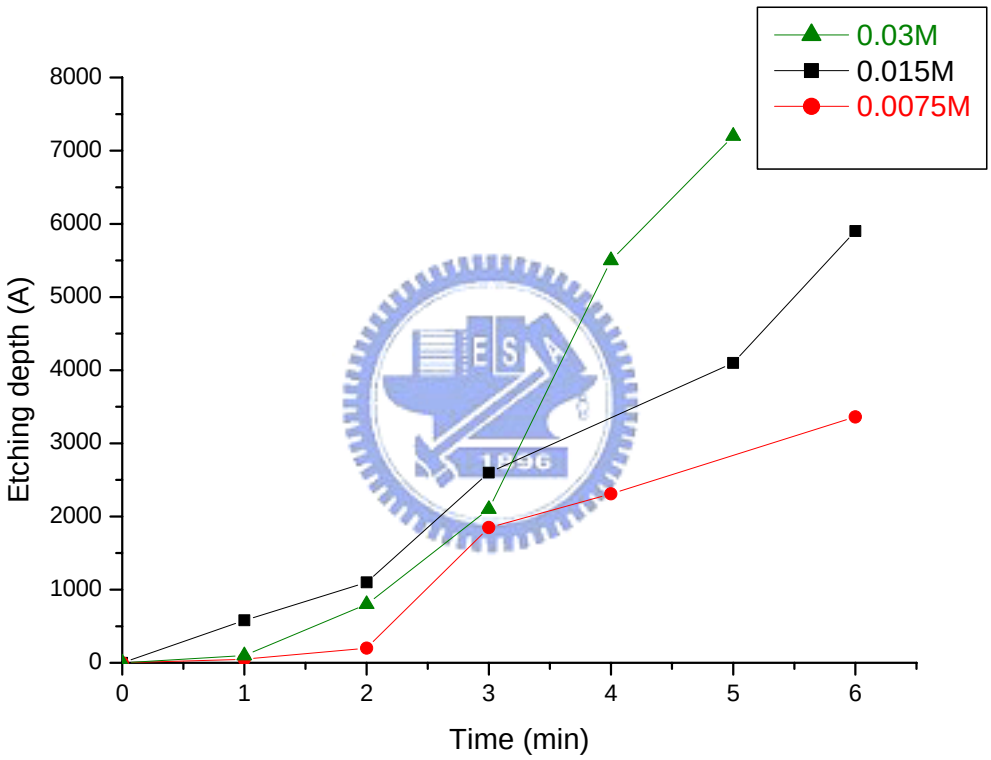
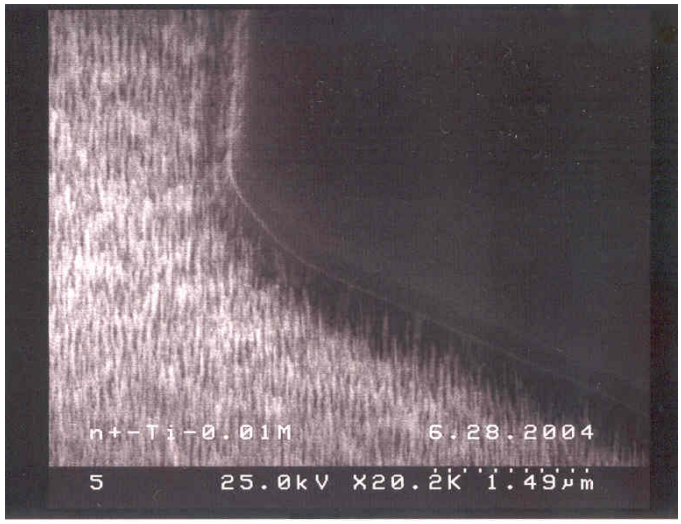


Figure 4.1 the etching rate of Ti etching mask for n+ GaN at 0.0075M, 0.015M, and 0.03M respectively.

(a)



(b)

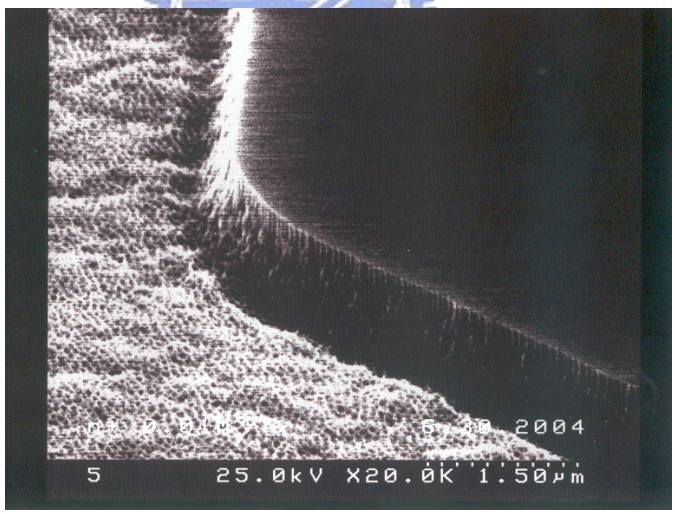
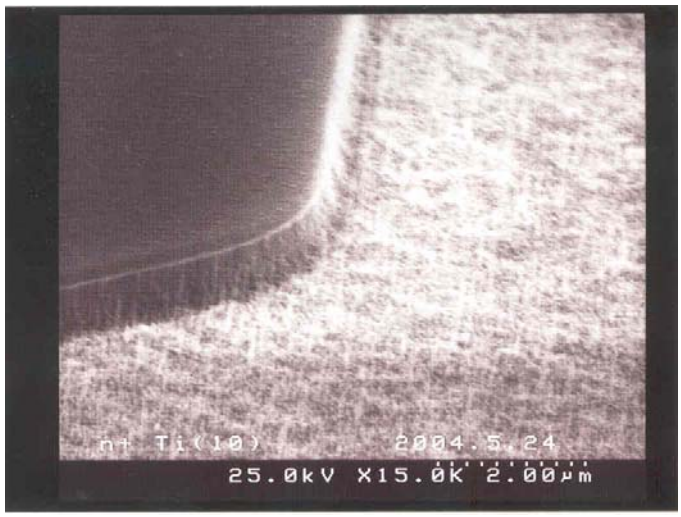


Figure 4.2 the SEM image for n+ GaN with 0.0075M KOH concentration (a) after PEC etching, (b) after KOH treatment

(a)



(b)

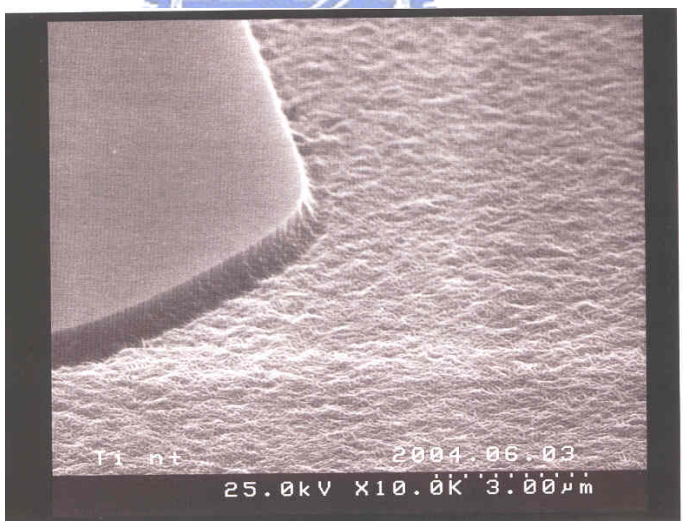
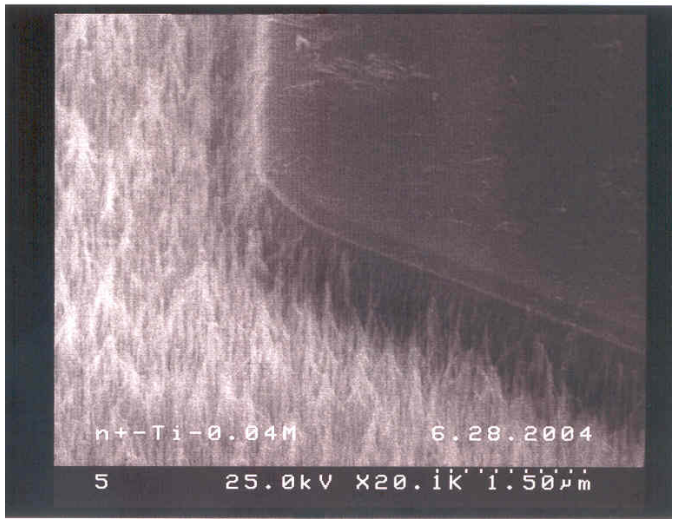


Figure 4.3 the SEM image for n+ GaN with 0.015M KOH concentration
(a) after PEC etching, (b) after hot KOH treatment

(a)



(b)

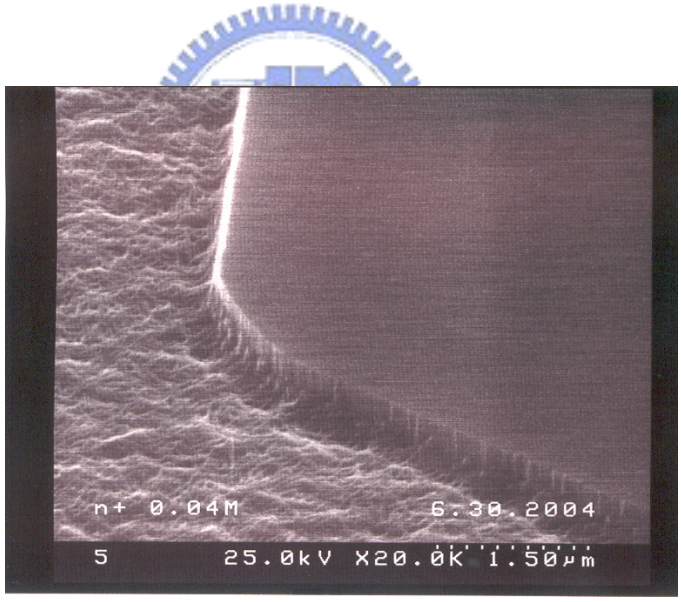
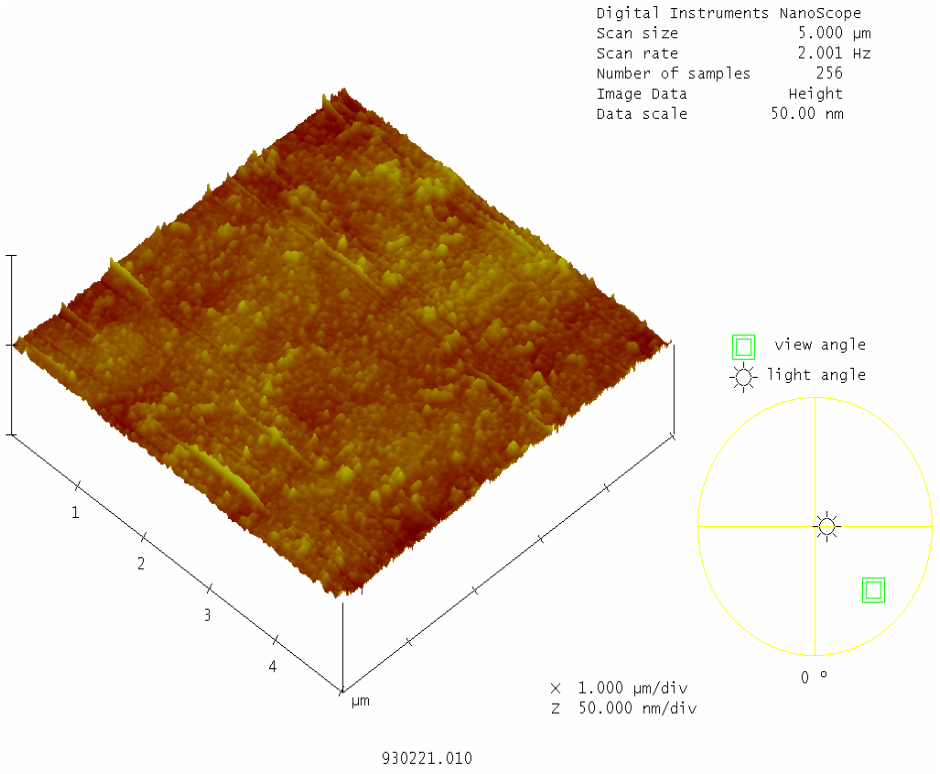


Figure 4.4 the SEM image for n+ GaN with 0.03M KOH concentration
(a) after PEC etching, (b) after hot KOH treatment

(a)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view angle
light angle
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2
3
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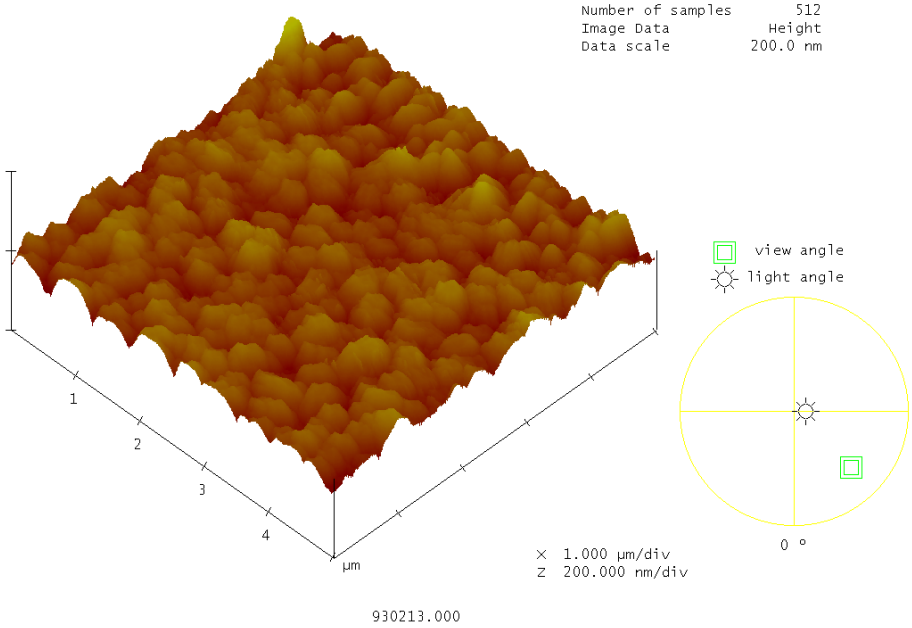
X 1.000 µm/div
Z 50.000 nm/div
930221.010

(b)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light angle
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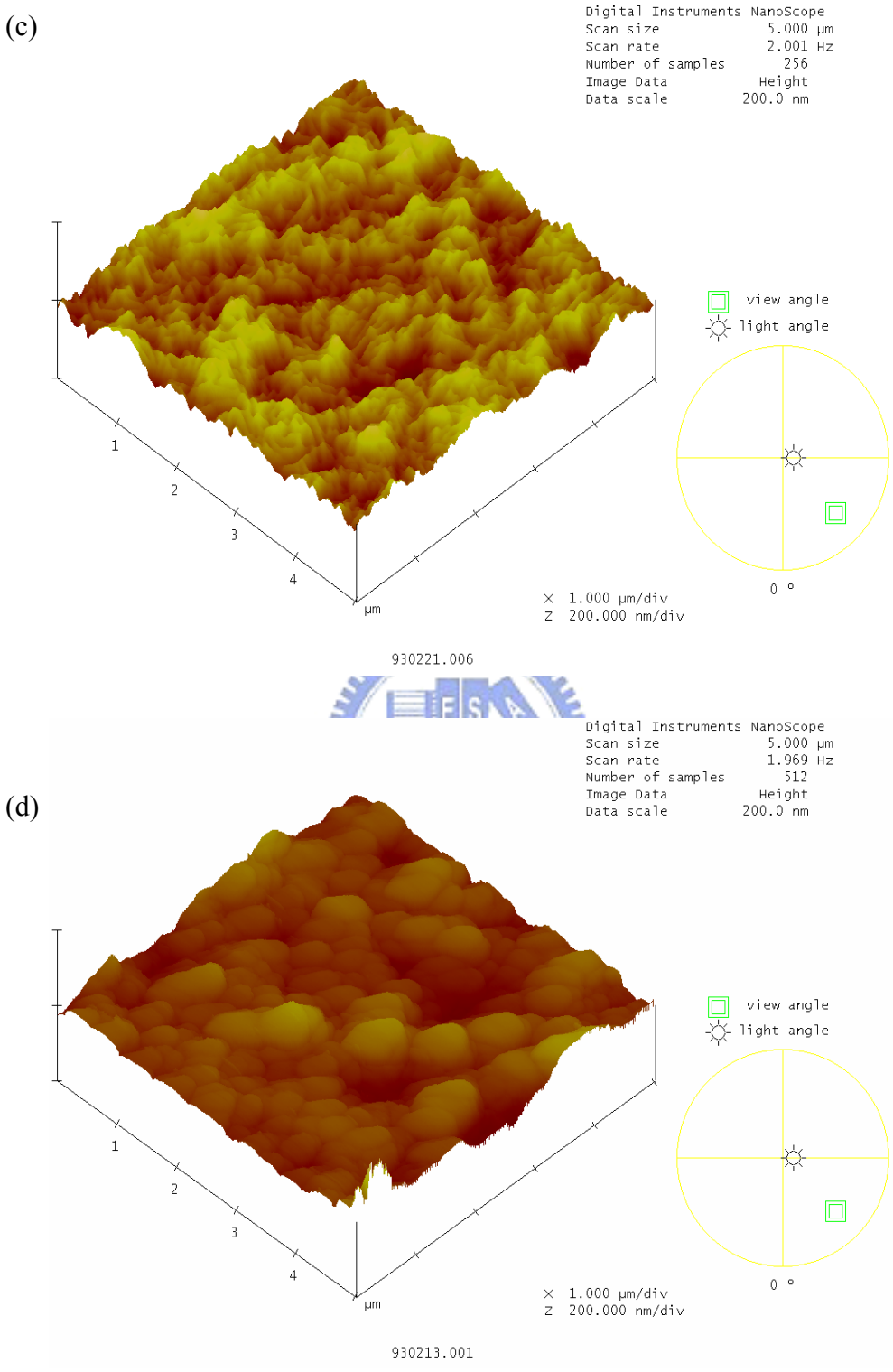


Figure 4.5 the AFM image for n+ GaN (a)unetched (b) 0.0075M (c) 0.015M (d)0.03M

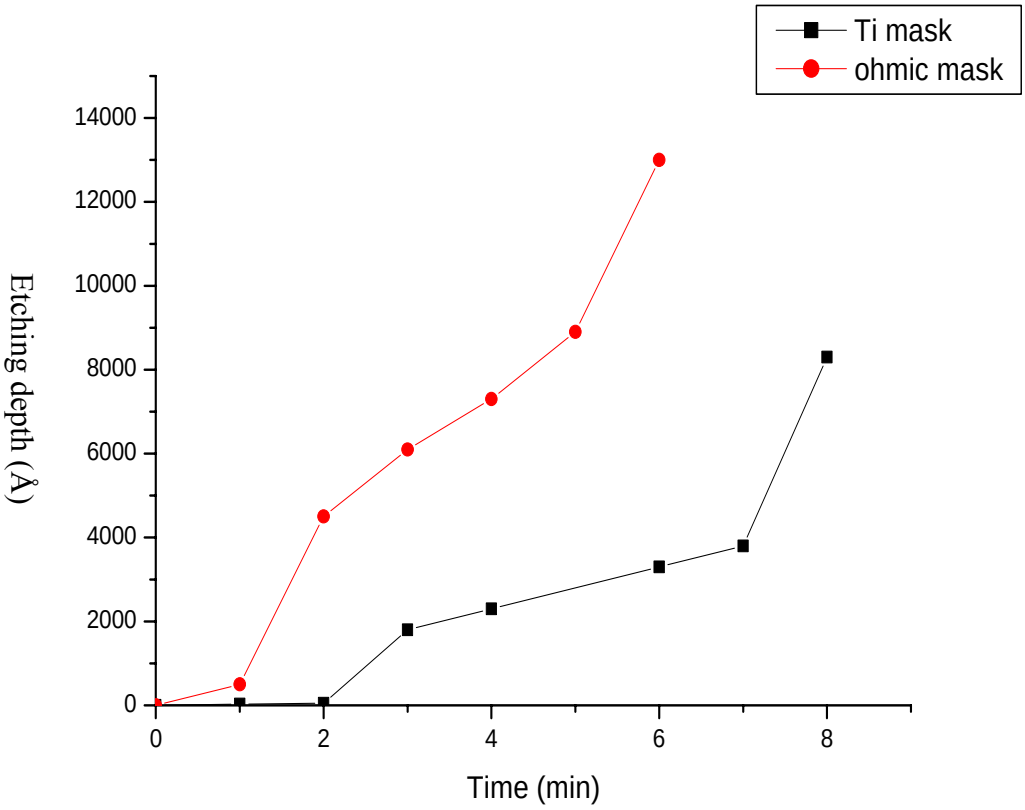
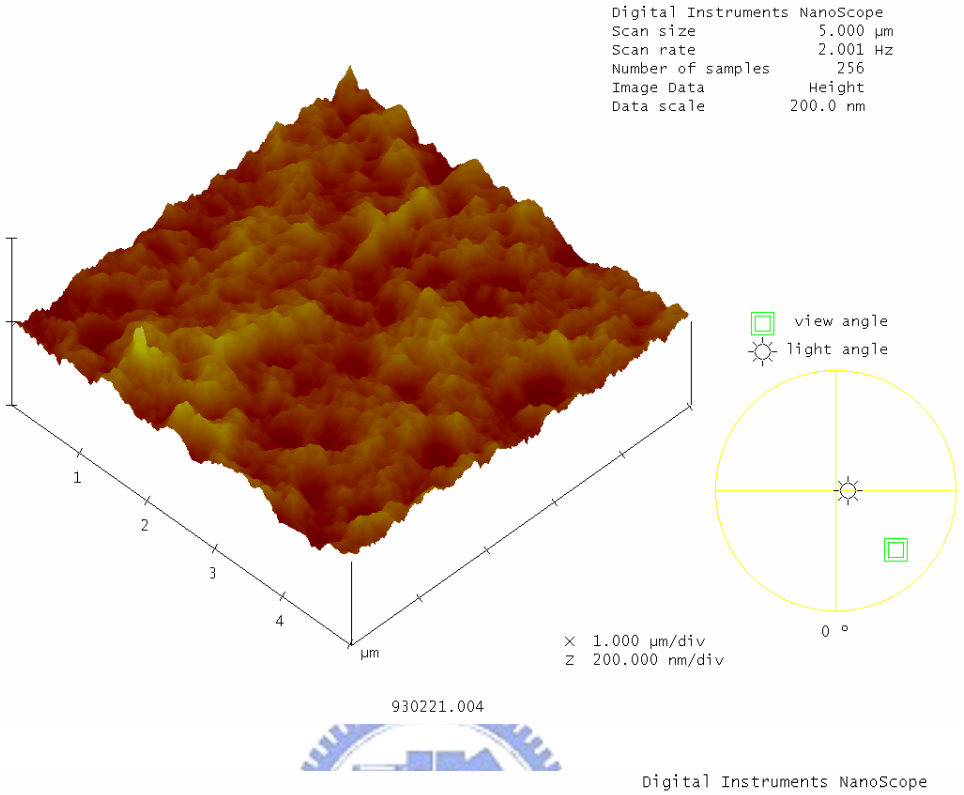


Figure 4.6 the etching rate of Ti and ohmic etching mask for n+ GaN at 0.015M solution concentration.

(a)



(b)

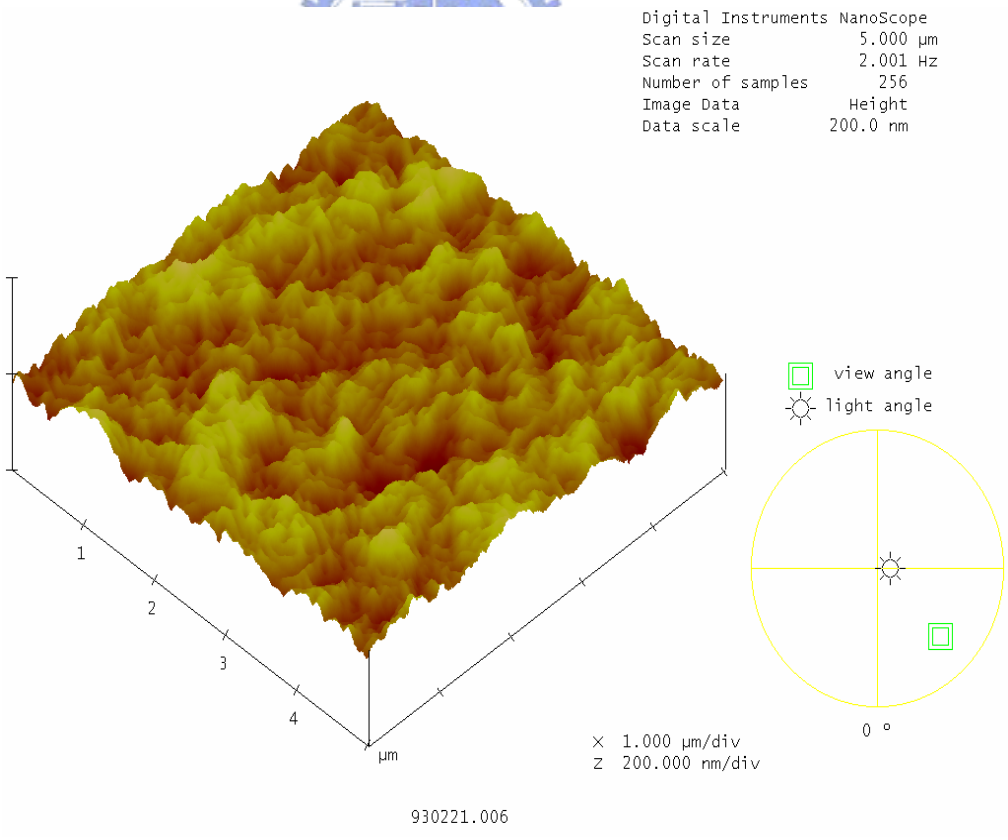
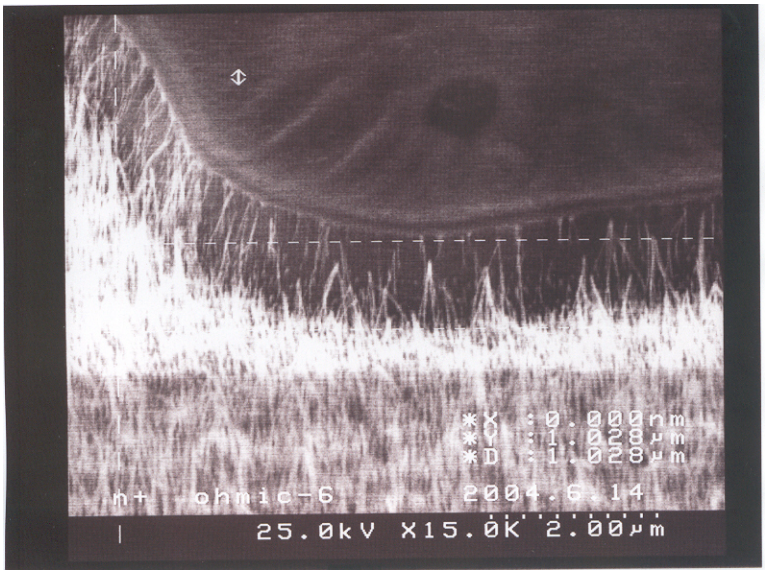


Figure 4.9 the AFM image for n+ GaN after hot KOH treatment (a)Ti etching mask (b)ohmic etching mask

(a)



(b)

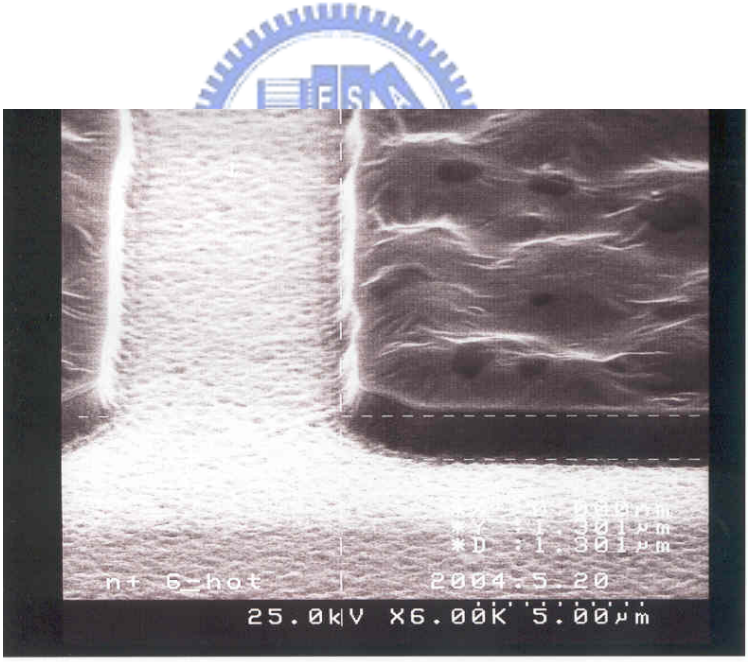


Figure 4.10 the SEM image for n+ GaN with ohmic mask using 0.015M KOH concentration (a)after PEC etching, (b) after hot KOH treatment

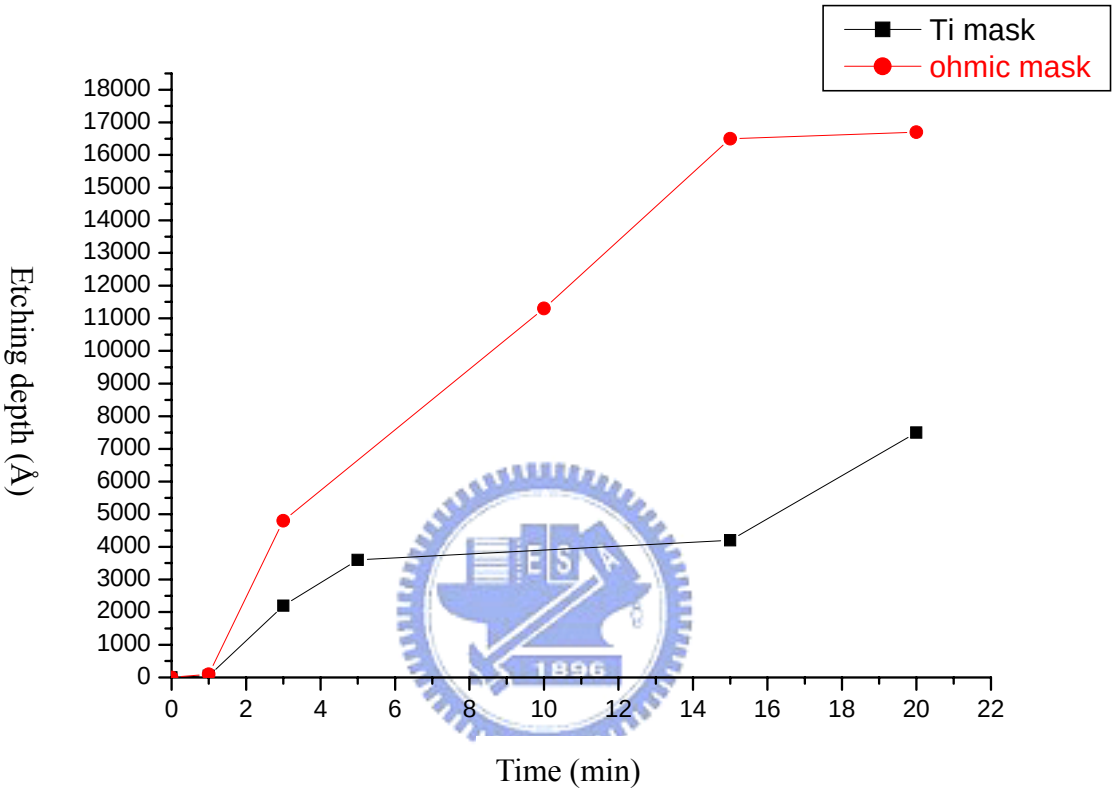
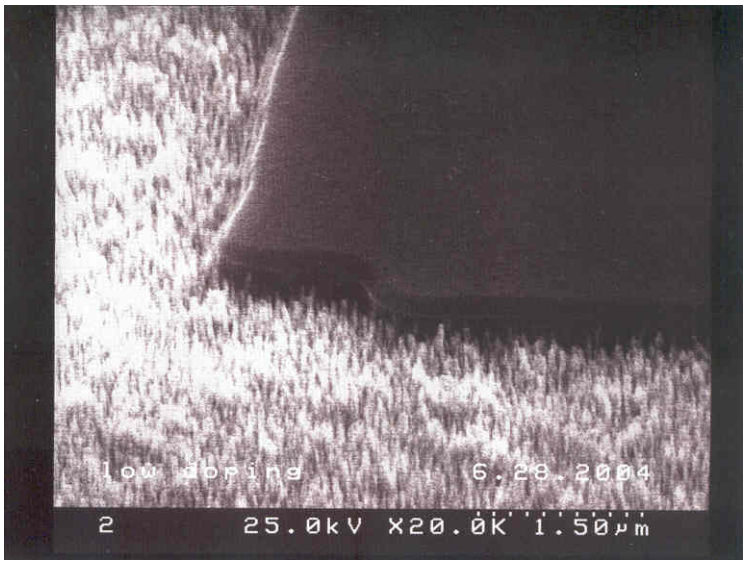


Figure 4.11 the etching rate of Ti and ohmic etching mask for low doping GaN at 0.015M KOH concentration.

(a)



(b)

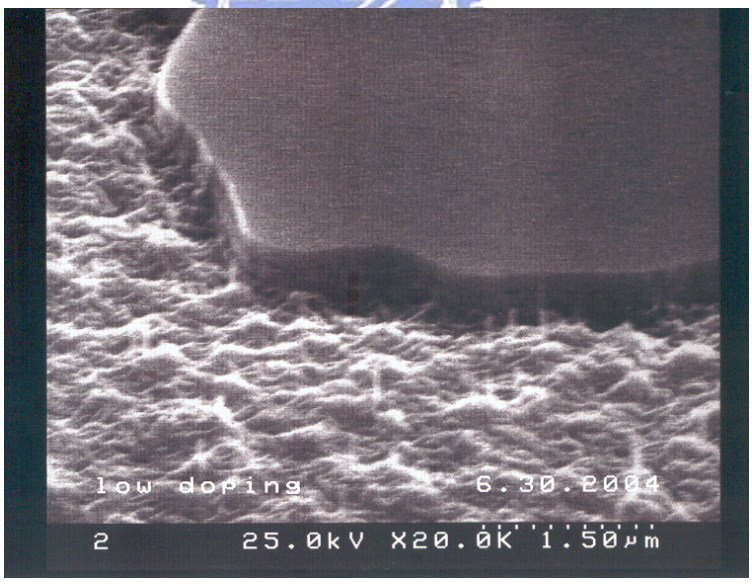
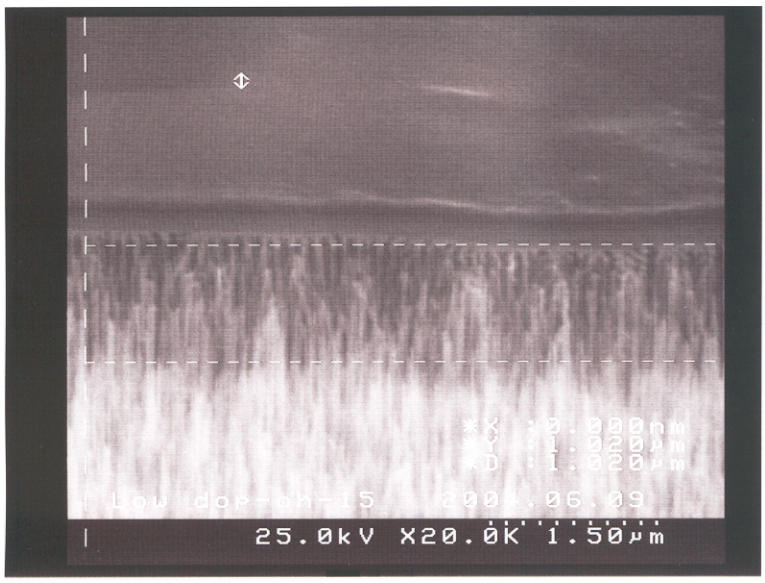


Figure 4.12 the SEM images for low doping GaN with Ti mask using 0.015M KOH concentration (a)after PEC etching, (b) after hot KOH treatment

(a)



(b)

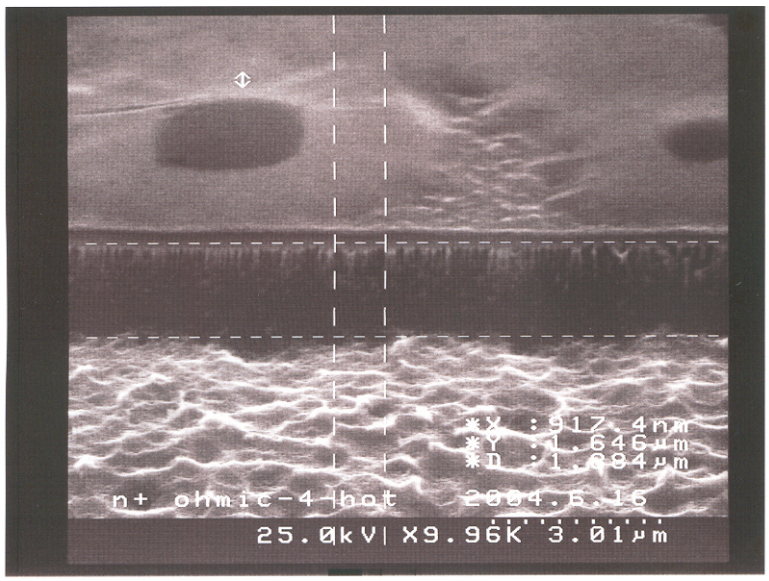
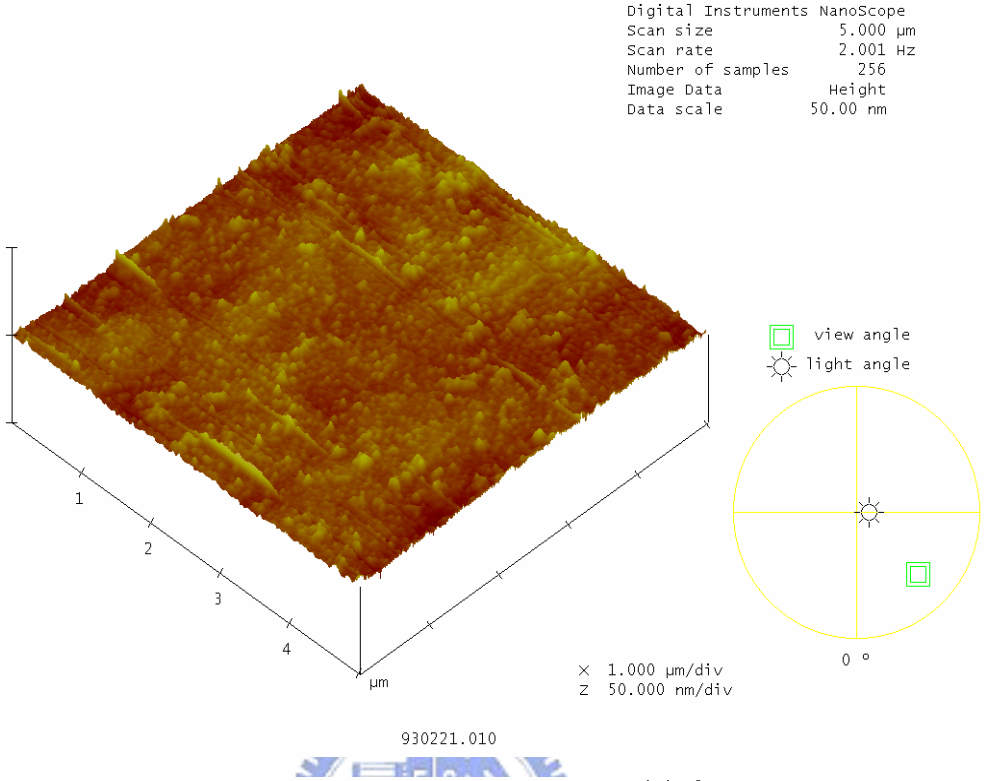


Figure 4.13 the SEM images for low doping GaN with ohmic mask using 0.015M KOH concentration (a)after PEC etching, (b) after hot KOH treatment

(a)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view angle
light angle
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2
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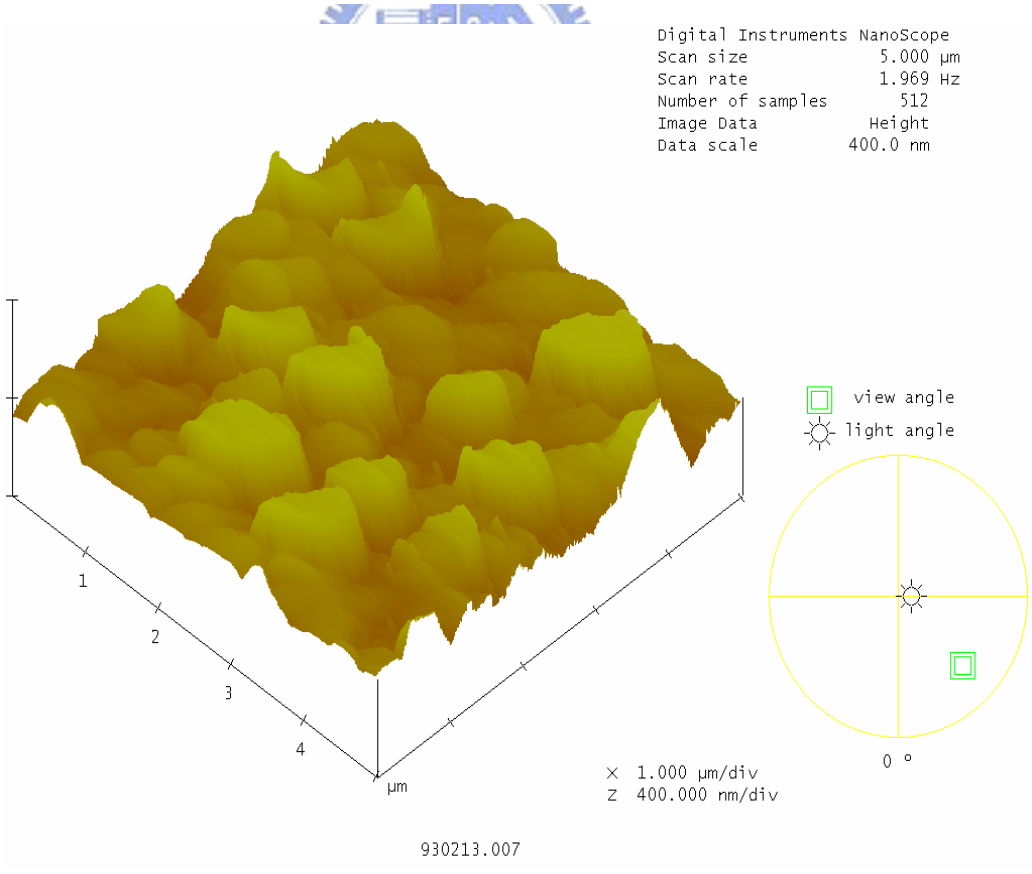
X 1.000 µm/div
Z 50.000 nm/div
930221.010

(b)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930213.007

(c)

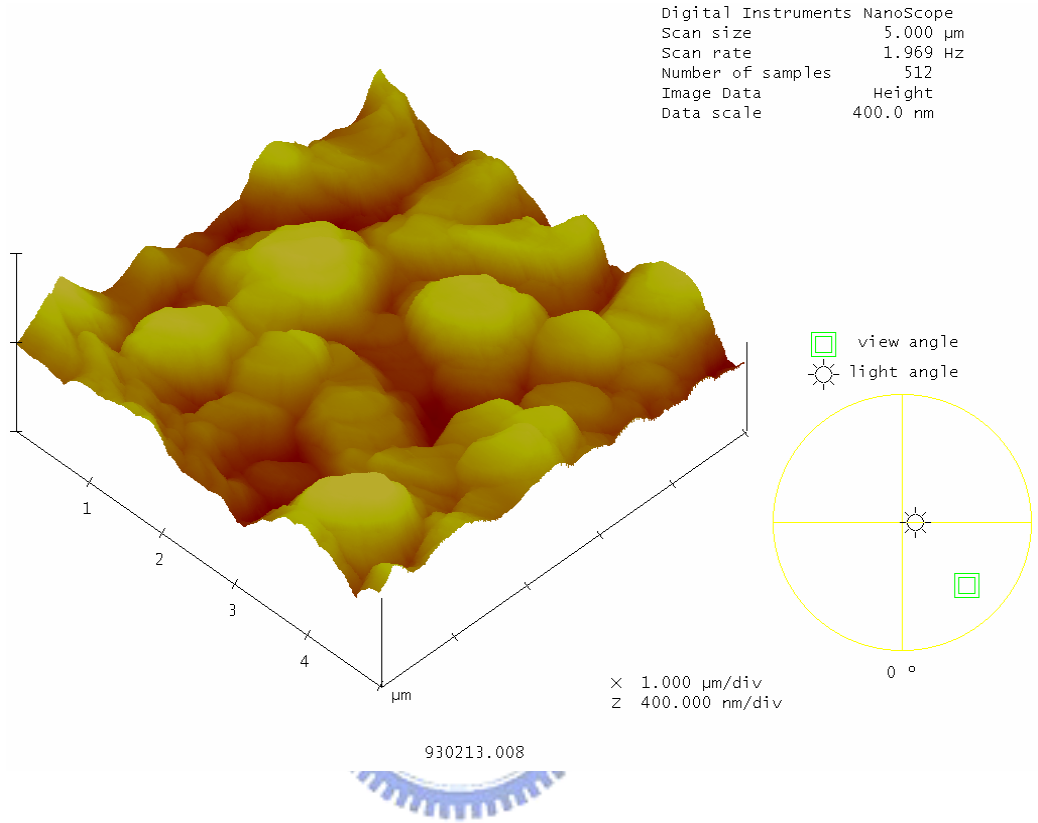
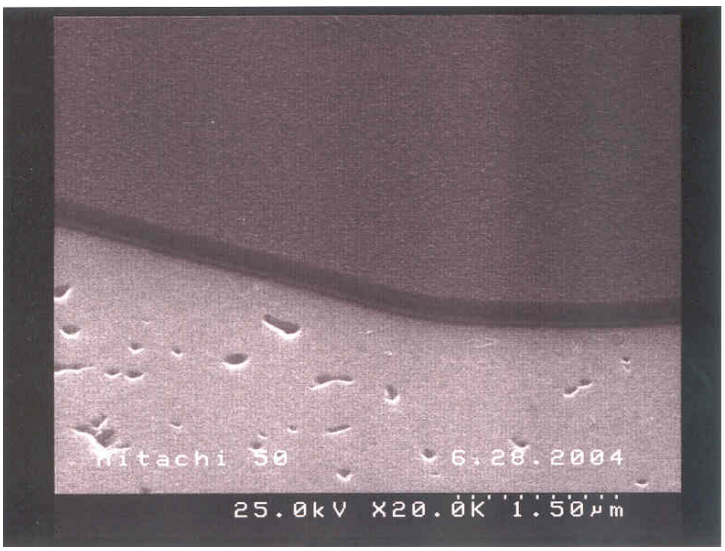
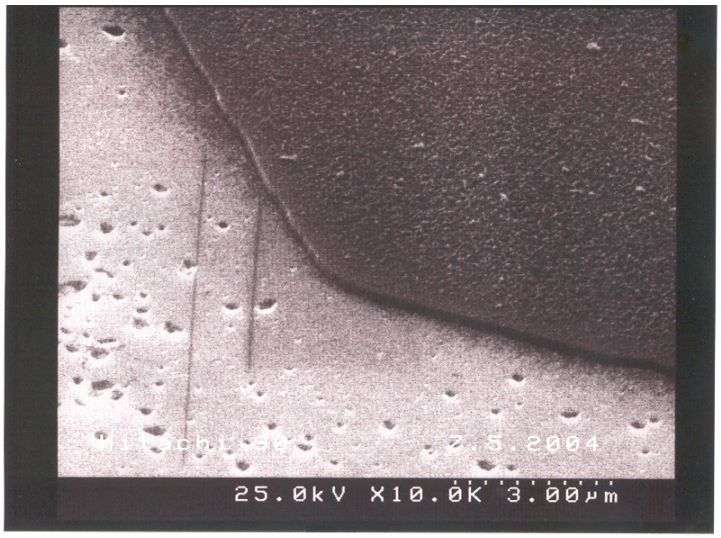


Figure 4.14 the AFM image for low doping GaN after hot KOH treatment (a)unetched surface (b)Ti etching mask (c)ohmic etching mask

(a)



(b)



(c)

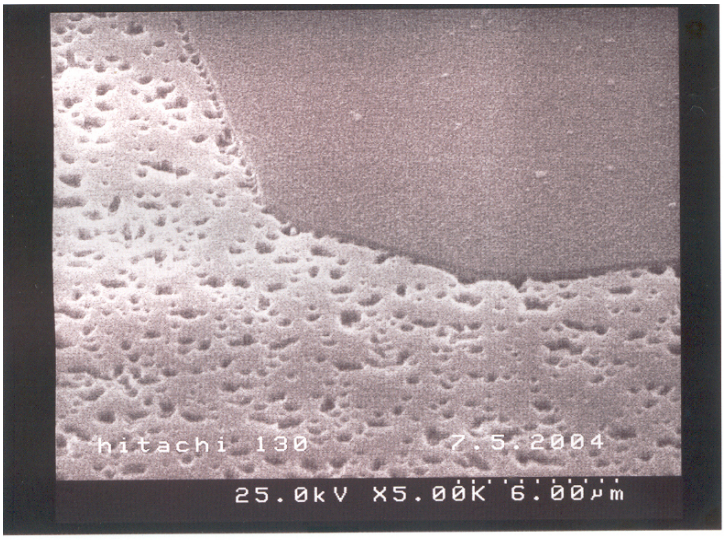
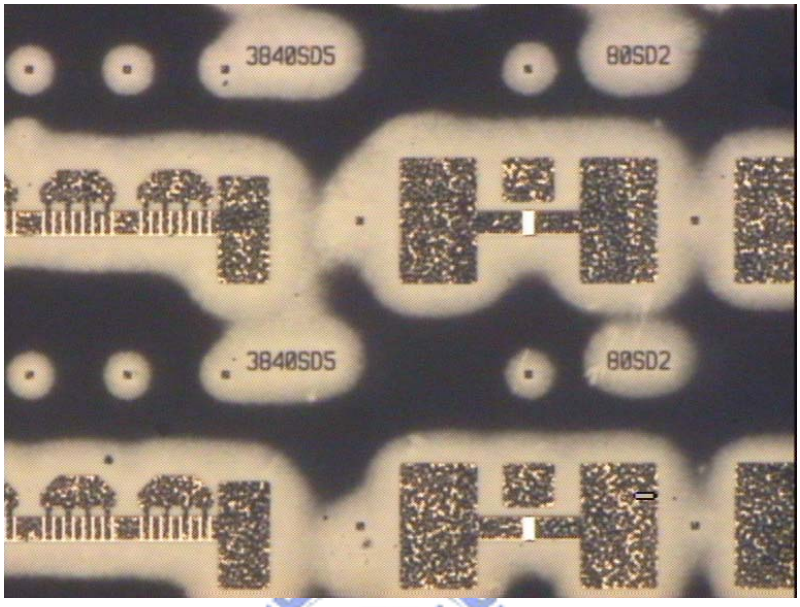


Figure 4.16 the SEM images for HEMTs device using the standard PEC etching (a) 50min (b) 90min (c) 130min

(a)



(b)

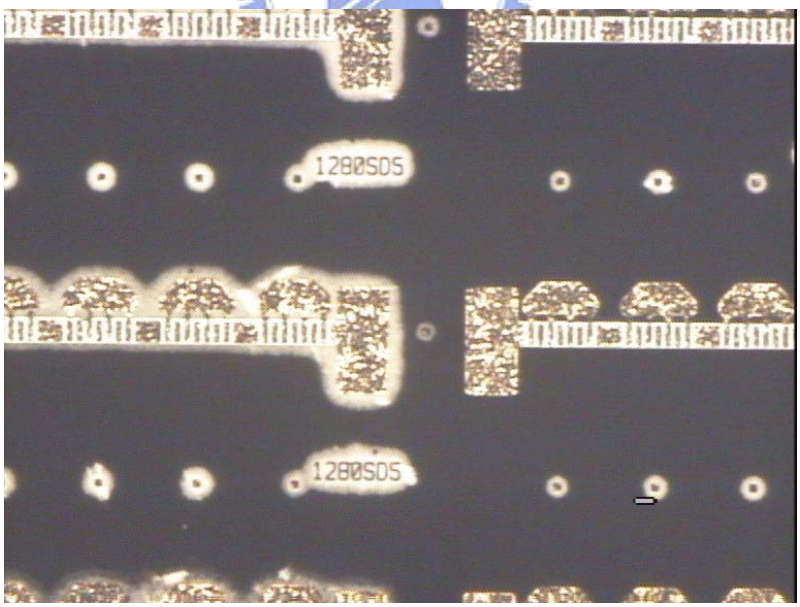


Figure 4.17 the optical microscope images for HEMTs device using ohmic etching mask (a) 0.015M (b) 0.0075M

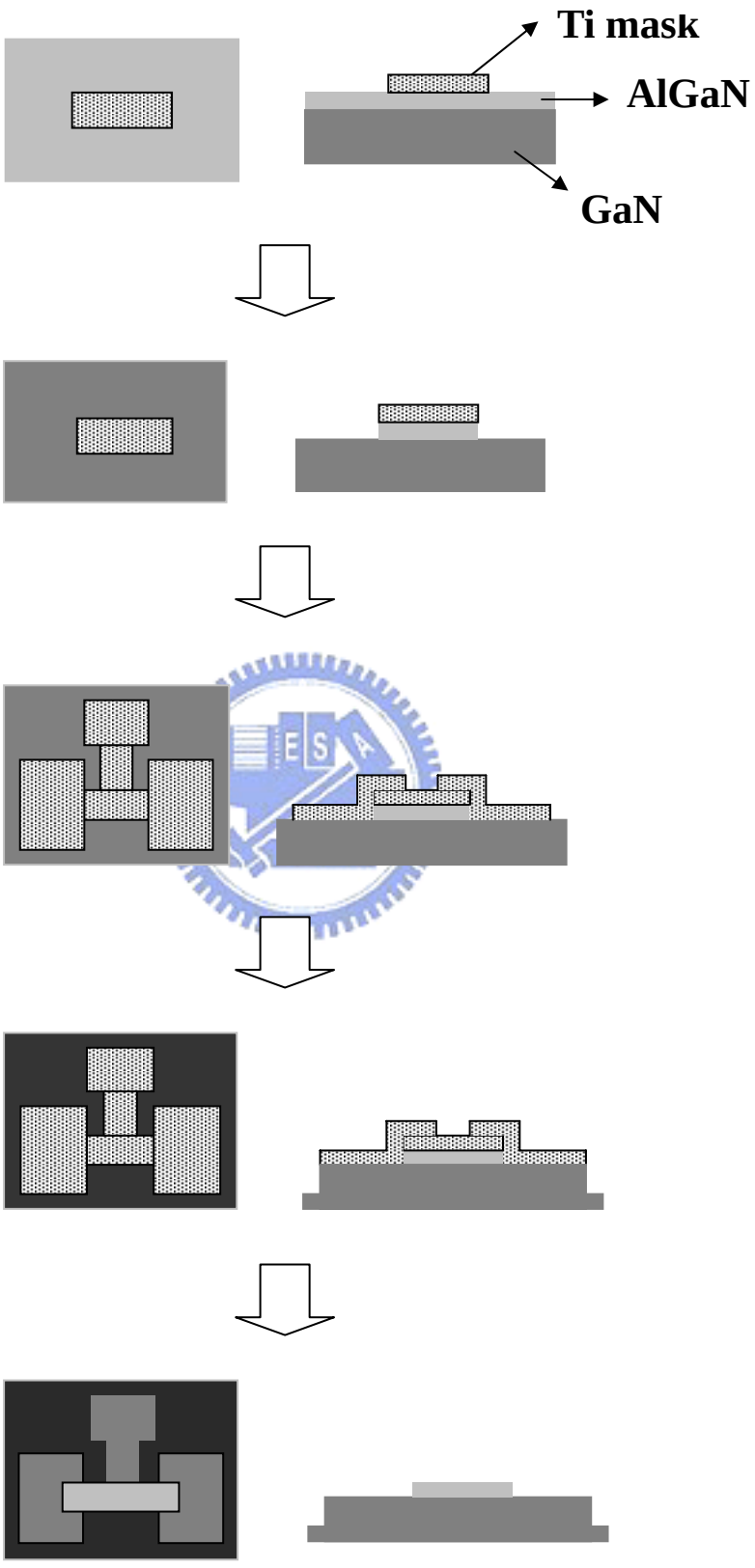
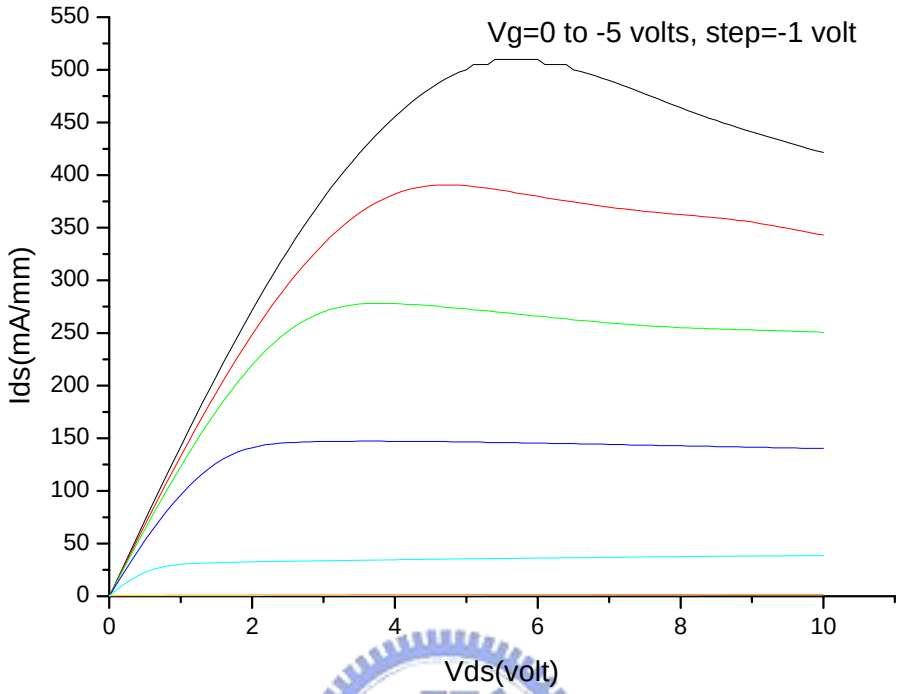


Figure 4.18 the process flow of device mesa isolation

(a)



(b)

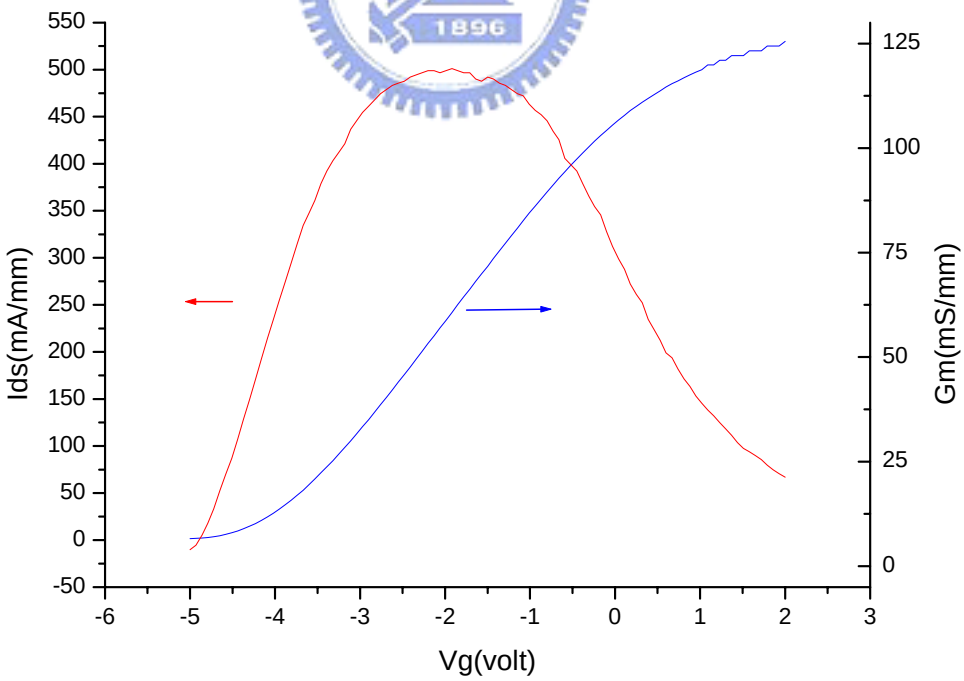


Figure 4.19 the DC performances of the device fabricated by PEC etching (a) IV curve (b) Gm

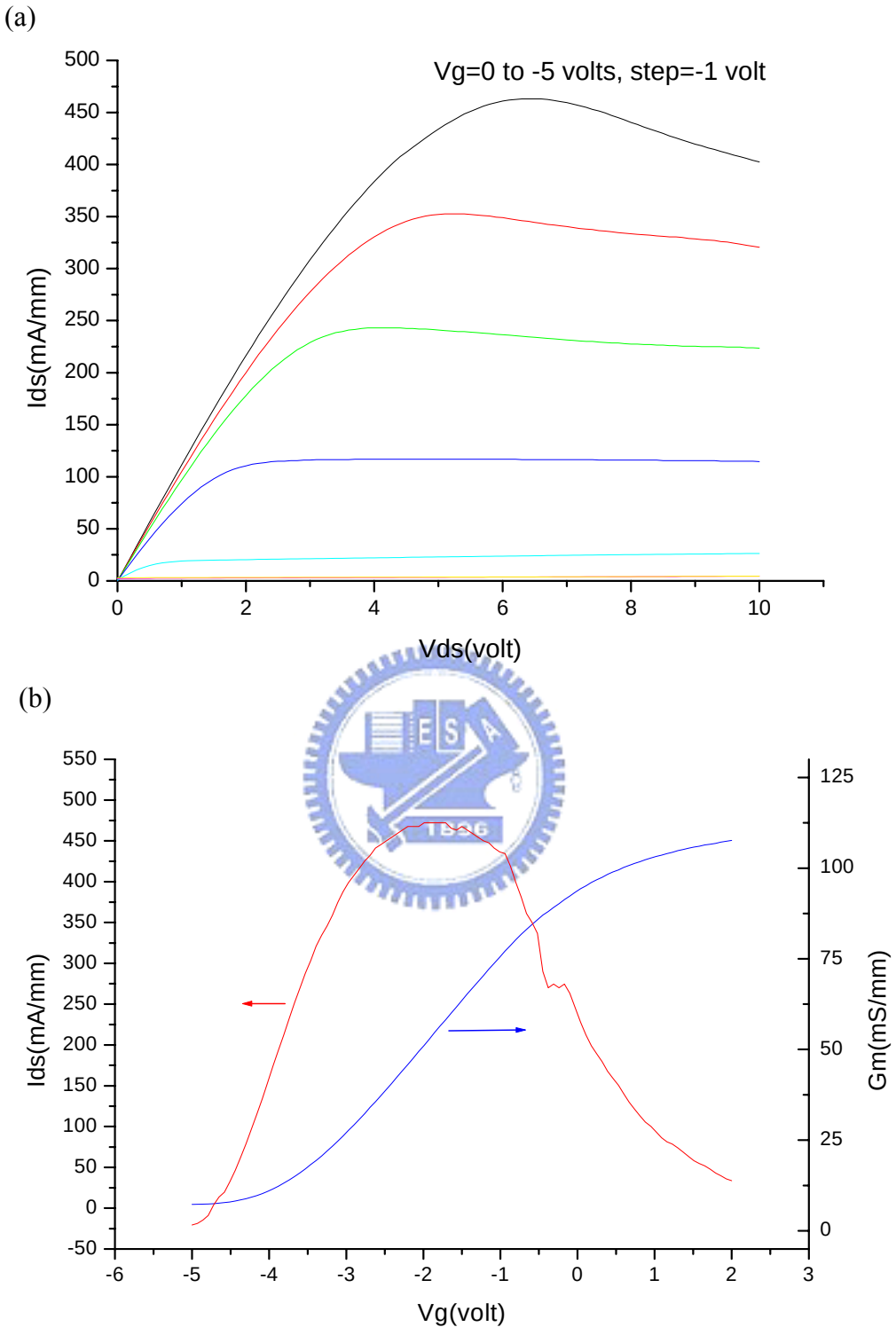


Figure 4.20 the DC performances of the device fabricated by dry etching
(a) IV curve (b) Gm