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COMMUNICATIONS

SUBMICROMETER SCALE PHOTOASSISTED WET ETCHING OF n–DOPED GALLIUM NITRIDE

Jaroslava Škriniarová[1] — Hans-Peter Bochem — Andre van der Hart Alfred Steffen — Hans Lüth — Peter Kordoš *

Photoelectrochemical etching (PEC) was applied to pattern gallium nitride surfaces on submicrometer scale. Sets of grooves having their widths from 0.26 to 1 μm were etched at various conditions. The effectiveness of submicrometer PEC etching in a KOH based electrolyte was demonstrated.

K e y w o r d s: photoelectrochemical etching, gallium nitride

1 INTRODUCTION

Gallium nitride based structures for high frequency and optical applications require patterning of the semiconductor material on micrometer and submicrometer scales. For gate recessing of MESFET and HEMT structures, shallow etching of a region with a typical width of 0.5–3 μm is necessary for the purpose of source-drain separation. Also for laser structures the corrugated surfaces of a distributed Bragg reflector are required. The typical size of patterned features is about 300–500 nm.

Dry etching is currently used in processing, however, it has several disadvantages, including the possibility of ion-induced damage surface and proton related modification of the electrical properties of the underlying layers. Wet chemical etching has been commonly used to solve this problems but only UV light assisted Photoelectrochemical etching (PEC) etching was successfully applied to pattern GaN [1]. Results of this etching technique were shown to be dependent on the electrolyte concentration and light intensity. PEC etching was demonstrated on features several micrometers large [1] and only Ping *et al* [2] used PEC etching for 1 μm gate recessing of GaN MESFET.

In this letter, we present, for the first time, UV assisted PEC etching of n^+-GaN on submicrometer scale. Problems which occurred during the etching are summarized.

* Institute of Thin Film and Ion Technology, Research Centre Jülich, D-52425 Jülich, Germany, skriniar@elf.stuba.sk
[1] On leave from the Department of Microelectronics, Slovak University of Technology, Ilkovičova 3, SK-812 19 Bratislava 1, Slovakia

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2 EXPERIMENTAL

The etching experiments were performed on an n^+-doped GaN ($n \sim 2 \times 10^{18}\,cm^{-3}$) $3.5\,\mu m$ thick epitaxial layer grown by MOCVD technique on sapphire. Non-alloyed Ti was used as an etch mask. The set of line openings with widths below one micrometer were formed by electron beam lithography. Etching was performed in a standard electrochemical cell with a Pt counter electrode. The illumination intensity of the non-filtered mercury-xenon lamp was varied up to $200\,mW/cm^2$ measured at 365 nm. As an electrolyte, non-stirred diluted KOH solution and KOH-based developer AZ400K kept at room temperature were utilized. After etching, the samples were characterized by a scanning electron microscope (SEM) with a resolution of 3 nm.

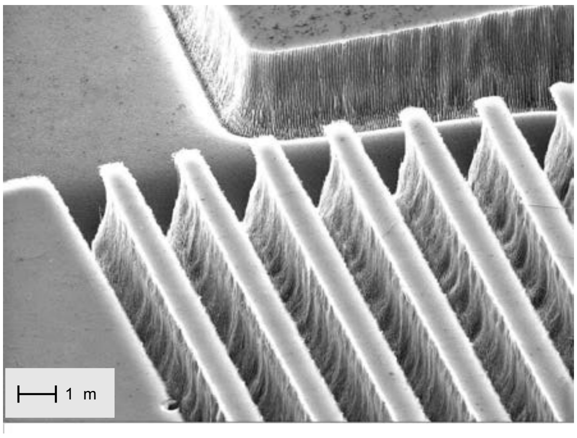

Fig. 1. n^+- GaN etched in AZ400K diluted with water (1:250). Grooves have a width of 1 μm. The Ti etch mask is removed.

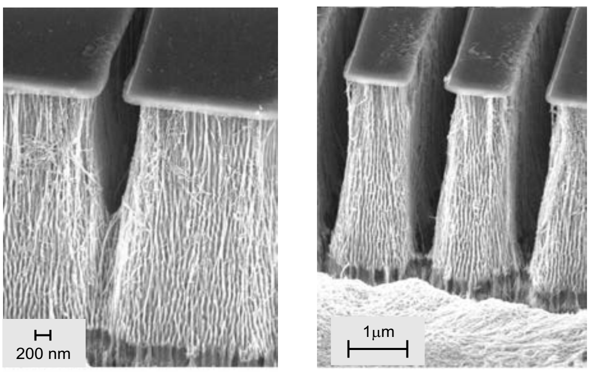

Fig. 2. SEM micrograph of etched grooves with (a) 260 and (b) 500nm openings in the Ti mask. See the text for etch conditions.

3 RESULTS AND DISCUSSION

We started with PEC etching conditions giving smooth controllable etching of n-GaN [1]. It was found that not-stirred low concentrated KOH water solution and higher illumination intensities led to results acceptable for gate recessing. At the illumination intensity $38\,mW/cm^2$ and AZ400K etchant concentration 1:250 the etched surfaced was smooth with several rod-like features that are typical for PEC etched GaN. The etched depth is about 200 nm, hence the etch rate was 40 nm/min.

Deeper etching at the aforementioned conditions reveals several problems of PEC etching. These are well demonstrated in Fig. 1 where a set of grooves etched through $1\,\mu m$ wide openings in the mask separated by $1\,\mu m$ from each other are presented. The side-walls are not very steep and are rough with fibrous texture. In addition, the etch rate is remarkably higher in the grooves near the large masked region than in the open ends of the grooves.

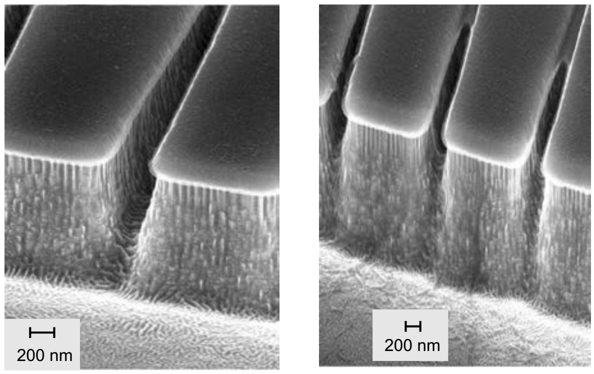

Fig. 3. SEM micrograph of etched grooves with (a) 400 and (b) 250 nm openings in the Ti mask. The etch solution 1.4 M KOH diluted with water (1:250) and subsequent KOH-based treatment were used.

The application of a KOH based electrolyte with a low concentration at sufficient high illumination intensity leads to diffusion limited etching [1], which suppresses selective etching of defects in GaN. Such etching conditions can be obtained when a gallium oxide layer at the GaN/electrolyte interface is formed [3]. An electrolyte consisting of a low concentrated KOH water solution can offer such conditions due to the reported reduced solubility of gallium oxide at pH bellow 12. However, an oxide layer remaining after etching can be a problem for device processing or for the properties of the device itself.

To avoid problems with gallium oxide we have tested PEC etching also in a concentrated AZ400K solution taking into account an acceptable etch rate. Water solution of AZ400K (1:50) was previously found to satisfy the criteria for gate recessing. Figures 2a and 2b present SEM micrographs of the grooves with 500 and 260 nm openings in the titanium mask, respectively. AZ400K water solution (1:50) electrolyte and illumination intensity of $38\,mW/cm^2$ were used during PEC etching. Also under these conditions mask underetching and a fibrous texture on the side-walls were observed. Additionally, while 500 nm wide grooves are etched through $2.5\,\mu m$ thick n^+-GaN down to the buffer layer, the grooves in 260 nm wide openings are V-shaped with a depth of only about $1\,\mu m$.

We verified the obtained results for the electrolyte with the same molarity as for AZ400K, but prepared of KOH alone. The etch rate in the grooves and the side-wall morphology were similar to those when AZ400K was used. The fibrous texture of the grooves walls observed could be partially removed by treatment in a hot 1.4 M KOH solution, as Figs. 3a and 3b present, while application of molten KOH leads to smooth side-walls [5].

The obtained results on PEC etched grooves can be considered from the viewpoint of their widths. When the width of the grooves is comparable with the wavelength of light, waveguide properties are manifested. Such a waveguide behaviour is well demonstrated for grooves with openings below 300 nm. As the width of grooves is less than the wavelength at the main emission peaks of the lamp used (313 and 365 nm), the effective intensity of illumination in the groove decreases rapidly, (see Figs. 2 and 3).

The grooves with dimension above the main wavelength of the used light behave differently from those mentioned earlier. The etch rate is even higher than in much larger open areas (*eg* 5 μm wide openings) and is related to the effectiveness of the mask to extract photogenerated electrons from the illuminated region [1].

Underetching of the mask, positive slope of side-walls and their fibrous texture can be related to the non-zero intensity of light at the edges of the mask. Therefore PEC etching can take place therein and is not suppressed by a concurrent mechanism of reduction of oxidising species like in the case of GaAs photoassisted etching [4]. In addition, the morphology of the PEC etched surface strongly depends on the illumination intensity used.

The fibrous texture is more pronounced for grooves side walls than for large masked features. This again underlines the Gaussian-like shape of light intensity inside the grooves. Therefore, the intensity of light is dropping more steeply for open area edges of the masked regions than for the side-walls of the grooves.

4 CONCLUSIONS

Photoassisted electrochemical etching of n-GaN is applicable to pattern n^+-doped GaN in submicrometer scale. To obtain controllable results it is necessary to account for the influence of the etch mask and the width of the projected grooves as well as the wavelength of the used light. The side-walls of the grooves are generally rough, which originates from the nature of PEC etching process, and can be reduced by subsequent treatment in KOH. The impact of such a treatment on the resulting groove width has to be considered.

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Jaroslava Škriniarová (Ing, CSc) received her Ing (MSc) and CSc (PhD) degrees from the Slovak University of Technology (STU), Bratislava, in 1977 and 1986. In 1993 she joined the Microelectronics Department of STU, at present she is there engaged in the research of optoelectronic devices, especially of wet etching processes.

Peter Kordoš (Ing, DrSc), **Hans-Peter Bochem**, **Andre van der Hart**, **Alfred Steffen** and **Hans Lüth** are with Institute of Thin Film and Ion Technology, Research Centre Jülich, Germany. Their biographies were not supplied.