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Ga focused ion beam etching of a Si_3N_4/GaN substrate for submicron selective epitaxy

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Abstract. Authors represent utilizing UHV Ga FIB for preparing a Si_3N_4/GaN substrate for submicron selective-area epitaxy. In result, GaN submicron stripes were grown in the 100, 200 and 500 nm windows of a Si_3N_4 mask layer. SEM investigations show good crystalline perfection of the grown stripes.

1. Introduction

There is a need for submicron patterned structures formation in the technology of III-N photonic and electronic devices. A topical issue is the formation of nonalloyed submicron contacts to the source and drain regions of a HEMT transistor [1]. A promising method is a selective epitaxial growth process [2]. It requires such complex, difficult and expensive methods as electron beam and extreme-ultraviolet lithography. An alternative method at the device development stage is nanolithography by focused ion beam (FIB). Among the works devoted to the selective epitaxy, the majority of them refer to the growth of quantum dots on substrates without masking coating [3, 4]. In this case, preliminary defined places are usually formed by focused ion beam on the substrate surface. Using substrates without masks, one can grow multilayer structures with a predetermined position of quantum dots [3]. However, this approach does not prevent the occurrence of epitaxial film islands between areas of deliberate crystallization, which are, as a result, the defects of structure. Utilization of masking coatings allows one to practically eliminate unintended growth [5-8]. The comparison of masks quality formed by various methods in a Ti film and the results of selective epitaxial growth of GaN layers [8] showed that the use of ion-beam lithography allows one to achieve substantially the same results as in the case of electron beam lithography but excludes a complicated step of removing the photoresist.

In our work, the possibility of submicron windows formation in a Si_3N_4 masking layer using direct ion lithography with a Ga focused ion beam is demonstrated. The results of studying the selectively grown epitaxial structures show good crystalline perfection.

2. Experiment

A 3 μm thick lightly Si-doped GaN layer was epitaxially grown on the (0001) sapphire wafer by metalorganic vapour phase epitaxy (MOVPE). The concentration of Si was $1\text{-}3\cdot10^{17}$ cm^{-3}. A 5 nm thick amorphous Si_3N_4 layer was deposited in the same technological process. SiH_4 and NH_3 were used as precursors, and the deposition temperature was close to 1000°C. A selective-area epitaxial mask was formed on Si_3N_4/GaN by our own designed ultra-high vacuum (UHV) Ga FIB equipped by an Orsay Physics "Cobra" ion gun. The windows of the mask were 200 µm long stripes of different widths: 100, 200 and 500 nm. The FIB etching parameters were 30 keV beam energy, 450 pA probe current and 10 nm beam step. The total exposure dose was close to $8 \cdot 10^{16}$ cm^{-2}. For the etching rate enhancement, preventing the etched material redeposition as well as appearing of gallium drops, XeF_2 was used as a precursor gas. The atomic force microscopy (AFM) measurements (see figure 1) of etched stripes showed an etching depth of 6-7 nm and an average roughness (Ra) of 0.53 nm. AFM and SEM images show good quality of the Si_3N_4 mask surface without any impurities after FIB etching.

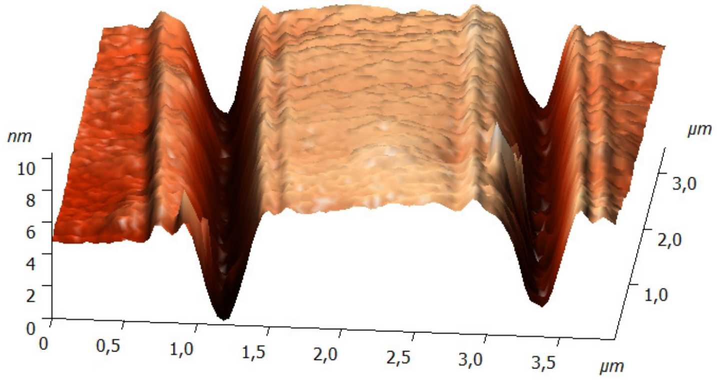
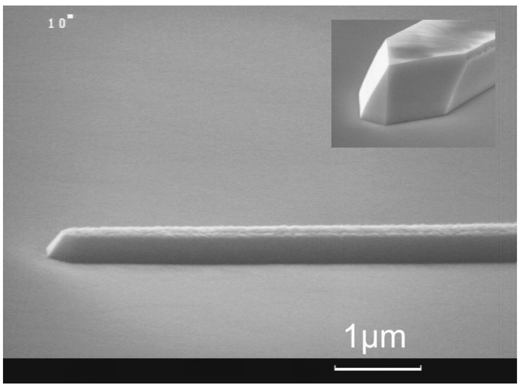


Figure 1. AFM image of the 500 nm wide FIB etched stripes on a Si_3N_4/GaN substrate.

Si+ doped GaN stripes were selectively grown on the FIB prepared substrates. The secondary electron microscopy (SEM) images of the stripes are shown in figure 2. Inset in figure 2 (a) shows the formation of the facets of the stripe.

(a) 

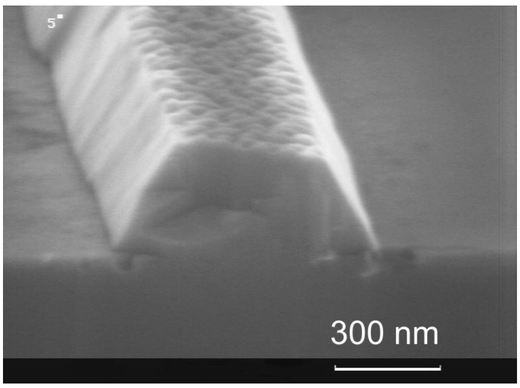
(b) 

Figure 2. SEM images of: (a) a selective-area epitaxilly grown submicron GaN stripe, inset shows the formation of the stripe facets; (b) a cleaved facet of the stripe.

3. Micro photoluminescence study

The micro photoluminescence (micro PL) technique was used for the estimation of doping and crystalline quality of the grown stripes. Figure 3 shows room temperature (RT) micro PL spectra of the Si-doped GaN epitaxial layer in the area between the stripes (a solid curve) and a highly Si-doped

GaN stripe grown in a 200 nm width window (a dashed curve). A HeCd laser was used for optical pumping.

The luminescence spectrum of the GaN epitaxial layer contains a typical for GaN near-band-edge luminescence (363 nm) peak and also blue band (430 nm) and yellow band (550 nm) peaks. The long-wave edge of the spectrum is modulated due to interference of light reflected from both the top and bottom boundaries of the GaN layer.

The luminescence spectrum of a stripe contains a highly broadened and long-wave shifted GaN interband luminescence peak and a bright yellow band (550 nm) luminescence. Broadening, long-wave shifting of band edge luminescence and a yellow band are typical for GaN epitaxial layers heavily doped by Si.

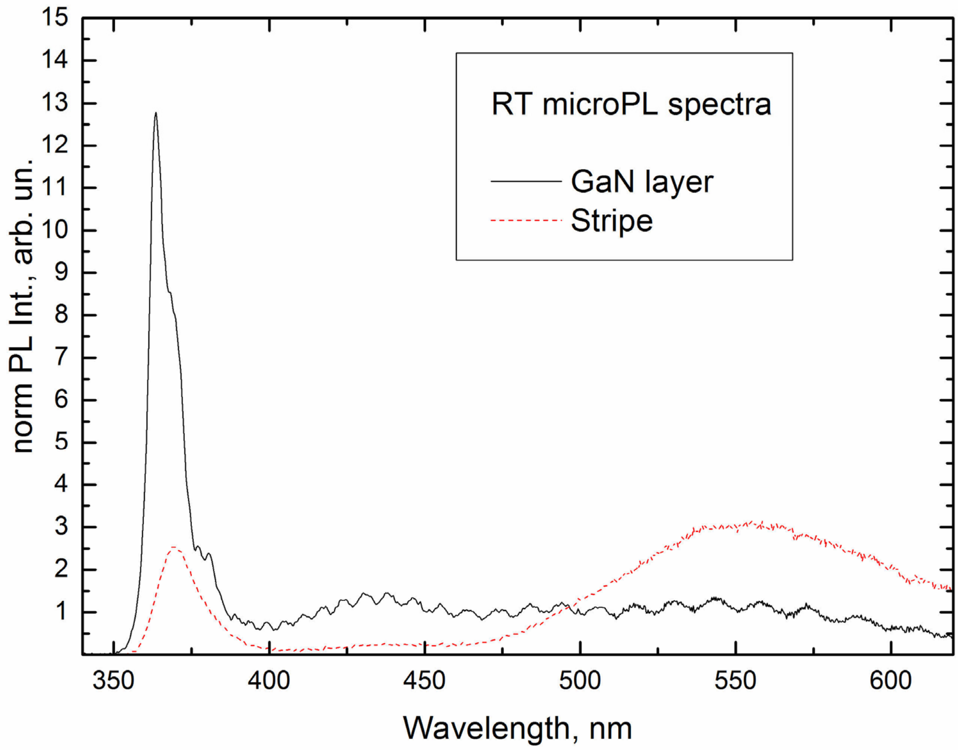


Figure 3. Micro PL spectra of the undoped GaN epitaxial layer and the highly Si-doped GaN stripe grown in a 200 nm wide window.

4. Conclusion

We have shown that FIB nanolithography can be used as a rapid technique for preparing masked substrates intended for selective-area epitaxy. Substrate surface investigations show good quality of the Si_3N_4 mask without any impurities after FIB etching. Formation of the stripe facets observed in the SEM images confirms good crystalline perfection of selectively grown material. The obtained results could be utilized for prototyping of submicron photonic and electronic structures, especially for nonalloyed ohmic contacts to HEMT transistors.

Acknowledgments

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References

[1] Denninghoff D J, Dasgupta S, Lu J, Keller S and Mishra U K 2012 *IEEE Elect. Dev. Lett.* **33** 6 785-7
[2] Li SF and Waag A 2012 *J. Appl.Phys.* **11** 7 071101
[3] McKay H, Rudzinski P, Dehne A and Millunchick J M 2007 *Nanotechnology* **18** 45
[4] Martin A J, Saucer T W, Rodriguez G V, Sih V and Millunchick J M 2012 *Nanotechnology* **23** 13
[5] Gierak J 2009 *Semicond. Sci. and Tech.* **24** 4
[6] Kitslaara P *et al* 2006 *Microelectronic Eneneering* **83** 811–14
[7] Wang Y L, Temkin H, Hamm R A, Yadvish R D, Ritter D, Harriott L H and Panish M B 1991 *Electronics Letters* **27** 15 1324-26
[8] Barbagini F, Bengoechea-Encabo A, Albert S, Martinez J, Garcia M, Trampert A and Calleja E 2011 *Nanoscale Res. Lett.*, **6** 1-9