GUIDES D'ONDES GaN SUR SUBSTRAT Si PRESENTANT DE FAIBLES PERTES A LA PROPAGATION DANS LE VISIBLE.

M. Gromovyi[1], F. Semond[2], J.Y. Duboz[2], G. Feuillet[3], M.P. De Micheli[1]

[1] University Nice Sophia Antipolis, LPMC UMR7336, Parc Valrose, 06100, France, marc.de-micheli@unice.fr

[2] CNRS, CRHEA UP10, Rue Bernard Grégory, 06560 Sophia Antipolis France

[3] CEA LETI, MINATEC campus , 17 rue des martyrs 38054 Grenoble Cedex 9,

RÉSUMÉ

Dans cet article nous présentons la caractérisation d'un premier guides d'onde, composé de couches d'AlN et de GaN épitaxiées sur substrat de Si. Le mode fondamental à 633 nm présente 5dB/cm de pertes à la propagation ce qui est déjà un bon résultat pour des guides en semiconducteur à cette longueur d'onde. Ces pertes augmentent avec l'ordre du mode. Une modélisation soigneuse de la structure complète permet de comprendre qu'elles sont en grande partie dues au substrat de Si, et quelles pourraient être fortement réduite en réalisant le guide sur un substrat de SOI judicieusement choisi.

1. INTRODUCTION

Fabrication of waveguides in GaN is attractive as this material has interesting electro-optic and nonlinear properties as well as a good transparency in the Visible and the UV. More over, it can be grown in periodically poled layers allowing fulfilling Quasi Phase Matching condition in very extended part of the spectrum. Nevertheless, the fabrication of low propagation losses waveguides in GaN has always be a challenge[1]. In the first part of this paper we present a careful characterization of a waveguide composed of an AlN buffer and a GaN guiding layer grown on a Si substrate. The second part is a numerical study showing how one should choose SOI substrate to realize lower losses waveguides.

2. WAVEGUIDE FABRICATION.

The sample we tested was epitaxially grown by ammonia-MBE on a 2" Si(111) wafer. It is composed of a 360nm AlN buffer grown at 1000°C on top of which was grown a 1µm thick GaN layer at 800°C. Due to a large thermal expansion coefficient mismatch between nitrides and the silicon substrate, nitrides epitaxially grown on silicon are under tensile strain at room temperature and cracks appear if the amount of tensile strain exceeds a certain value. For this sample, layer thicknesses are adjusted in order to decrease as much as possible the wafer bow indicating that the tensile strain is mostly compensated by playing with the lattice mismatch in between GaN and AlN.

3. WAVEGUIDE CHARACTERIZATION.

The waveguide was characterized using the prism coupling technique and a HeNe laser at 632.8 nm, in order to measure the effective indices of the propagating modes. In this layer we have been able to observe 4 TE and 4 TM modes. The observation of the diffusion at the surface (Fig 1) allows visualizing the important defects and assessing propagation losses in the areas presenting no local defects.

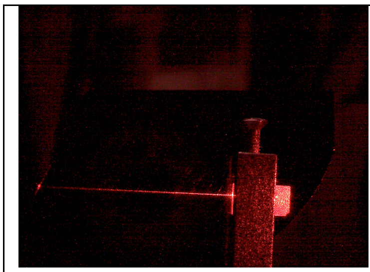
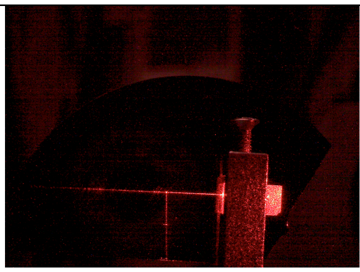
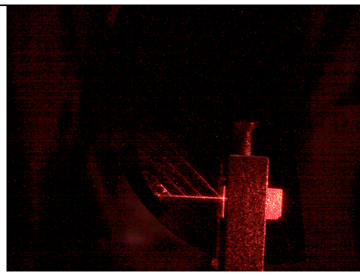
		

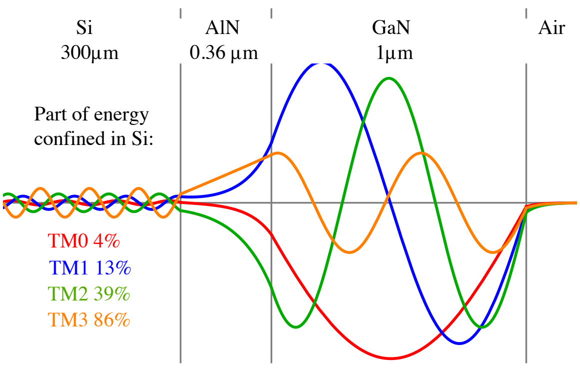
Fig. 1a : Propagation in an area presenting no point defects	Fig. 1b : Typical point defect, due to cracks in the AlN layer.	Fig. 1c : Typical point defects, due to cracks in the AlN layer.

From the observations reported in Fig 1, it is possible to see that the central part of the 2” wafer is almost crack-free while the density of cracks increases close to the edges of the wafer. On this sample we tried to make the AlN layer thick enough (360nm) to isolate the modes from the Si substrate. This thick layer presents a lot of strain, responsible for the cracks. Choosing situations of the type of Fig.1a, we assessed to 5dB/cm the propagation losses for the fundamental mode, by measuring the decrease of the signal along the propagation line, assuming that the diffusion is uniform in this area. To make these measurements, we carefully choose the injected intensity in order to keep the signal in a range where the camera (we used a very simple one) can be supposed to have a linear response, but the results are nevertheless affected by an important uncertainty. Despite this uncertainty, the obtained value indicates that those layers are of good quality at this wavelength and present a good potential for device fabrication in the UV and the Visible. For the first order modes, the diffusion at the surface is no longer visible after 1cm of propagation and even shorter distances for higher order modes indicating that, for these modes, the losses reach 20dB/cm or more.

4. WAVEGUIDE MODELING.

The evolution of the losses with the mode order can be explained by calculating the field distribution for the different modes. For this calculation we neglected the fact that Si is absorbing at this wavelength. (Fig.2)

Fig.2:Field distribution for the different modes.



One can see that the proportion of the energy traveling in the Si is very different from one mode to the other, which explains that the propagation losses are also very different.

A trivial way to reduce the propagation losses could be to increase the AlN thickness, but this cannot be done today without increasing the numbers of cracks in this layer. One has therefore to find another strategy to further reduce the propagation losses in the GaN waveguides.

We propose to use SOI wafers as substrate instead of simple Si wafers. These substrates exist with a great variety of SiO_2 and Si film thicknesses[2]. In order to choose the most appropriate, we tested numerically several possibilities, fixing the thickness of AlN and GaN respectively to 300 and 400 nm which corresponds to a monomode waveguide at 632.8 nm and varying the thickness of the Si layer, the thickness of the oxide layer being large enough to isolate the structure from the Si substrate. Preliminary calculations indicated that this is already the case with the commercial SOI wafer presenting a 2µm thick SiO_2 layer.

In Fig.3, we plotted the amount of energy in the Si layer as a function of its thickness. The calculation shows a resonant behavior which can be explain by the fact that the structure SiO_2 / Si / AlN / GaN / air, can be considered as two coupled waveguides, a Si waveguide (SiO2 / Si / AlN) and a GaN waveguide (AlN / GaN / air).

This result also indicate that it is possible to obtain structures for which the amount of energy confined in the Si layer can be as small as 0.1% which should allow realizing structures with losses lower than 0.5 dB/cm.

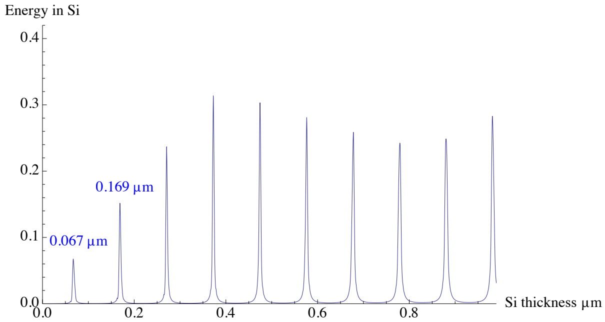


Fig.3 Energy in the Si layer as a function of its thickness.

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[2] See for exemple www.soitec.com/en/products-and-services/microelectronics