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# Nonlinear interactions in extremely low loss GaN planar waveguides.

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Abstract: Combining MBE and MOVPE we have been able to fabricate GaN epitaxial planar waveguides exhibiting ultra low loss in the visible (≤1dB/cm @540nm) and allowing efficient NIR to visible nonlinear conversion.

## State of the art

Several groups have studied GaN waveguides on Sapphire substrate [1-3]. In general, loss measurements are realized in the near Infrared @1.5µm and the best published result is around 1dB/cm for the fundamental mode [1,2]. At shorter wavelengths, the propagation losses rapidly increase to reach 8 dB/cm @633nm [1].

## Design and realization of a frequency doubler using modal phase matching.

To realize such a device we chose to use a structure (Fig. 1) with a GaN core and an AlGaN buffer and we designed it to achieve modal phase matching between the TM0 mode at a wavelength between 1.2µm and 1.3µm and the corresponding SH in the TM2 mode. In order to be able to optimize the overlap integral between the interacting modes we need to invert the polarity of the material during the growth, which can be done by MBE. Therefore, we chose MBE to realize this structure on a 2" sapphire substrate despite the fact that in this first attempt we did not perform the polarity inversion.

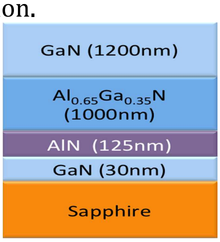


**Fig. 1. Structure of the MBE waveguide**

| | | TM0 | TM1 | TM2 | TM3 |
|---|---|---|---|---|---|
| MBE surface | 633nm | 7±1 | 13±3 | 16±3 | n.a. |
| | 543nm | 7±2 | 15±3 | n.a. | n.a. |
| MOVPE surface | 633nm | <1 | <1 | 3±1 | n.a. |
| | 543nm | <1 | <1 | 4±1 | 6±1 |

**Table 1 : Propagation losses in dB/cm @ 633 nm and 543 nm**

## Linear and Nonlinear Characterization of the MBE layer

Using a prism coupling set-up we measured the propagation losses by monitoring the diffused light along the propagation with a camera. The obtained results reported in Table 1 indicate that the propagation losses of this structure are typical of the state of the art. We obtained slightly better results for the fundamental mode in structures realized on Silicon [4] but in that case the TM2 mode exhibit higher losses due to the absorption in the Si substrate. Using a second prism and a pulsed tunable source in the infrared (EKSPLA NT242 OPO) we were able to visualize the SH signal at different wavelength for different modes combination. Allowing the beams to propagate 5mm between the two prims, we measured the fundamental and the SH powers after the output prism and we obtained 0.5µW peak power @620 nm for 20W @1.24µm.
Beside these optical characterizations, we performed a numerical study showing that the evolution of the propagation losses with the mode order we observed can be

explained by the scattering due to the surface roughness. Therefore we decided to cover the tested structure with a thin layer of GaN grown by MOVPE.

**Waveguide with a MOCVD cap.**

Indeed, MBE and MOVPE GaN layers present very different surface roughness (Fig. 2). As the MOVPE layer is very thin (50nm) the mode structure is not changed but the propagation losses are dramatically reduced (Table 1) underlining the influence of the surface roughness on the propagation losses. In the red as well as in the green, the losses of the first modes cannot be measured as they are lower than the precision of this measurement set-up, 1dB/cm.

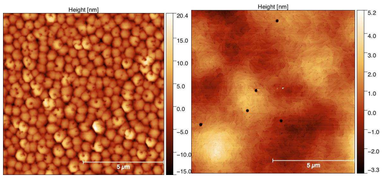

**Fig. 2 AFM picture of the MBE (left) and the MOVPE (right) GaN surfaces**

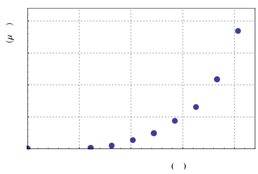

**Fig. 3. SH power as a function of the pump power**

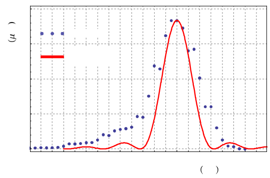

**Fig. 4 SH phase matching curve**

Using the two prisms set-up, we measured the SHG efficiency and observed also a dramatic improvement due to the reduction of the losses. In this case, the useful propagation distance between the prisms is limited by the OPO bandwidth (0.7nm) and the homogeneity of the structure. Allowing 5mm propagation between the prisms it was possible to plot the SH power dependence as a function of the pump power (Fig. 3) and the phase matching curve (Fig. 4). The first one shows the typical quadratic dependence of the SH signal and indicates that for 20W pump peak power we obtain 20µW SH peak power @632.5nm. On the phase matching curve, the effect of the width of the pump and the lack of homogeneity of the waveguide can be seen as the experimental curve (blue points) differs from the theoretical one calculated for a monochromatic pump (in red in Fig. 4) but these results are very positive. We will complete them by more accurate nonlinear measurements and realize similar structures using planar polarity inversion in order to optimized the overlap.

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