Preliminary characterization of Highly Uniform GaN layers grown by PAMBE in Compact 21 with an ADDON Nitrogen RF plasma source

Introduction / Summary

In this note, Riber GaN Proces Technology Center (PTC), reports on the growth of GaN layers and (Al,Ga)N/GaN quantum wells and their optical properties within the frameworks of the development of the new ADDON Nitrogen Radio Frequency (RF) plasma source, series RFN50/63/100 fitted on a commercial Compact 21 MBE reactor.

The first purpose of this application note is to highlight that Compact 21 T GaN MBE system using the ADDON N RF source RFN50/63 is a well proven machine to achieve thick GaN layers as well as (Al,Ga)N/GaN quantum wells grown on commercial 2" GaN sapphire templates. Results show both a high crystalline quality and optical properties consistent with the state-of-the-art or better.

Furthermore, preliminary studies demonstrate the capability of the system/source to produce very uniform layers in properties, composition and photoluminescence energy peaks across the wafer thanks to the use of the beam shaping end-piece of the N RF plasma source. This beam-shaping end-piece is tailored to the Riber Compact21 systems to achieve excellent uniformity. Dedicated end-pieces are available for each systems including Epineat and Production MBE machines from Riber.

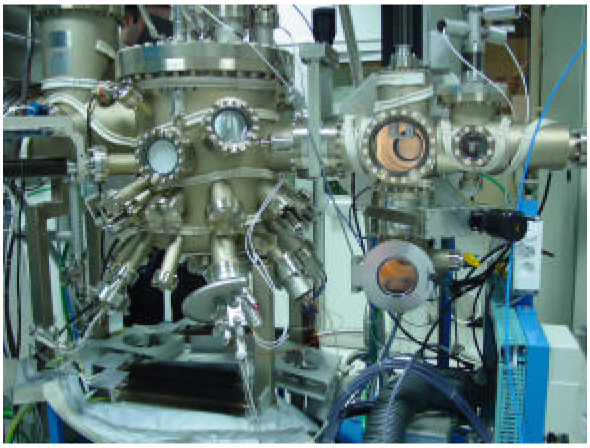

Figure 1: Compact 21 GaN MBE system

Figure 2: N RF plasma source model RFN50/63

Experimental

The Nitride layers were grown in a RIBER Compact 21 MBE reactor (fig 1) equipped with a Gallium ABN 60 effusion cell, an Aluminum cold neck effusion cell and an N RF plasma source model RFN50/63 (fig2) . This source was operated at a 1.8 sccm and 400 watts giving a growth rate of 0.45 µm per hour (450 nm/h).

Crystalline and optical properties were investigated by low temperature photoluminescence (PL) technique performed with a HeCd laser (laser excitation at 325nm) and the 244 nm line of a frequency-doubled Ar laser. Surface roughness is deduced from root mean square (rms) roughness value of the atomic force microscopy (AFM) scans.

Growth and crystalline quality of thick GaN layer

A 1µm thick GaN layer was grown at 720-730°C, with a growth rate of 0.45µm/h on GaN on sapphire template. The best GaN structural quality is achieved by deposition near the stoechiometry (V/III flux ration ˜ 1), in a slightly Ga-rich region with 2-3 monolayers (MLs) segregating at the growth front.

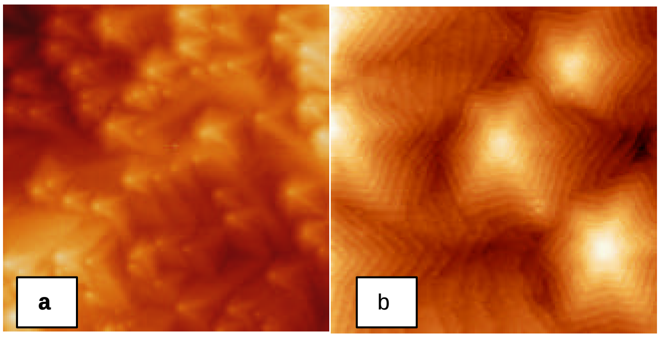

Figure 3: a) 5X5µm² AFM image and **b)** 1x1µm² AFM image of the 1µm thick GaN layer grown on GaN template substrate by PA-MBE.

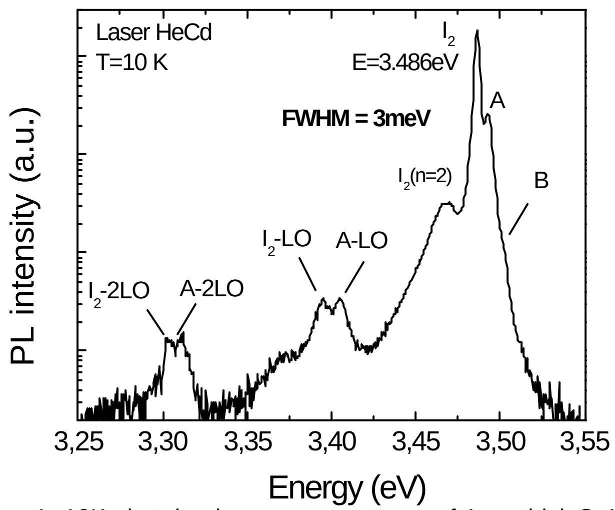

Figure 4: 10K photoluminescence spectrum of 1µm thick GaN layer grown on GaN template substrate by PA-MBE

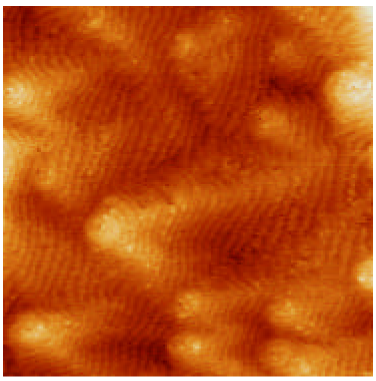

Figure 5: A 2x2µm² AFM image of the (Al, Ga)N quantum well surface

A 5x5µm2 AFM scan of the GaN layer surface (Fig. 3.a) shows a spiral growth morphology with a roughness of 1 nm and atomic steps are also visible on the surface. Higher magnification AFM picture (Fig. 3.b) indicates that the spiral growth patterns observed present a screw-type dislocation at their top consistent with a step-flow growth mode.
The PL spectrum (figure 4) shows the high quality of the sample. At 10 K, the intense band edge is dominated by a sharp emission (FWHM of 3 meV) located at 3.486 eV and corresponding to the neutral donor bound exciton I_2. The free exciton *A* and free exciton B recombinations can also be observed. The line labeled $I_2(n=2)$ is the two electron replica of the donor bound exciton line. Furthermore, strong phonon replicas linked to both donor bound excitons (I_2-LO, I_2-2LO) and free excitons (A-LO, A-2LO), indicating the excellent structural and crystalline quality of the epitaxial layer, are well resolved.

Growth of GaN / (Al,Ga)N quantum wells

The GaN/(Al,Ga)N quantum well (QW) samples were grown on a 0.5µm thick GaN buffer layer deposited on GaN on sapphire templates. The quantum well, barrier and buffer layer were grown at 720-730°C with a growth rate of about 0.45µm/h (1.8 sccm N2 flow / 400 Watts). The Al composition of (Al,Ga)N barrier is approximatively 6.5-8%. A typical 2x2 µm2 AFM scan of the (Al,Ga)N surface shows a smooth surface (Fig. 5), with apparent atomic steps and terraces underlining the good quality of the (Al,Ga)N layer. The typical rms value calculated from several AFM images of 5x5µm² is less than 1nm.

Outstanding Homogeneity of GaN / (Al,Ga)N quantum wells

To assess the homogeneity of the samples, photoluminescence spectra were recorded from the centre to the edge of the 2" wafer at 17K using the 244 nm line of a frequency-doubled Ar laser. Figure 6, shows the evolution for one of the QW samples of the energy of (Al,Ga)N peak, QW peak and phonon replicas peaks.

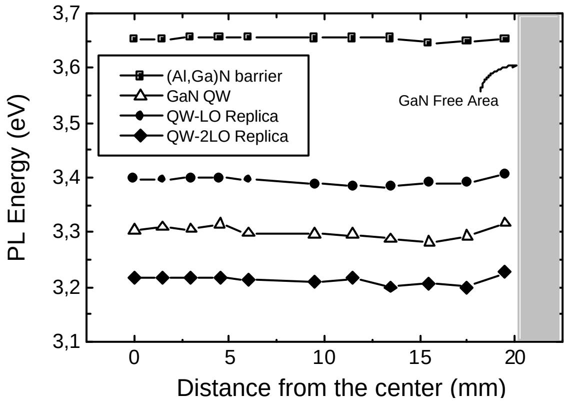

Figure 6: Photoluminescence energy position of the (Al, Ga)N barrier, GaN quantum well, and its phonon replicas across the wafer for one of the quantum well samples.

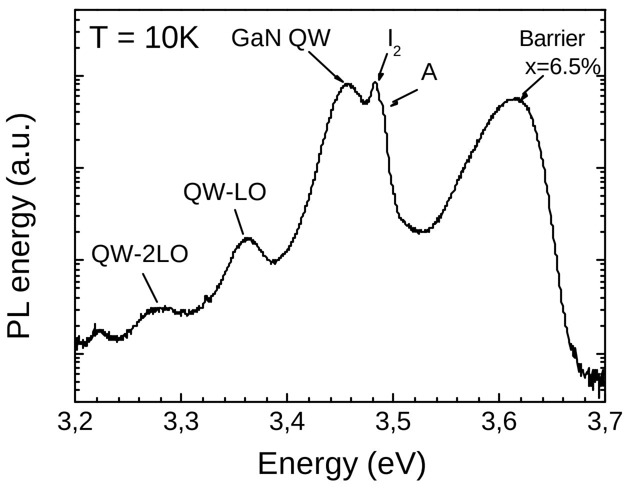

Figure 7: 10K photoluminescence spectra of one of the quantum well samples

The energy position of the (Al,Ga)N peak and, as a consequence the Al content is very uniform across the sample. Indeed a typical fluctuation of ±0.15% for the Al content in AlGaN is obtained. On the other hand, energy position of the QW peak as well as the phonon replicas are very uniform too. Energy fluctuation of ±8.5-10meV corresponding to a thickness fluctuation less than ±2 monolayers, i.e the height of 1 step, is obtained for the GaN QW.

Crystalline quality of GaN/(Al,Ga)N quantum wells

Figure 7 displays the PL spectrum of one of the QW samples. Band edge PL from the barrier is observed, together with the free exciton *A*, the neutral donor bound exciton I_2 and the QW luminescence band followed by two phonon replicas (lines labelled QW-LO and QW-2LO). Firstly, the (Al,Ga)N peak appears at 3.650 eV which corresponds to the targeted Al composition of 6.5%. Secondly, the intense quantum well PL peak, whose the linewidth is 30 meV, conjugated with its strong phonon replicas confirm the excellent crystalline quality. It is noteworthy that the FWHM of the I_2 peak of the GaN buffer layer after gaussian deconvolution is smaller than 3.5meV.

Conclusion

In summary, we have grown III-V nitride structure in our Compact 21T MBE research system using the new ADDON Nitrogen RF plasma source model RFN50/63 equipped with a beam shaping piece tailored to the Compact 21 geometry. We have shown that structural and optical properties are consistent with state of the art results, making our growth process and dedicated equipment among the best for III-N technologies

About GaN PTC

GaN PTC in collaboration with CRHEA/CNRS Valbonne, France allows customers and prospective users to test the Compact 21T GaN for growth of structures or target specific device properties to enhance and accelerate their process knowledge. Training courses may be tailored to meet individual requirements. Experience accumulated in advance of system delivery saves months of post-installation process development.

For more information please contact

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RIBER

Riber is the world leading supplier of MBE processing equipments and related services

The company has reached its 500 th system, with at least one system in each of the 35 countries involved with MBE, which represents around 48% of market worldwide.

Capitalizing on 30 years of experience, core philosophy of the company is to design systems in close association with customers. Riber invented and designed majors features which are now found is all MBE systems.

Riber plays a key role in the development of MBE technology, providing customers with solutions from equipment to epitaxial growth.

APPLICATION NOTES

Outstanding uniformities of GaN quantum wells – 608 27 M 62, 2005

State of the art quality of GaN &AlGaN quantum well grown on GaN template –608 26 N 02, 2005

Preliminary characterizations of III-N layers by PA-MBE in Compact 21 –608 28 R 92, 2006

Process improvement in the growth of AlGaN/GaN heterostructure on silicon by Ammonia MBE –608 29 N 72, 2007

State of the art highly doped GaN layers grown by Ammonia MBE –608 29 P 92, 2008

Optimization for InGaN epilayers grown by PA-MBE in Compact 21 –608 29 P 42, 2008

New growth method for InGaN based quantum well by PA-MBE in Compact 21 –608 29 P 92, 2008

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