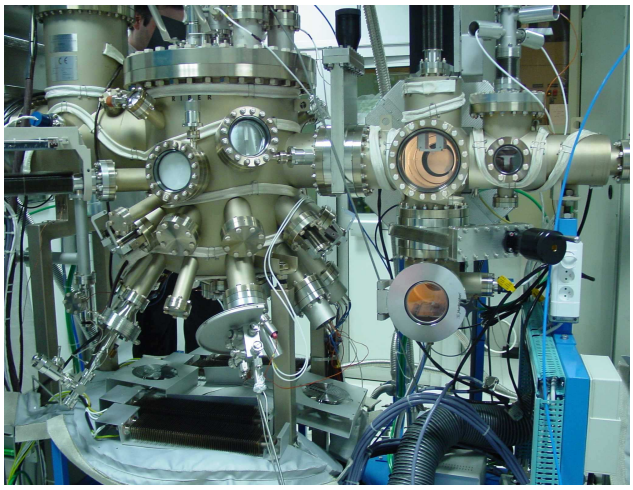

Compact 21 GaN MBE system

APPLICATION NOTE

Growth of GaN Qantum Dots Embedded in Very Thin Nitride Epilayers

Summary

Group-III nitride materials are already widely used as an efficient active layer in conventional blue-violet emitting devices operating at room temperature. Due to their strong exciton binding energy and large band offset, GaN/(AlGa)N quantum dots (QDs) are also expected to play a major role in the design of novel UV light sources based on very thin (< 120 nm) free-standing nanocavities. The choice of such structure lies in the possibility to achieve strong optical confinement and single mode operation but it leads to difficulties in the fabrication process when trying to etch group-III nitride materials. To circumvent these difficulties, one would want to grow very thin nitride epilayers directly on silicon and use the good etching selectivity between silicon and nitrides. It is then necessary to ensure that optically efficient GaN QDs can be grown that close to the silicon substrate interface i.e. on highly defected nitride epilayers.

We report the results of a work achieved in our GaN Process Technology Center in collaboration with the CRHEA-CNRS at Valbonne, France, demonstrating the embedment of GaN QDs in very thin nitride epilayers directly grown on silicon that exhibit strong spontaneous emission up to room temperature [1].

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Double zone MS effusion source

Experimental

Samples were grown by ammonia MBE in a RIBER Compact 21 reactor.

Ammonia flux is delivered by an injector, model HTI with run (to the substrate) and vent (to the vent pump) valves as close as possible to the epitaxy chamber to deliver rapid flow switching with very low transient time to deposit and control very thin layers.

Gallium and Aluminum were evaporated using respectively Riber MS double-filament effusion cell and single-filament effusion cell with Cold-Neck crucible. These cells demonstrated very stable working conditions over full and long campaigns under ammonia atmosphere. All heated parts, like filament gauge or substrate oven are ammonia resistant. No deterioration of these parts are noticed. An Ammonia recovery procedure has been set up and optimized and can be accomplished as often as necessary depending on the application. An automated version is also available.

Results

As followed *in-situ* by RHEED and confirmed by AFM (Figure 1), GaN QDs could be grown on (Al,Ga)N stacks as thin as 35 nm directly deposited on silicon (111). By adjusting the GaN deposited thickness, QD densities from $2x10^{9}$ cm^{-2} to $1.6x10^{11}$ cm^{-2} could be achieved.

In order to study the optical properties of such QDs, we have fabricated a 120-nm-thick sample containing 3 planes of $GaN/Al_{0.55}Ga_{0.45}N$ QDs. By stopping the sample rotation during GaN growth, the GaN nominal thickness deposited to form QDs is continuously varied through the 2-inch Si(111) diameter wafer from 7 to 12 monolayers (MLs) resulting in a gradient of both QD height and density.

Along with the QD height should vary their photoluminescence energy.

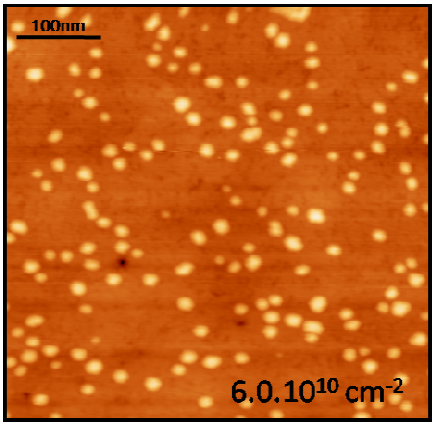

Figure 1: AFM image of GaN QDs grown on a 35 nm thin (Al,Ga)N stack on Si (111). The QD density is $6.0x10^{10}$ cm^{-2} corresponding to an initial GaN deposition of about 9MLs.

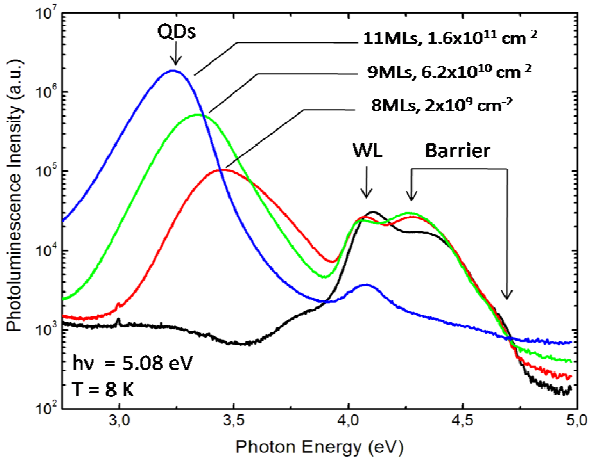

Figure 2: Evolution of the LT PL spectrum along the GaN/$Al_{0.55}Ga_{0.45}N$ QDs gradient. Spectra corresponding to a GaN deposition of 7 (black line), 8, 9 and 11 MLs are shown.

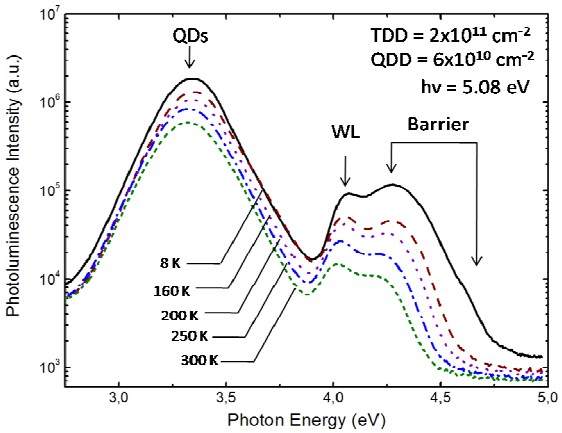

Figure 3: QD PL spectra versus temperature. The QD density is 6.0x10¹⁰ cm⁻² corresponding to a GaN deposited thickness of 9 MLs. The threading dislocation density is 2.0x10¹¹ cm⁻².

That is exactly what exhibits the low temperature spectra of this sample (figure 2) : the main feature shifts by about 240 meV (from 3.23 to 3.47 eV) when decreasing the GaN deposited thickness. Both, the emission energy of QDs lower than the bulk GaN bandgap as well as the shift along the height gradient are well accounted by the presence of a built-in electric field resulting in a large quantum confined Stark effect.

The spectra clearly exhibit two other features at 4.06 and 4.21 eV corresponding respectively to the wetting layer and the $Al_{0.55}Ga_{0.45}N$ barrier.

Temperature-dependent photoluminescence spectra (Figure 3) show that one third of the QD photoluminescence intensity remains visible up to room temperature. Despite the fact that the threading dislocation density of this sample ($2x10^{11}$ cm^{-2}) is even larger than the QD density, this remaining photoluminescence ratio is very close to what is usually reported for state of the art GaN/(Al,Ga)N QDs grown on much thicker and less dislocated nitride epilayers [2].

Conclusion

In summary, we have demonstrated the growth of GaN QDs on very thin (Al,Ga)N epilayers directly grown on silicon substrates. Despite the vicinity of the silicon substrate interface and a larger defect density, GaN QDs embedded in very thin (< 120 nm) (Al,Ga)N layers exhibit PL up to RT and behave very similarly to state of the art GaN QD samples. This represents a significant step toward the fabrication of novel short wavelength optoelectronic devices based on free-standing membranes

About GaN PTC

GaN PTC in collaboration with CRHEA/CNRS Valbonne, France allows customers and prospective users to test the Compact 21 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 process development after installation.

[1] S. Sergent *et al.*, Applied Physics Express **2**, 051003 (2009).
[2] T. Huault *et al.*, Applied Physics Letters **92**, 051911 (2008