

## Influence of the addition superlattices on the luminescence processes in nano-heterostructures based on nitrides

E A Menkovich<sup>1</sup>, S A Tarasov<sup>1</sup>, A V Solomonov<sup>1</sup>, S Suihnonen<sup>2</sup>, O Svensk<sup>2</sup>,  
L Riuttanen<sup>2</sup>, H Nykanen<sup>2</sup>

<sup>1</sup>Saint-Petersburg Electrotechnical University "LETI", Prof. Popova 5, St. Petersburg 197376, Russia

<sup>2</sup>Department of Micro and Nanosciences, Aalto University, Micronova, PL 13500, Aalto, 00076, Finland

E-mail: [menkovichea@gmail.com](mailto:menkovichea@gmail.com)

**Abstract.** The effect of addition of superlattice (SL) and the structure of the upper barrier layer on the luminescence processes occurring in light-emitting nanoheterostructures was studied. It was shown that the optimum is using of structures with two SL: InGa<sub>N</sub> / InGa<sub>N</sub> structure in the lower part and the AlGa<sub>N</sub> / Ga<sub>N</sub> for the top p-layer. It is shown that the using of the SL InGa<sub>N</sub> / InGa<sub>N</sub> in the vicinity of the active region optimally compensate the elastic stresses and the piezoelectric field at the hetero boundaries. Such compensation of elastic stresses reduces the formation of dislocations in these structures, which increases the radiation intensity.

### 1. Introduction

Nano-heterostructures based on nitrides are widely used in modern nanoelectronics devices and photonics. Their applying in the creation of short-wavelength light emitting diodes is important. Difference of layers lattice constants in such structures forms significant elastic stresses in the heterointerfaces. Presence of such elastic stresses especially serious influences beside to the active region of the emitter. Also degradation accelerates for structures with significant elastic stresses. Degradation is caused by an increased defect formation occurring as a result of the relaxation of elastic stresses.

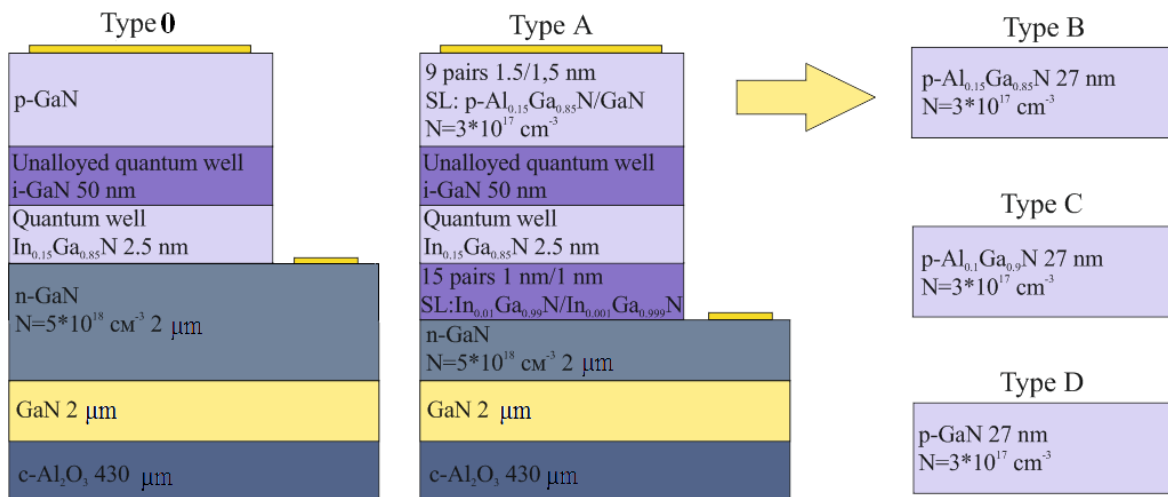
To reduce these effects in nitride based nanostructures for light-emitting diode typically use complex structure of the active region which contain several unrelated InGa<sub>N</sub> quantum wells. This allows to redistribute the elastic stresses between the layers and reduces the magnitude of their impact on the heterointerfaces. However, such methods do not fully allow to avoid the appearance of negative effects listed above.

One of the known methods which improve the parameters of emitting nanostructures is to use superlattices of different composition. Thus, the superlattice located between the substrate and the active region substantially reduce defects in the active region. This is primarily due to reduction of the dislocation density of threading through the epitaxial layers to the substrate surface. However, using the superlattice active region in that area, including above it might help offset the effect of elastic stresses and associated.



## 2. Sample and experimental technique

The authors studied the luminescence of the semiconductor nitride nano-heterostructures on the basis of solid solutions (Al, Ga, In)N having multiple quantum wells and superlattices, created by MOCVD method on the sapphire substrate (figure 1). The nano-heterostructures had the same structure except the last p-GaN epitaxial layer. The n-GaN buffer and contact layers were grown on the *c*-Al<sub>2</sub>O<sub>3</sub> substrate having 4 μm thickness. Structures without superlattices were used as reference (type 0). The SL in the other structures consisting of 15 In<sub>0,01</sub>Ga<sub>0,99</sub>N and In<sub>0,001</sub>Ga<sub>0,999</sub>N layers each having 1 nm thickness were added before the active region. The active region comprised one 2.5 nm width In<sub>0,15</sub>Ga<sub>0,85</sub>N quantum well. Further the low-alloyed 50 nm thickness i-GaN layer was grown. The final p-GaN layer was of four types: the first type represented SL comprising 9 pairs of Al<sub>0,15</sub>Ga<sub>0,85</sub>N and GaN layers of 1.5 nm thickness (type A), the second type - p-AlGaN layer with 15% aluminum fraction (type B), the third type - p-AlGaN layer with 10% aluminum fraction (type C) and the forth type - p-GaN layer (type D). The final A, B, C, D layers thickness was 27 nm. Carrier concentration in these layers was  $N = 3 \cdot 10^{17} \text{ cm}^{-3}$ .



**Figure 1.** The structure of the studied samples.

The nano-heterostructures study were conducted by means of the author's elaborated diagnosis test system for the investigation nano-heterostructures operating parameters [3]. The system allows determining all general features of the solid-state emitters and products on its base: spectral, watt- and volt-ampere characteristics, luminescence intensity and efficiency. In the submitted research the samples represented undivided luminescent chips on the sapphire substrate. Therefore, for the diagnosis the probe station was applied. Several sets of substrates were investigated, each contained several tens of chips. Results for efficiency and power of radiation for the chips of the same type were almost close. The paper are presented experimental results summarizing the array of data obtained for a few hundred light-emitting nano-heterostructures.

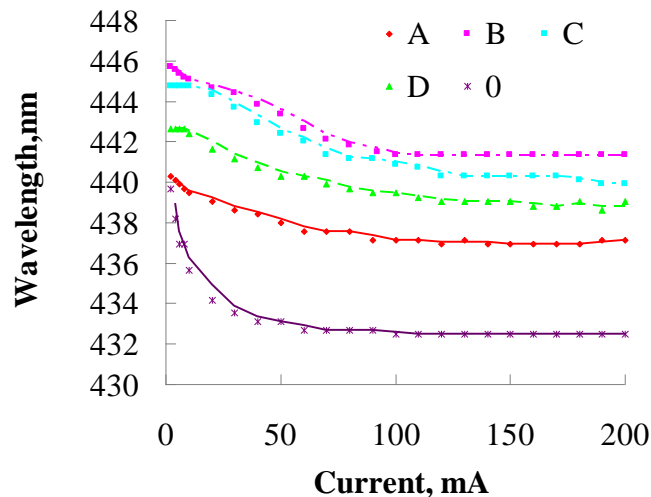
## 3. Experimental results and discussions

According to [1, 2] the structures failing to comprise superlattices under low currents (up to 10 mA) demonstrated the significant shift up to 10 nm spectrum luminescence maximum forward to short-wave region. This effect can be explained by the influence of elastic stresses and piezo-fields arising at heteroboundaries in nanostructure as a result of great difference of the lattice parameters.

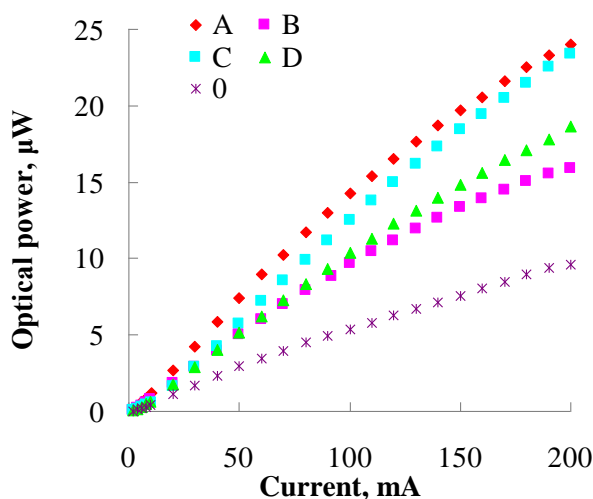
The active region and wells located there are influenced by three main components: p-n junction built-in electric field; built-in field induced by deformations; external field conditioned by an applied voltage. In spite of the essential p-n junction field influence on luminescent nanostructures properties in the whole, it cannot be considered as the main cause of the above mentioned effect arising. The nanostructure active region under low currents provides low external voltage drops. Against these

drops built-in field contribution induced by deformations can be well recognized. Due to this the shape of well is strongly distorted and a quantum-confinement Stark shift arises. This leads to the significant distance decrease between working levels. With external voltage increasing the built-in field influence is compensated and the shift is decreased.

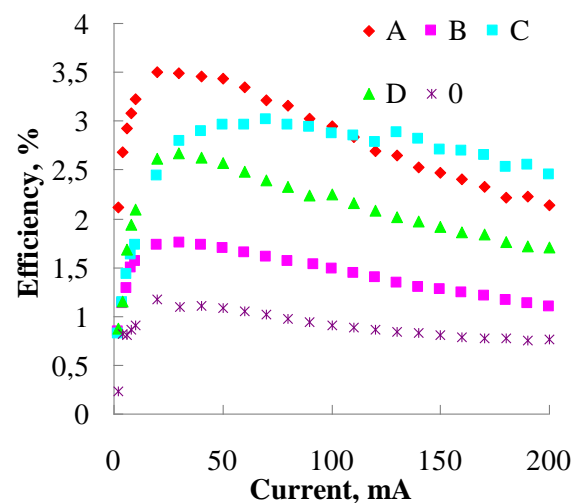
In structures containing no superlattices (type 0) a significant shift of the peak wavelength was observed (fig. 2). SL in the nanostructures allowed to partly compensate elastic stresses thereby the discussed effect was decreased to 2.3 nm for type A. For the type B structures the shift was 1.8 nm, 4.3 nm - for the type C structures and 3.4 nm for type D structures. This mean incomplete elastic stresses compensation at the single quantum well interface and higher layers in the type A structure. Probably, the residual elastic stresses within the structure relax without crystal lattice defects formation, therefore it had higher steadiness and operation efficiency. Furthermore, this assumption is confirmed by a lower luminescence efficiency of the type B structures where the influence of elastic stresses regarding the wavelength shift is decreased due to the dislocations formations and luminescent efficiency decreasing.



**Figure 2.** Wavelength peak dependence on the operating current.



**Figure 3.** The optical capacity dependency on the current.



**Figure 4.** The dependency of the efficiency on the current.

Comparative analysis of A, B, C, D type structures also allowed studying of the final barrier electron intended layer structure influence of the regarding the radiators' luminescent and other

operating features (figures 3 - 4). The luminescence efficiency of the samples was relatively low, since they were part of the unseparated wafer without additional lenses.

Considering the achieved optical power and efficiency values the addition of superlattices (type A) 3,5% and 2,7 mW correspondingly under the current 20 mA provides the best effect. A more weak effect is provided by the usage of p-AlGaIn layer with aluminum portion 10% (type C) (2,4% and 1,6 mW correspondingly). Further increasing of Al concentration makes the parameters of obtained samples (type B) (1,7% and 1,8 mW correspondingly) significantly worse. In this case appears that negative influence of the lattice mismatch and increased defect formation associated both which exceed the advantages resulting from improved charge carrier confinement. Apparently, in this case, the negative influence of the lattice mismatch and the associated increased defect exceed benefits. This effect strongly proved itself so that optical power of reference type D structures with the barrier layer without aluminum be higher than the samples of type B (2,6% and 1,7 mW correspondingly). This effect could be reduced in the superlattice structures due to voltage rearrangement in thin layers consisting in superlattices.

Also it was demonstrated that all studied nanoheterostructures are operable up to the currents exceeding 150 mA. The optical power saturation was not observed in the type A, C, D structures except the type B structures which had the lowest efficiency proving their high imperfection. The optical power dependencies of the type A and type C structures coincide while the efficiency is distinguished. The addition of superlattice results in relatively small number of dislocations that doesn't affect the device operation efficiency.

#### 4. Conclusion

Thus, it was established that the structure with two InGaIn and AlGaIn superlattices have high operation steadiness and the best operating characteristics. It is demonstrated that the InGaIn/InGaIn superlattices usage beside the nanostructure active region provides that the elastic stresses and piezofields at the heteroboundary are optimally compensated. Such stresses compensation reduces dislocations formation in the mentioned structures, what in turn increases the radiation intensity. It is shown the significant influence of the upper barrier layer on the radiators' parameters and is found that the AlGaIn/GaIn superlattices usage is optimal.

#### References

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