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Present and Future Nitride-Based Devices

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1. Present Status of GaInN-Based Devices

Establishment of high-yield growth technology utilizing low-temperature deposited (LT-) buffer layer on a sapphire substrate by metalorganic vapor phase epitaxy and realization of conductivity control by doping with Si, or Mg followed by the dehydrogenation treatment resulted in the vast expansion of nitride research world wide. Products and sales of nitride-based visible-LEDs and violet-LD show extremely high growth rate in the market. It is expected that they will soon occupy the major portion in the opto-electronics industry.

2. Why AlGaN ?

Detectors and emitters in the UV-region are one of the next target for nitrides, which will give a big impact on the market as visible-LEDs. In order to establish such UV opto-electronics, high-quality and well-controlled AlGaN is essential.

3. Defect and Stress Control of AlGaN Growth

Crystalline quality of AlGaN on a sapphire substrate covered with the LT-AlN buffer layer is much superior to AlGaN directly grown on a sapphire. However, it progressively degrades with increasing AlN molar fraction. Although it was significantly improved when AlGaN was grown on a high-quality GaN, at the same time crack network originated from the lattice mismatch between AlGaN and GaN was generated with a high-density if thickness of AlGaN exceeds the critical value. In-situ stress monitoring showed that stiffness of AlGaN is modulated by Si doping or Mg doping, in other words, tensile stress during growth is increased by Si-doping or Mg-doping.

We solved the fracture problem in AlGaN/GaN heterostructure utilizing another LT-AlN layer. LT-AlN is inserted between underlying GaN layer and upper AlGaN layer, therefore we call it "LT-interlayer". Crack-free thick AlGaN is achieved. Combination of the stress*thickness product measured by multi-beam optical stress sensor system and the thickness estimated by the interference of the optical beam showed that tensile stress during growth of AlGaN on a GaN is much reduced by the LT-interlayer. Therefore, nearly free standing AlGaN can be grown on a GaN covered with the LT-interlayer. Another effect of the LT-interlayer was revealed by transmission electron microscopy. The LT-interlayer acts as a filter against threading dislocations having screw component. AlGaN-based pin-type flame sensor which is not only solar-blind but also fluorescent-light-blind has been demonstrated.

Although dislocations having screw components are much reduced, additional pure edge-type dislocation was generated with a density as high as 10^{10} cm^{-2} or more at the LT-interlayer, which is found to act as the non-radiative recombination center. Therefore, fabrication of highly luminescent AlGaN has been still one of the critical and difficult issues in nitride semiconductor.

Several epitaxial lateral overgrowth (ELO) techniques have been performed to grow partially low–dislocation density GaN. The process of ELO is an initial selective growth on the window area and the following lateral growth on the mask area, the basic idea of which was originated from the micro-channel epitaxy in the growth of GaAs on Si. In case of Al containing alloys, however, poly crystals tends to deposit on the mask. Therefore, it is not easy to apply ELO technique to the growth of Al containing alloys.

We applied maskless lateral growth technique on the growth of Al containing alloys. Trenches were formed on a high-quality thick GaN. Threading dislocations were bent during lateral growth of AlGaN on a trench area. Therefore, low-dislocation density region is obtained on the trench. Due to the lattice mismatch between AlGaN and GaN, however, many cracks were formed. In order to achieve both crack-free and low-dislocation density, we combined the LT-interlayer and maskless lateral growth technique. At first, trenches were formed on GaN. Then, an LT-AlN was deposited on the GaN having trench. Finally, AlGaN was grown on the patterned GaN covered with the LT-interlayer. Dislocation density is 10^8 cm^{-2} or less on the trench area. So, dislocation is reduced more than two orders of magnitude while simultaneously fracture is avoided.

4. Performance of UV-LED

LED having $GaN/Al_{0.08}Ga_{0.82}N$ MQW active layer was fabricated on these partially high quality $Al_{0.22}Ga_{0.78}N$ layer. Before the growth of $GaN/Al_{0.08}Ga_{0.82}N$ M deposited at 500 °C on the GaN with the periodic trenches. After growing the active layer, we grew 400 nm thick Mg doped p-$Al_{0.20}Ga_{0.80}N$ cladding layer and 20 nm thick p-GaN contact layer. Thin Ni/Au is deposited on the p-GaN contact layer as a semi-transparent window. We also formed Ti/Au pad on the semi-transparent window and Ti/Al Ohmic contact on the underlying n-$Al_{0.22}Ga_{0.78}N$ layer exposed by RIE. Emission of this LED was measured from the top of the sample. The usual performance of UV-LED is 0.6mW at the forward current of 50 mA, 4.8 V, DC with an emission peak wavelength of 352.0 nm and FWHM of 6.0 nm. This performance is limited by the non-radiative component on the terrace region and the poor heat dissipation.

5. Electron Device

High breakdown field and high electron saturation velocity in ntirdes undoubltedly show that terahertz transistor will be achieved by the combination of nitride and nano-fabrication technology. It will surely give a big impact on the communication industry in the new area.

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