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EQE Enhancement Dependency on Reflective p-type Electrode of Ni/Mg and Rh in AlGaN UVC LED with Transparent p-AlGaN Contact Layer.

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Abstract

It is still hard to improve low Light Extraction Efficiency (LEE) of AlGaN UVC LED. Therefore, we investigated effects to enhance EQE by using Ni/Mg and Rh as p-type reflective electrodes of AlGaN UVC LED. And then, we compared with Ni/Al p-type reflective electrodes proposed by us so far.

1. Introduction

UVC LEDs are demanded for the applications of sterilization or medical fields, and a large market for UVC LED is expected in near future. In the past several years, an internal quantum efficiency (IQE) and an electron injection efficiency (EIE) have been significantly improved [1,2], however, the light-extraction efficiency (LEE) is still quite low (～10%) because of an UV light absorption in p-GaN contact layers. For realizing high LEE in UVC LEDs, a p-GaN free structure and highly-reflective p-type electrode are required. Previously, we reported on about 1.7 times LEE improvement and 7% max external quantum efficiency (EQE) for a 279 nm AlGaN UVC LED by using a transparent p-AlGaN contact layer and a highly reflective Ni(1nm)/Al p-electrode instead of a conventional p-GaN contact layer and a Ni/Au p-electrode [3,4]. In case of using Ni/Al electrode, fine tune for thickness of Ni is needed in order to maintain performance of LED [5]. Even though best tune is done, the reflectivity of Ni/Al electrode cannot exceed 80%. Therefore, finding new material or its complex superior than Ni/Al electrode as p-type electrode is meaningful, now.

In general, Rh is relatively easy to ohmic-contact to p-type semiconductor and relatively reflective (R≃70%) to UVC light without complex structure such as Ni/Al. As another candidate similar to Al, Mg is known as one of reflective metal to UVC light. Even if reflectivity of them are not higher than that of Al but any other properties of them are better such as electrical property, tolerance to environment and so on, they will be useful.

2. Purpose

Because it is still hard to increase LEE of AlGaN UVC LED, we investigated EQE enhancement effect by new (not yet proposed by us) reflective p-type electrode such as Ni/Mg and Rh and compared them with Ni/Al electrode proposed so far.

3. Experiments and results

3.1 EL measurement

Figure 3.1.1 shows the structure of LED samples with p-type electrode of Ni/Mg or Rh. The typical specifications of LED samples except for electrode are that peak wavelengths are around 280nm, that max EQEs are around 3~4% in case of using conventional Ni/Au p-electrode and that p-contact layers are transparent p-AlGaN layers. Size of reflective p-type electrode is 0.25x0.25 mm^2. We measured I-L characteristics to detect output light through backside of sapphire substrate by Si-photodetector with size of around 1x1cm^2.

Figure 3.1.2 shows I-L and I-EQE characteristics for Ni/Mg and Rh. And as summary of fig.3.1.2, figure 3.1.3 shows EQE enhancement factor dependency on reflective p-electrode, including data of Ni/Al proposed by us so far (ref. [5]). Comparing with that of Ni/Al (blue broken line), EQE enhancement factors of Ni/Mg (purple solid line) and Rh (green solid line) are not so high such as 1.5~1.6 and 1.3~1.4 times, respectively.

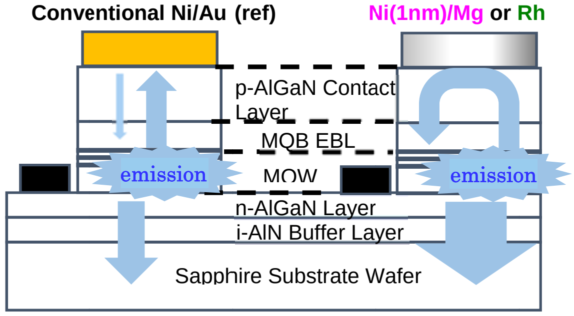

Fig.3.1.1 Structure of LED samples. Left-hand indicates the case of conventional Ni/Au p-electrode for reference and right-hand indicates the case of highly reflective p-electrode of Ni(1nm)/Mg and Rh.

(a)

(b)

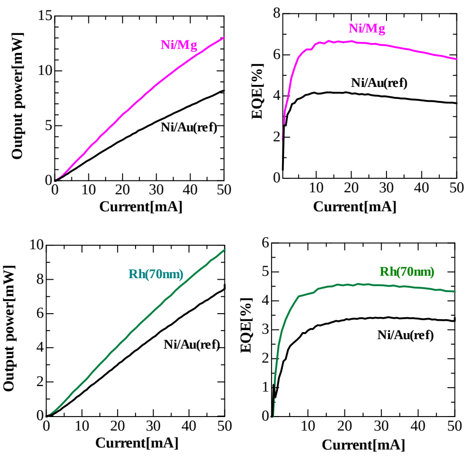

Fig.3.1.2 Characteristics of I-L (L/H) and I-EQE (R/H) of AlGaN UVC LED with reflective p-type electrode of (a) Ni/Mg and (b) Rh, respectively

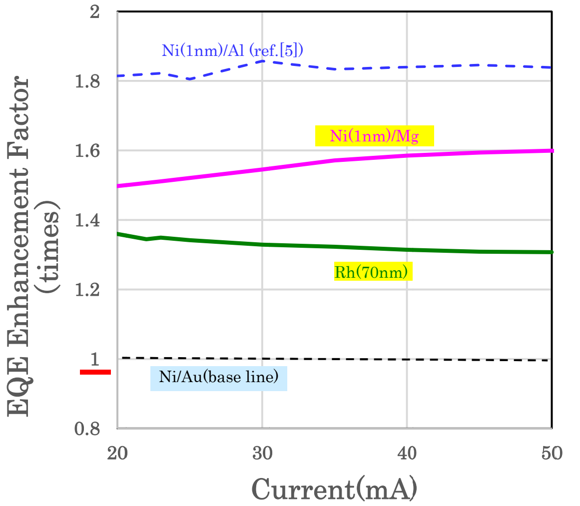

Fig.3.1.3 Dependency on reflective-p-electrode of EQE enhancement factor. Two solid lines of purple and green indicate case of Ni(1nm)/Mg and Rh, respectively. Two broken lines of blue and black indicate case of Ni(1nm)/Al and Ni/Au (base line), reflectively.

3.2 Reflectivity measurement

To investigate any reasons for lower EQE enhancement in case of Ni/Mg and Rh in previous section, we directly measured reflectivity of them.

Figure 3.2.1 shows the structures of sample of Mg(200nm), Al(200nm), Ni/Mg(1nm/200nm), Ni/Al(1nm/200nm) and Rh(70nm) on both-sides-polished sapphire substrate. 2 samples of Ni/Mg (1nm/200nm) and Rh (70nm) were evaporated as monitor samples during electrode evaporation of LED samples described in above section.

Figure 3.2.2 shows the results of relative reflectivity spectra of these 6 samples. In this spectra, the reflectivity of Al mirror sample is assumed to be 1 (base line). Two broken lines of purple and blue indicate the reflectivity spectra of Mg and Al on sapphire substrate, respectively. Solid lines of purple, blue, green and black indicate reflectivity spectra of Ni(1nm)/Mg, Ni(1nm)/Al, Rh and Ni(20nm)/Au on sapphire substrate, respectively. Comparing between Mg and Al or between Ni/Mg and Ni/Al, reflectivity of the former are unintentionally higher than those of the latter. But for Ni/Mg and Ni/Al, differential reflectivity decreases at shorter than 280nm perhaps due to absorption of Ni. The reflectivity of Rh in this experiment also was not so high against our initial expectation. Perhaps, Rh thickness of this

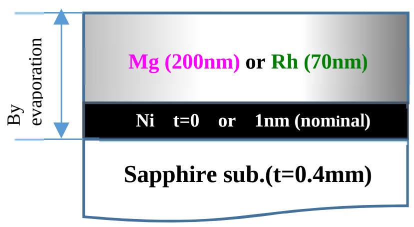

Fig.3.2.1 Structure of samples of Mg(200nm), Al(200nm), Ni/Mg(1nm/200nm), NiAl(1nm/200nm) and Rh(70nm)

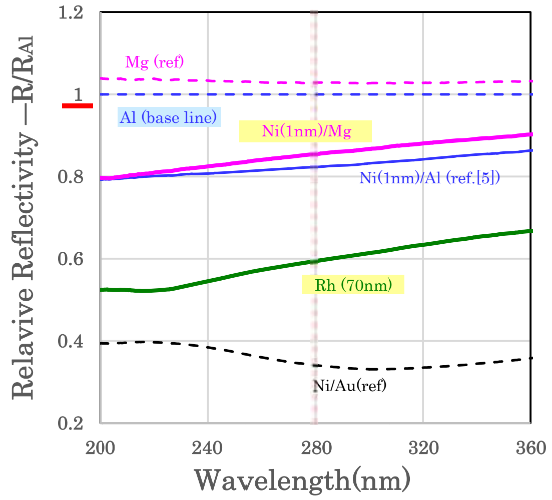

Fig.3.2.2 Reflectivity spectra of mirror samples. Two broken lines of purple and blue indicate mirrors of Mg and Al (base line) on sapphire substrate without Ni, respectively. Solid lines of purple, blue, green and black indicate mirrors of Ni(1nm)/Mg, Ni(1nm)/Al, Rh and Ni(20nm)/Au on sapphire substrate, respectively.

sample might be too thin (t~70nm) that is unintentionally caused by shortage of material source during evaporation.

4. Conclusions

For Rh, its thickness was thought to be not enough to increase reflectivity fully in this experiment. Also for Ni/Mg, the EQE enhancement factor was not higher although the reflectivity was unintentionally higher than those of Ni/Al. In case of thinner Ni, it is more severe to keep the balance between reflectivity (i.e. LEE) and injection efficiency. To conclude whether Ni/Mg and/or Rh are superior or not than Ni/Al as highly reflective p-type electrode of UVC AlGaN LED with transparent p-AlGaN layer, more systematical and more fine investigation will be still needed for thickness of Ni and/or Rh in similar to previous our work for Ni/Al (ref. [5]).

References

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