

Gallium Nitride Nanowire Enhanced High Intensity Discharge Luminance System

Jeff. T. H. Tsai, Zi-Jie Liao
Graduate Institute of Electro-Optical Engineering, Tatung University
Taipei, Taiwan thtsai@ttu.edu.tw

ABSTRACT

We demonstrated a high intensity discharge lighting system which contains gallium nitride nanowires on the electrodes to enhance the power efficiency of the system. Gallium nitride thin films have been used in blue light-emitting diode (LED). However, when this material was fabricated in a nanowire structure, the high aspect ratio of the geometric outlook makes it become an idea plasma ignition enhancer. Carbon nanotube has been used in plasma based lighting system for reduction of the power consumptions. We use GaN nanowire as the enhancer on the electrodes of the HID system which gives a better ignition voltage but also eliminate the usages of mercury in the conventional HID system. Due to the high temperature occurs when plasma ignited, the partial GaN dissociated to release Ga ions into the lamp. Ga ion has large capture cross-section of electron which helps the lamp electrodes maintain a high electric resistance. This could enhance the power efficiency and also prevent the sputtering effect on the cathode and enhance the lighting system's life-time. This approach also makes such HID system more environmental friendly. Hence, it is possible to produce a mercury-free plasma light lamp.

Keywords: gallium nitride, high intensity discharge lamp, nanowire

1 INTRODUCTION

High intensity discharge (HID) lamp has been introduced to the commercial market for decades. Arc discharge from noble gases such as argon or xenon can produce very high intensity of visible light when high voltage (1 to 3 kV) in plus mode across on the tungsten electrodes in the illumination system. Due to high current density through electrodes, the temperature usually reaches to 2000 °C near the region of the electrodes. This high temperature evaporates electrodes gradually which reduce the lifetime of the lamp. Also, for enhance the resistivity to reduce the electron bombardment to the electrodes, mercury vapor was introduced to the commercial product to enhance the intensity of the light emission and its lifetime.

We demonstrate a HID lamp with gallium nitride (GaN) nanowire embedded in the tungsten electrodes. The enhancement of the nanostructure reduces the plasmas ignition voltage has been demonstrate [1] due to high field

enhancement factor from the nanostructure which reduced the electron emission from the surface of the electrode. We have grown the GaN nanowire on several tungsten wires from a low pressure chemical vapor deposition system (LPCVD). These dense GaN nanowires embedded into the HID electrodes can reduce 25% of ignition voltage and enhance the 17% of efficiency from our illumination system. Gallium ions will released from GaN nanowires when arc discharge ignition. Theses gallium acts as the same function as mercury in the commercial lamp which also enhances emission of the visible light.

2 EXPERTIMENT

The experiment relates two parts: 1. nanowire growth and electrode preparation 2. HID assembly and lighting test.

2.1 Nanowire growth and electrode preparation

There are several methods to produce GaN nanowires [2-3]. In our case, GaN nanowires were produced by conventional vapor-liquid-solid (VLS) method. First, we deposit an ultra-thin gold film on a 0.4 mm tungsten wire. In order to coating this thin layer of gold uniformly all over the surface of W wire, a rotation stage was used to ensure every part of W was exposed under the plasma during the sputtering process. From the SEM observation, this gold film was estimated to be a thickness of 80 nm. The W wire with gold film was then heated up to 800 °C in a conventional low-pressure chemical deposition system (LPCVD) to transform the gold film into nano-cluster islands within 50 min then cool down to room temperature. Such isolated gold particles become an effective catalyst for growing GaN nanowires.

The LPCVD was then heat up to 800 °C for 50 min heat-up cycle, a Ga ingot was loaded into the quartz entrance of the LPCVD and placed in front of the gas inlet entrance which has the surrounding temperature of 680 °C. Ar and He mixture gas as the carrier gas to carry the vaporize Ga ion into the growth zone. Two kind of gas was inlet into the growth chamber; N₂ or Ammonia. Due to the different in dissociate rate, Ammonia provides better dissociated nitrogen source which can form the GaN nanowire in a perfect crystalline structure. On the other hand, nitrogen gas has limited dissociate rate which produce GaN nanowire in a partial crystalline, partial amorphous structure. However, all the product are in a

nanowire structure with around 50 to 400 nm in diameter and 2 to 10 μm in length. The GaN nanowire micrograph shows in Fig. 1.

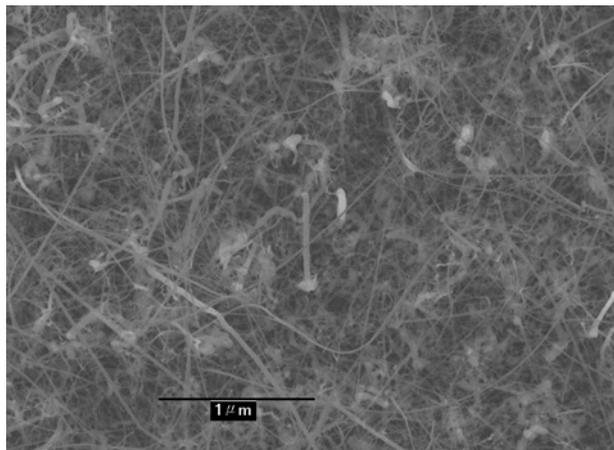


Figure 1: A low-magnification SEM micrograph of GaN nanowire growth on the W electrode

These nanowires were characterized by EDS and TEM to discover their microstructure and the degree of crystallization. It is clear to see in the TEM analysis that the nanowire growth by ammonia as nitrogen source produce highly crystalline structure (Fig.2) whereas the nanowire produced by the nitrogen gas just can form crystal structure partially (Fig. 3).

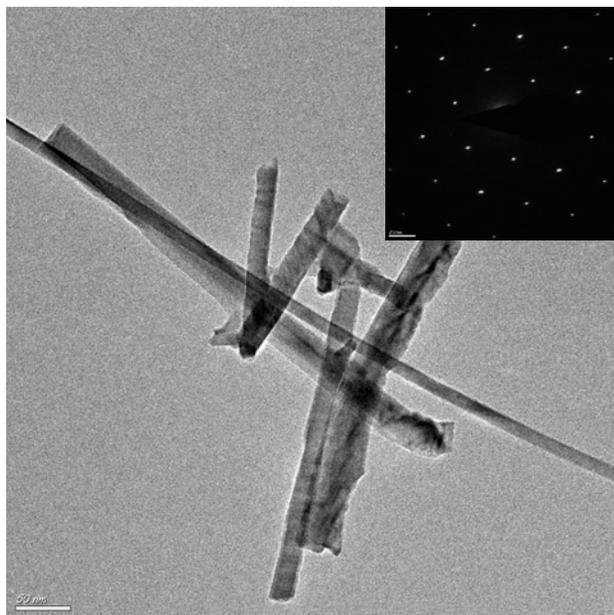


Figure 2: A low-magnification TEM micrograph of fully crystalline GaN nanowire. The inset of TEM image shows GaN hexagonal crystal structure.

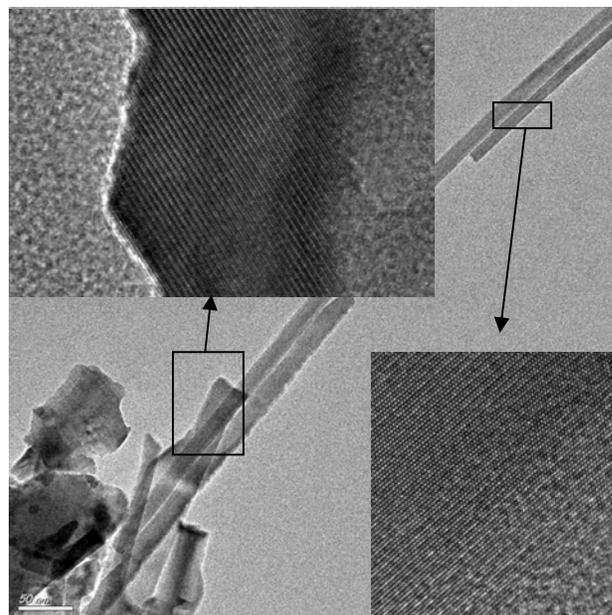


Figure 3: GaN nanowire in partial crystalline structure can be observed in the high magnification.

We also use EDS to evaluate the construction in such nanowire. The nanowire with highly crystalline structure contents 1:1 ratio of gallium to nitrogen. However, the low crystal structure has oxygen, nitrogen and gallium in a ratio of 2:1:1 at amorphous area.

2.2 High intensity discharge lamp assembly

High intensity lamp contains high pressure Xe with low volume of Hg in vapor form. For the convenience of lighting test process, we use a quartz tube with 6 mm in diameter as the lamp body. Two electrode holders were placed in the both ends of the tube which allows us to adjust the distance between the two nanowire coated electrode. One end of the tube was attached to a vacuum pump to pump out the residual gas. Another end of the quartz tube was attached to the high pressure cylinder with a pressure regulator which allows use to pressure the tube from 50 to 380 psi. The system was placed in a clear plastic box for safety protection from high pressure explosion. The assembly shows in figure 4.

Two power supply were used in the light test to provide this prototype HID's input power. Conventional HID power supply requires a 12 VDC input typically used in automobiles and motorcycles. The power was transfer into a 1 to 10 KHz 10KV pulse mode via an inverter electronic device which gives electrodes in a very high temperature near 1200 $^{\circ}\text{C}$ [4]. Another 5KV high voltage power supply was used in a VDC mode and transform into a pulse mode by cutting voltage down to ground in 100 Hz by a high voltage insulated gate bipolar transistor (IGBT).

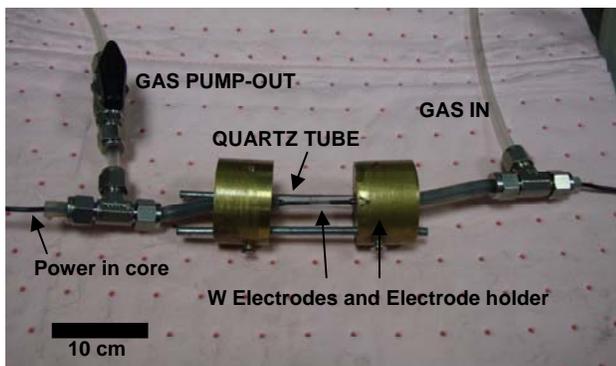


Figure 4: The HID assembly, the electrode gap was adjustable and we set the gap in 2 mm.

We use bare W wires as the control sample to evaluate the nanowire's function and also measured the emitting light from the intensity to the emission spectra.

3 RESULT AND DISCUSSION

The prototype assembly can be lighted up when conventional power supply was attached on the power-in core. This power supply gives 35 W power output to produce the light intensity of 100K nits typically in the commercial HID lamp. When we test our system, an unstable arc was generated at the electrode gap. Such unstable arc was eliminated by reduce power into 20 W. After fine tune the gas pressure 40 psi and reduce power to 22 W, the arc zone produce high intensity light as show in fig.6.

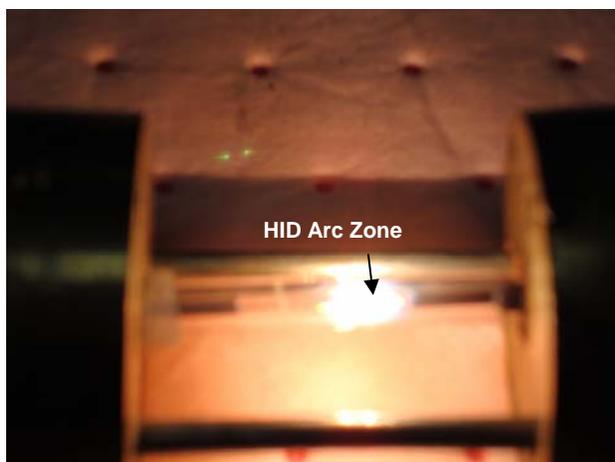


Figure 6: The bright light emits from the arc zone from the GaN nanowire enhanced electrode. This picture was taken with an automatic white balance adjusted camera.

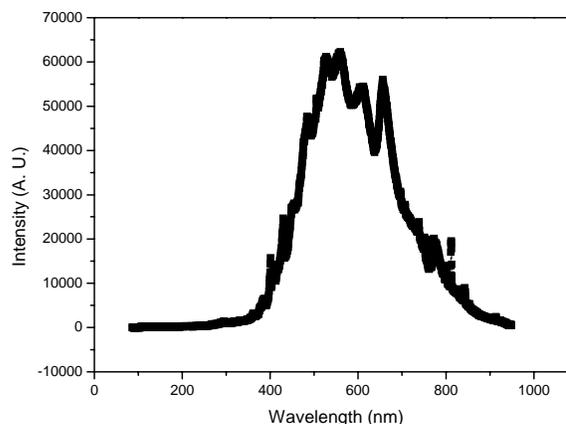
The performance of the nanowire assisted HID lamp was measured, compare to the control sample, the nanowires

can actually improve in power consumption, plasma ignition voltage and light intensity. The results show in Table 1.

	power consumption (W)	ignition voltage(V)	light intensity(Lux)
Control sample W only	20	1700	250
Experimental sample with nanowire	17	1400	255

Table 1: Control and experimental sample comparison in power consumption, ignition voltage and light intensity.

The emission spectrum was also measured from this prototype HID assembly by filling Ar as plasma source. The results show that few Ga ions may be excited when observed the spectrum [5]. As the Ga has large capture cross-section as mercury which enhanced the power utility in such plasma based lighting application as in cold cathode fluorescent lamp (CCFL). Therefore when plasma ignited, the high temperature near the tip of the electrode will release certain part of GaN nanowires and dissociated into Ga ions and evaporated into chamber. This gives an opportunity of Ga ions to capture free electrons before them bombard into cathode.



4 CONCLUSION

In summary, we produce an environmental friendly, high efficiency HID with nanostructure enhancer embedded. These results represent a route to use nanomaterials with a

conventional product to develop high efficiency lighting system.

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REFERENCES

- [1] J. T. H. Tsai, H. C. Ko, *Appl. Phys. Lett.*, **88** 013104 (2006).
- [2] Z. Zhong, F. Qian, D. Wang, and C. M. Lieber, *Nano Lett.* **3**, 343 (2003).
- [3] C. T. Lin, G. H. Yu, X. Z. Wang, et al., *J. Phys. Chem. C* **112**, 18821 (2008)
- [4] K.C. Paul, T. Takemura, H. Matsuno, T. Hiramoto, F. Dawson, J.J. Gonzalez, A. Gleizes, G. Zisis, A. Erraki, and J. D. Lavers, *IEEE Trans. Plasma Science*, **32**, 118 (2004).
- [5] T. Hartmann, K. G. unther, S. Lichtenberg, D. Nandelst, L. Dabringhausen, M. Redwitz, J. Mentel, *J. Phys. D: Appl. Phys.* **35** (2002) 1657–1667