Optical and Current Noise of GaN Based Light Emitting Diodes

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Ultraviolet (UV) light emitting diodes (LEDs) are expected to find applications for solid-state lighting, water and air purification, bio-agent detection, and biological fluorescence experiments. For identifying miniscule amounts of hazardous biological pathogens and for the detection of fluorescence from protein molecules excited with the UV light (200-300nm) the light source must exhibit low noise and high stability over tens of minutes. We report on the low frequency fluctuations of the current and light intensity of SET UVTOP® LEDs (fabricated by SET, Inc.) with wavelengths ranging from 265nm to 340nm.

Ultraviolet LED structures were grown in a custom-designed vertical metalorganic chemical vapor deposition (MOCVD) system, with trimethyl aluminum (TMA), trimethyl gallium (TMG), silane, Cp2-Mg, and NH_3 as precursors and basal plane sapphire as substrates. The AlN buffer and superlattices were grown by the Migration Enhanced MOCVD (MEMOCVD.) The active region consisted of 5 periods Si-doped $Al_{0.5}Ga_{0.5}N/Al_{0.4}Ga_{0.6}N$ quantum wells.

We measured both optical and current noise for the UV LEDs. The noise spectra of the light intensity fluctuations at frequency f<10^3-10^4Hz were consistently close to the 1/f noise. The spectra of the current noise, however were typical for superposition of *1/f* and generation – recombination (GR) noise. The relative spectral noise density of photodiode current fluctuations S_I^{phd} / I_{phd}^2 (which is the optical noise) as a function of the LED current for several LEDs studied is shown in Fig.1. As seen, the relative spectral noise density of the light intensity fluctuations decreases with the increase of the LED current. At high currents, the difference in the noise level for different wavelength LEDs is small, with the exception of the shortest wavelength 265nm LEDs, which demonstrated high dispersion of the noise levels from device to device. Open symbols show the noise level for the first generation 280nm LEDs, which is more than two orders of higher than that of recent devices. The SET UVTOP® LEDs demonstrate the noise level of the same order of magnitude or smaller than the longer wavelength LEDs (NICHIA NSHU550A and NICHIA NSPE510S.)

Recently we introduced the LED noise quality factor [1]

$$\beta = \frac{S_I}{I_{phd}^2} fn \frac{\tau}{q} I_{LED} , \qquad (1)$$

where f is the frequency, n is the number of chips connected in series, τ is the radiation life-time, q is the electronic charge, and I_{LED} is the LED current. The lower the value of β, the better is the LED noise quality. Fig. 2 shows the β as a function on the wavelength for different LEDs for I_{LED} =20mA. For a crude estimate, we assumed $\tau/q \sim 10^{10}$ A^{-1} for all devices. As seen, all LEDs demonstrate the quality factor β of the same order of magnitude, with exception of the shortest 265nm LEDs.

The noise spectra of the LEDs current fluctuations multiplied by frequency f are shown in Fig.3. The characteristic time constant of the GR noise is 10^{-2}-10^{-3}s. While for some LEDs GR noise was observed for the whole range of LEDs currents, for the majority of the devices this GR noise dominated only at low currents I_{LED}<10^{-4}A.

Fig. 4 shows the dependence of the LED current noise for three 280nm LEDs on current. For the first generation LEDs, this dependence is typical for any p-n junction form. At low currents, the slope of the dependence is close to the $S_I^{LED} \propto I_{LED}$ law, showing that the main contribution of noise originated from the barrier resistance. At high current $S_I^{LED} \propto I_{LED}^2$, which is typical for the noise from diode series resistance. The second generation LEDs demonstrate markedly different behavior. For the current, where GR noise dominates, the spectral noise density exhibits non-monotonic current dependence. This effect is

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explained using the theory of the GR noise. At high currents the noise for the second generation LEDs is smaller than that for the first generation devices manifesting less contribution to noise from the series resistance (base and contact noise).

To conclude, the second generation SET UVTOP® LEDs with the AlN buffer and superlattices grown by the Migration Enhanced MOCVD demonstrate optical and current noise substantially smaller than those for the first generation LEDs. This result is achieved due to the reduction of the noise from series base resistance. A small noise level in the second generation LEDs will allow us to achieve a larger signal-to-noise ratio for studying steady state and time-varying UV fluorescence of biological materials.

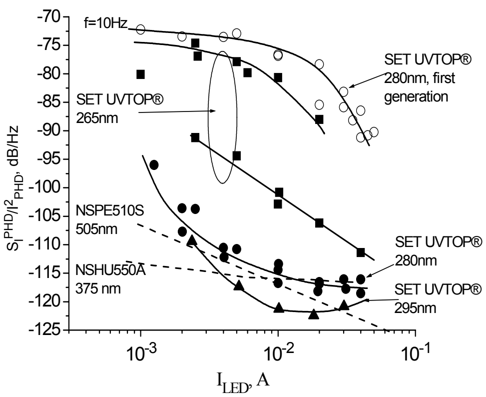

Fig. 1. Dependence of relative noise spectra S_I^{phd}/I_{phd}^2 on LED current, I_{LED}, for different LEDs. Frequency of analysis f=10 Hz. LED load resistance R_{LED}=1kΩ. Dashed lines show the noise level for NICHIA NSHU550A and NICHIA NSPE510S.

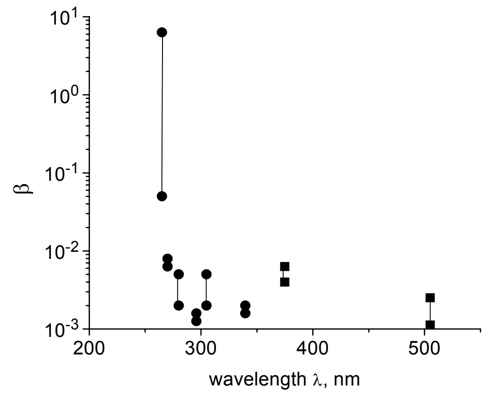

Fig. 2. Quality factor β as function of the LED wavelength for the second generation SET UVTOP® LEDs (circles), Nichia LEDs NSHU550A and NICHIA NSPE510S (squares).

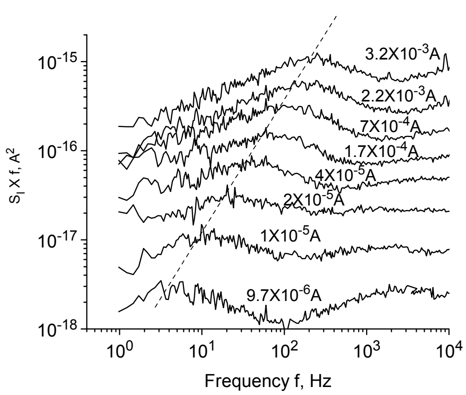

Fig. 3. Dependences $S_I \times f$ for the second generation SET UVTOP® 280nm LEDs for different currents. Curves are shifted vertically for clarity.

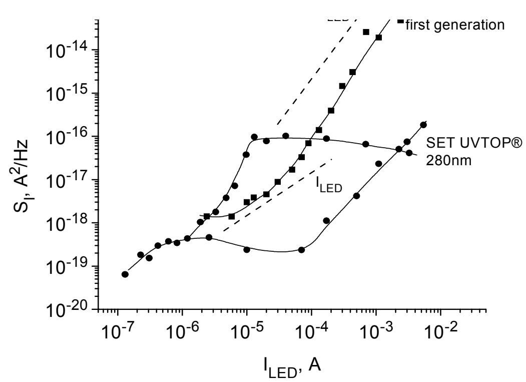

Fig. 4. Spectral noise density of current fluctuations as function of the LED current for the first and second generation SET UVTOP® 280nm LEDs.

References

[1] S.L. Rumyantsev and M.S. Shur, Yu. Bilenko,, P.V. Kosterin, and B.M. Salzberg, Low frequency noise and long-term stability of non-coherent light sources, Journal of Applied Physics, v 96, n 2, 966-969 (2004).