Photon-Correlation Cathodoluminescence Spectroscopy in a SEM: A Tool to Analyze the Performance of Optoelectronics Devices

Sylvain Finot[1], Corentin Le Maoult[2], Etienne Gheeraert[1], David Vaufrey[2], and Gwénolé Jacopin[1*]

[1] Univ. Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, Grenoble, France
[2] Univ. Grenoble Alpes, CEA, LETI, Grenoble, France
*Corresponding author: gwenole.jacopin@cnrs.fr

In order to establish the relationship between luminous efficiency and material characteristics, it is essential to precisely measure the relative contribution of radiative and non-radiative recombinations. This is usually obtained through the measurements of the luminescence decay time as a function of temperature. To do so, the commonly used technique is time-resolved photoluminescence spectroscopy [1]. However, this technique does not allow nanoscale resolution, which is the relevant scale for defect characterisations.

To go beyond these limitations, fast electrons can be used as a highly localized excitation source for luminescence measurements. This technique is called cathodoluminescence (CL) spectroscopy. Recently, picosecond time-resolved CL technique has been developed to reach at the same time high spatial and high temporal resolutions [2,3]. However, it is difficult to obtain a high brightness pulsed electron gun, which leads to reduced spatial resolution, low CL intensity or photocathode aging issues.

In this work, to circumvent these limitations, inspired by the pioneering work of Meuret et al. [4], we took advantage of the specific statistics of electron-hole pair generation by fast electrons. Indeed, in a secondary electron microscope, the interaction of the incident electron with the semiconductor generates almost instantaneously (< 1 ps) a bunch of electron/hole pairs (typically > 300). These electron-hole pairs can then radiatively recombine with a probability that decreases with time, according to their carrier lifetime. Hence, by studying the autocorrelation function of the CL intensity ($g_2(\tau)$), a strong bunching is expected at $\tau = 0$ ($g_2(\tau = 0) \gg 1$). More importantly, by fitting $g_2(\tau)$, we access to the local carrier lifetime without the need for an expensive pulsed electron gun [5].

Thus, to measure the $g_2(\tau)$ of the CL signal, we built a Hanbury Brown and Twiss (HBT) interferometer to analyze the CL photon statistics [6]. We apply the method to investigate the influence of surface recombinations on the optical properties of InGaN/GaN quantum wells near a mesa edge with a spatial resolution of 100 nm and a time resolution better than 50 ps thanks to spatially-resolved time-correlated cathodoluminescence spectroscopy (SRTC-CL) [7].

First, depth-dependent CL spectroscopy is presented to emphasize the importance of possible artefacts of standard CL spectroscopy. Then, the carrier lifetime variation near a sidewall obtained by SRTC-CL enabled us to quantify the impact of surface recombinations on a single micro-LED with a nanoscale resolution. Finally, the robustness of this technique is demonstrated by comparing samples with different surface treatments. By coupling this technique with a simple diffusion model, we demonstrate that the combination of KOH treatment and Al2O3 passivation layer drastically reduces surface recombinations. These findings emphasize the need for nanoscale time-resolved experiments to quantify the local changes in internal quantum efficiency of micro-devices [8].
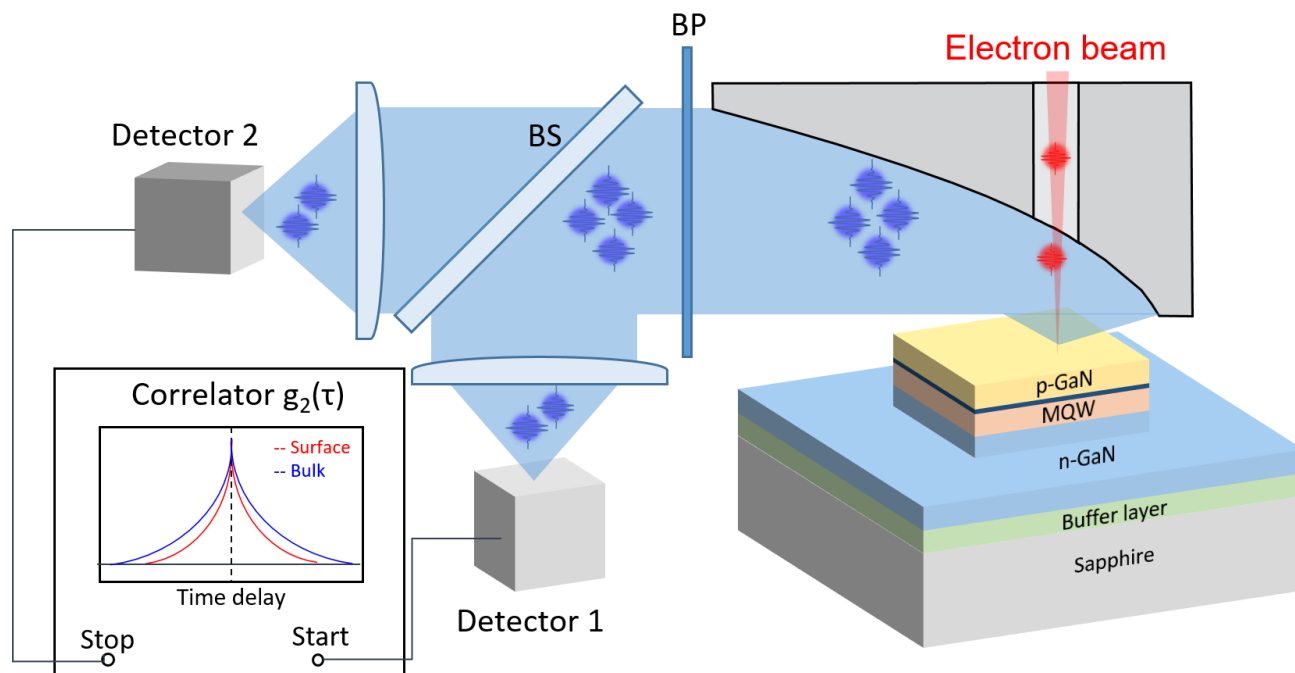
Figure 1. Schematic diagram of the experimental setup.

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