

# Taking the temperature of light-emitting diode external quantum efficiency

Team seeks to disentangle the various effects that impact performance.

**R**esearchers based in Korea and USA have been studying the temperature dependence of external quantum efficiency (EQE) for a range of commercial light-emitting diodes (LEDs) [Jun Hyuk Park et al, J. Appl. Phys., vol119, p023101, 2016]. The team sought to disentangle the various effects that impact LED performance such as non-radiative Shockley-Read-Hall (SRH) recombination and carrier freeze-out.

SRH recombination through mid-gap states reduces efficiency at higher temperatures. By contrast, carrier freeze-out is a low-temperature factor.

The III-nitride compound semiconductors suffer particularly from high activation energies for the acceptor states that create p-type conduction through hole transport (Table 1). These activation energies are more severe in the wide-bandgap semiconductors needed for shorter-wavelength radiation. This factor leads to an imbalance between the hole and electron concentrations.

The team — from Pohang University of Science and Technology (POSTECH), Chonbuk National University, Rensselaer Polytechnic Institute in the USA, and Samsung Electronics — characterized 620nm red alu-

**For the AlGaInP red LEDs, the effect of SRH recombination on EQE is stronger compared to the effect of hole freeze-out. The effect of asymmetry in carrier concentration is relatively smaller for the AlGaInP red LED. In the AlGaN DUV LEDs, the effect of hole freeze-out is stronger than that of SRH recombination due to the larger acceptor activation energy and the resulting larger carrier asymmetry**

minium gallium indium phosphide (AlGaInP), 450nm blue gallium indium nitride (GaInN), and 285nm deep-ultra-violet

aluminum gallium nitride (AlGaN) LEDs.

The epitaxial materials for these devices were derived from metal-organic chemical vapor deposition (MOCVD).

The active regions were multiple quantum wells: 38-period AlGaInP/AlInP, 5-period GaInN/GaN, and 5-period AlGaN/AlGaN.

Characteristics were measured under pulsed current injection to avoid self-heating of the devices.

The EQE was measured

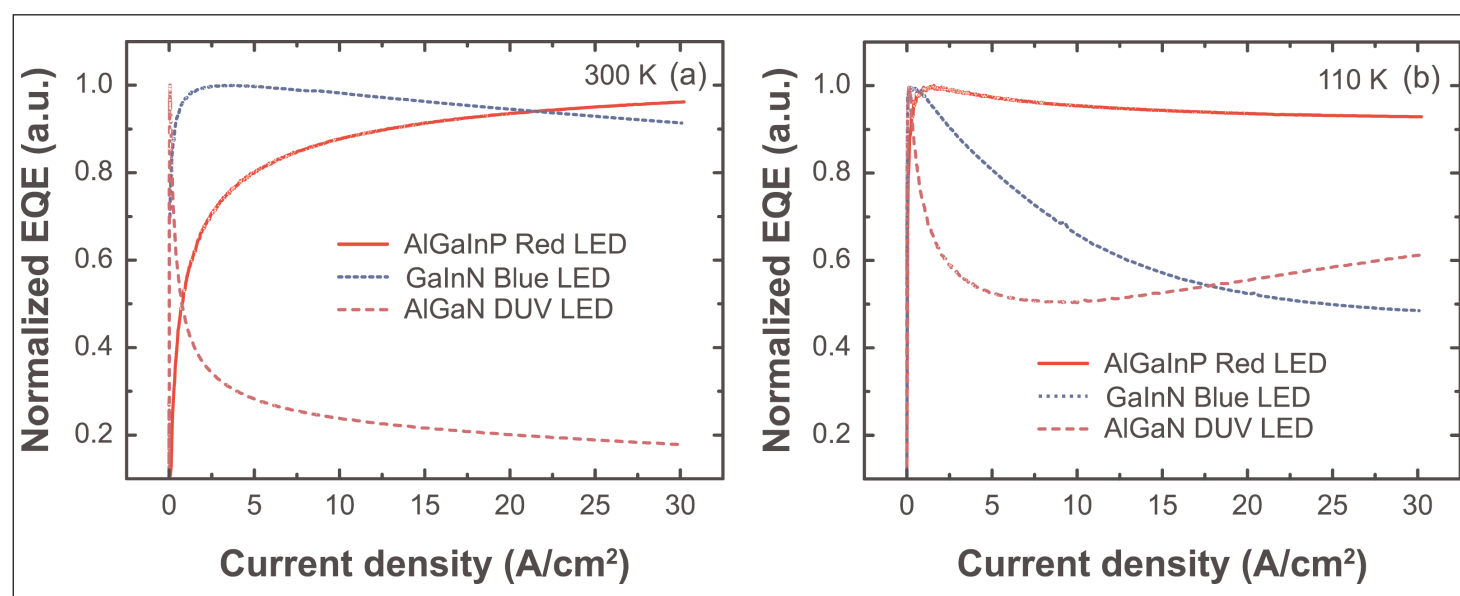


Figure 1. Normalized EQE curves as a function of current density for AlGaInP red LED, GaInN blue LED, and AlGaN DUV LED measured at (a) 300K and (b) 110K.

**Table 1. Typical activation energies for electron donor and acceptor impurities.**

	Donor	Acceptor
AlInP	80meV	76meV
GaN	15meV	170meV
AlN	62meV	630meV

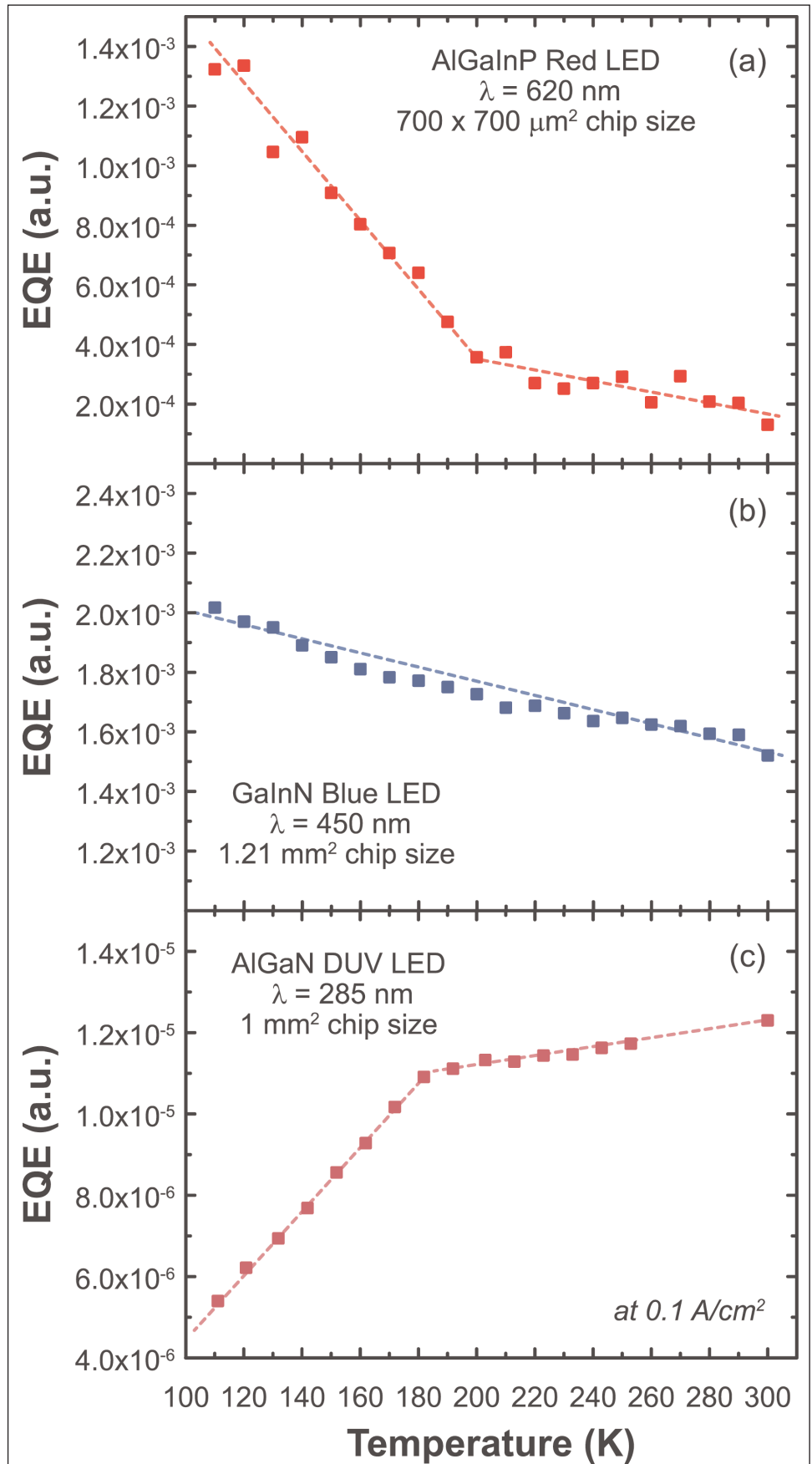
at a range of temperatures. At room temperature (300K), there was no efficiency droop before  $30\text{A}/\text{cm}^2$  for the red device, while the blue and DUV LEDs showed droops of 8.6% and 82.1%, respectively, at  $30\text{A}/\text{cm}^2$  (Figure 1). Lowering the temperature to 110K created a small droop of 7.1% for the red LED. The blue device had an increased droop of 48.8%.

The AlGaIn LED at 110K had a minimum EQE at  $10\text{A}/\text{cm}^2$  and then increased to give a droop of 38.8% on the initial peak at  $30\text{A}/\text{cm}^2$ .

The researchers comment: "The AlGaIn DUV LED has an intrinsically large asymmetry in carrier concentration at cryogenic temperatures, so that the EQE initially decreases (droop), then reaches an EQE minimum point (minimum of 'U-shape'), and then increases again due to the field-ionization of acceptors by the Poole-Frenkel effect."

The Poole-Frenkel effect describes how, under an applied field, acceptor impurities ionize more easily, increasing hole concentration. The DUV LED also had a different temperature behavior under low current injection (Figure 2), with an increase rather than decrease at higher temperature.

The researchers comment: "the experimental data indicate that, for the AlGaInP red LEDs, the effect of SRH recombination on EQE is stronger compared to the effect of hole freeze-out. That is, the effect of asymmetry in carrier concentration is relatively smaller for the AlGaInP red LED. On the contrary, in the AlGaIn DUV LEDs, the effect of hole freeze-out is stronger than that of SRH recombination due to the larger acceptor activation energy and the resulting larger carrier asymmetry." ■



**Figure 2. Temperature-dependent EQE curves for (a) AlGaInP red LED, (b) GaInN/GaN blue LED, and (c) AlGaIn DUV LED measured at  $0.1\text{A}/\text{cm}^2$ .**

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