Thermal droop in indium gallium nitride light-emitting diodes

Researchers have developed a model of thermal droop in InGaN LEDs through both experiment and simulations.

Researchers based in Europe and India have been developing models of thermal droop in indium gallium nitride (InGaN) light-emitting diodes (LEDs) through experiment and simulations [C. De Santi et al, J. Appl. Phys., vol119, p094501, 2016].

Thermal droop is important in commercial devices since the temperature increases with continuous operation through Joule heating. Some commercial LEDs are rated for operating up to 175°C. Higher operating temperatures can lower device costs through reduced thermal management requirements. However, devices running at 150°C can lose up to 25% of optical power, compared with room-temperature operation.

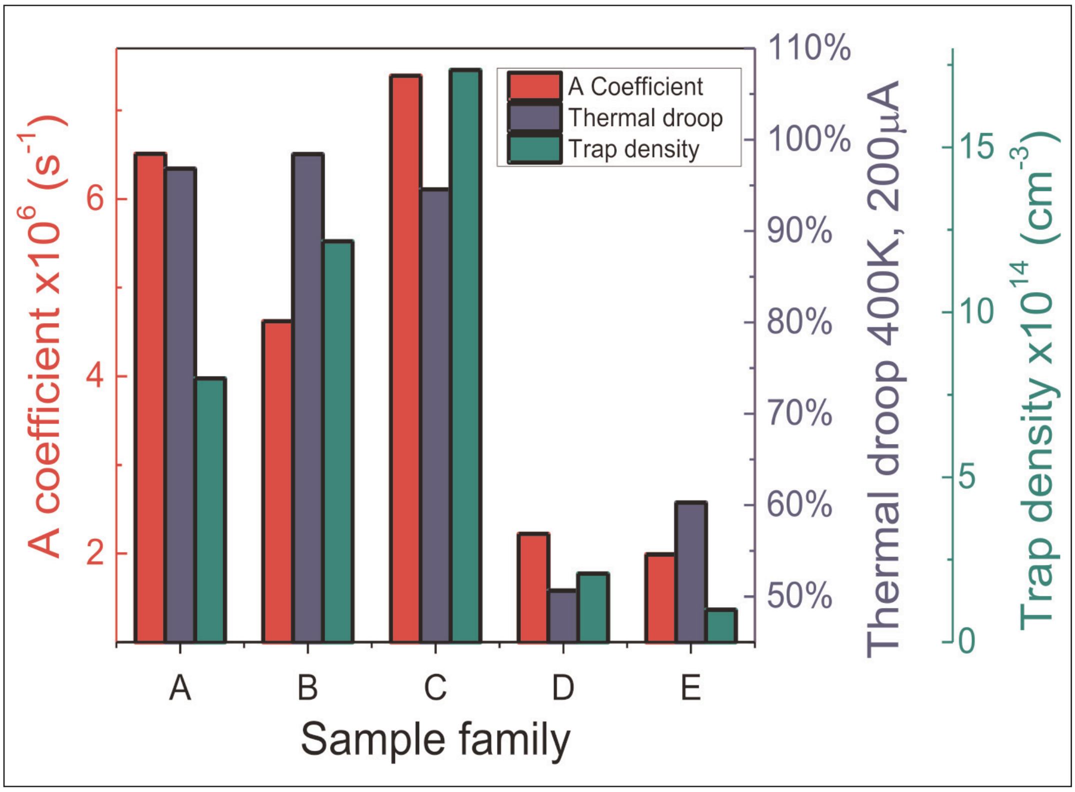


Figure 1. Correlation between SRH A coefficient, obtained by differential lifetime measurements, trap density evaluated by C-DLTS, and amount of thermal droop.

Generally, InGaN LEDs become less efficient at high temperature. Thermal droop is separate from the more intensively studied efficiency droop at high current. Indeed, efficiency experiments are usually carried out under pulsed operation to avoid Joule self-heating.

University of Padova in Italy, Osram Opto Semiconductors GmbH in Germany, Politecnico di Torino in Italy, and Anna University in India tested a range of c-plane devices on silicon with different point defect densities. The defect levels were estimated using capacitance deep-level transient spectroscopy (C-DLTS).

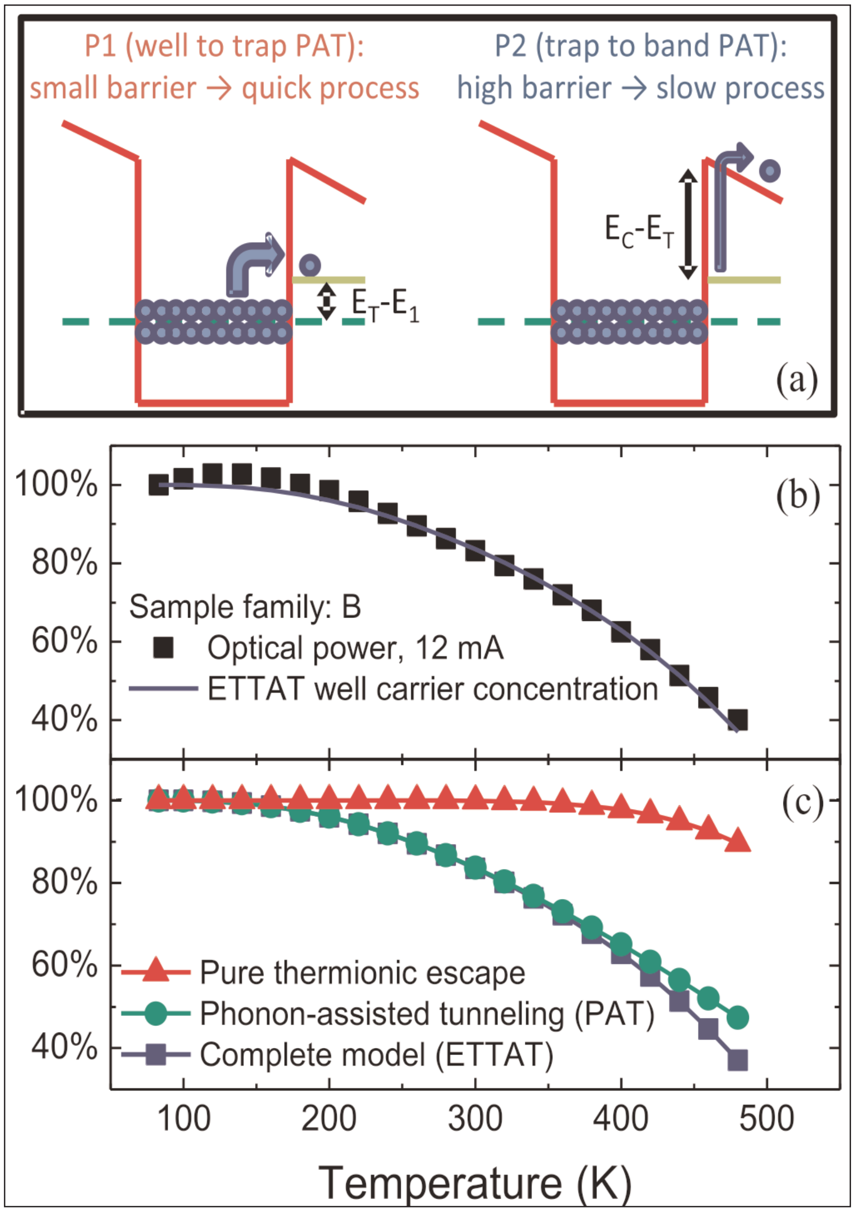
The device materials were grown using metal-organic vapor phase epitaxy (MOVPE) with the following layer sequence:

- an aluminium nitride buffer layer;
- a 5μm aluminium gallium nitride/gallium nitride buffer layer;
- a silicon-doped n-type gallium nitride current-spreading layer;
- a 3nm single quantum well;
- a p-type aluminium gallium nitride electron-blocking layer; and
- a p-type gallium nitride contact layer.

The thermal droop was greatest in devices with high defect density, losing more than 99% of output power when the temperature increased from 83K to 475K.

The team relates this behavior to non-radiative Shockley–Read–Hall (SRH) recombination through defect energy levels in the bandgap. The researchers add, however: "thermal droop cannot be explained by simply taking into account the increase in SRH recombination at high temperature levels."

Figure 2. (a) Sketch of proposed escape model, (b) agreement between experimental data and model, and (c) breakdown of overall curve into the two components.



These conclusions were reached through simulation and increasing the defect densities in the devices by applying 100mA stress at 75°C, causing performance degradation. Although non-radiative SRH recombination increased, and photoluminescence decreased, under stress, the magnitude of the thermal droop remained constant, modulo experimental variations.

The quality of the electron-blocking layer has been found to affect thermal droop performance. "This suggests that another possible mechanism for explaining thermal droop is the escape of carriers from the quantum wells," the researchers write.

The researchers considered and found wanting three possible models for such escape: thermionic, phonon-assisted tunneling, and thermionic trap-assisted tunneling. The team therefore developed an "extended thermionic trap-assisted tunneling" process, which consisted of two phonon-assisted tunneling steps. The first step raised the carrier to a trap state, while the second step took the carrier to the external conduction band (Figure 2). The trap acts as a reservoir of electrons for the second step. ■

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