High efficient 635nm resonant-cavity light-emitting diodes with modified electron stopped layers

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Abstract **In this work, the analysis of thermal, electrical and optical properties of 635 nm InGaAlP resonant-cavity light-emitting diodes is presented. We show that including the electron stop layer in both side of active layer improves the efficiency of such device due to increasing the electron capture efficiency in the quantum wells. Theoretical analysis is proved by experimental work.**

I. INTRODUCTION

MICRO-DISPLAY based projectors require projection lamps. Currently high intensity discharge (HID) lamps are used. They have a very high luminance, but limited life, and require a color wheel. Light-emitting diodes (LEDs) have a very long lifetime, and don't require a color wheel, which increases the acceptance and flexibility of a color sequential projection display considerably. With an LED illuminator white points and color gamuts can be changed dynamically, and can be optimized to the source material or viewing conditions. The external quantum efficiency η_{ext} is the key performance figure for high-efficiency LEDs [1] and stands for the number of photons generated per injected electron and depends on the fraction of carriers injected in the useful active region η_{inj}, the fraction of spontaneous recombination that is radiative η_{rad} and the extraction efficiency of the generated photons η_{extr} in the form $\eta_{ext} = \eta_{inj}\eta_{rad}\eta_{extr}$. These three contributions are representative for the more or less successive introductions of optimization.

It is at this stage ($\eta_{inj}\eta_{rad} \approx 1$) that it is appropriate to optimize η_{extr}, which is limited to 2–4% by Snell's law for conventional planar LEDs due to the high refractive index contrast between the source material and the surrounding medium. This optimization happened in the early nineties, when cavity optics entered the world of LEDs with the resonant-cavity LED (RCLED). In these devices, the active layer is embedded in a cavity with at least one dimension of the order of the wavelength of the emitted light. Under those circumstances, the spontaneous emission process itself is modified, such that the internal emission is no longer isotropic.

Schubert *et al.* presented the RCLED as a conceptual novel LED in 1992 [2,3]. From this time the extraction efficiency was improved up to 50 %.

II. STRUCTURE DESCRIPTION

Like in standard red LEDs, the GaAsP material system is increasingly substituted by the high-quality AlGaInP for use as active medium. Due to the absorbing substrate (GaAs or Ge), the device is preferably top emitting with a cavity sandwiched in between two DBR mirrors incorporating an appropriate current injection design. Devices in the 600- to 650-nm range are described by several research groups, showing η_{ext} up 10% [4, 5].

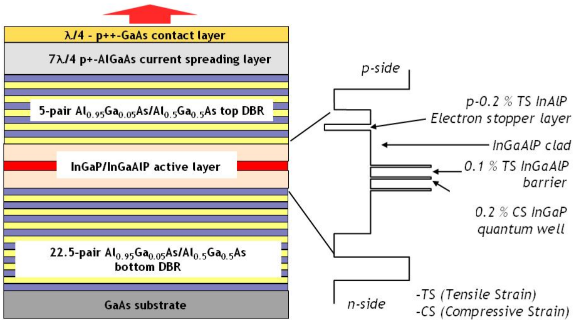

Fig. 1 Red RCLED structure with active layer details

Red RCLED with 635 nm of emission wavelength (Fig. 2) consist of 2 AlGaAs distributed Bragg reflectors (DBR) and 1-λ cavity InGaP/InGaAlP quantum well structure. InGaP/InGaAlP quantum well structure constructing 1-λ cavity consists of 0.2 % of compressive-strained InGaP and 0.1% tensile-strained InGaAlP barrier due to the low conduction band offset [8]. The conduction band offset of lattice matched InGaP/InGaAlP material system as 165 meV is about a half of the conduction band offset of lattice matched InGaAs/AlGaAs material system 350 meV. Due to the low conduction band offset, electrons in the quantum wells can easily escape from the well reducing internal quantum efficiency in the lattice-matched InGaP/InGaAlP material system. But the quantum well structure with compressive-strained quantum well and tensile-strained barrier increases the offset, thus increasing the internal quantum efficiency.

III. NUMERICAL SIMULATIONS AND DESCRIPTION OF RESULTS

Several software tools were used in the process of designing and optimizing the devices. Besides using the self-consistent

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model implemented in CrossLight's package APSYS (to evaluate the emission spectrum, band structure, absorption edge, potential barriers, etc.), several transfer matrix-based programs have been developed in house to help the design process [7].

Fast and flexible transfer-matrix-based calculations of the reflection coefficient dependencies (upon wavelength, incidence angle, polarization, layer contrast, layer thickness, number of DBR periods) and of the optical field distributions played an important role in the device development—mostly in the early design stages—and in understanding the angular emission of the RC-LEDs.

Figure 2 shows the calculation of conduction band distribution for structures with ESL in p-side (solid line) and 2 ESLs in both sides of active layer. The material and doping concentrations for both layers are depicted on figure. Including the second stop layer to the n-side of structure increase the capture efficiency and makes the energy distribution in the active layer region more uniform.

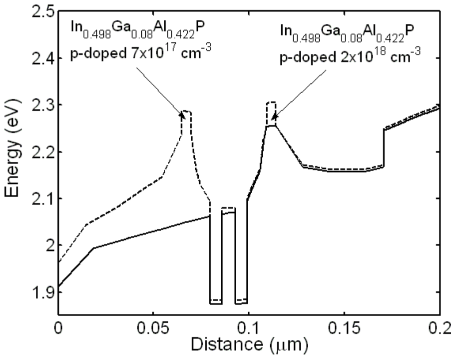

Fig. 2 Conduction band distribution with 1 ESL (solid line) and 2 ESLs (dashed lines).

Such modification allows increasing the total efficiency of device as shown on Fig. 3

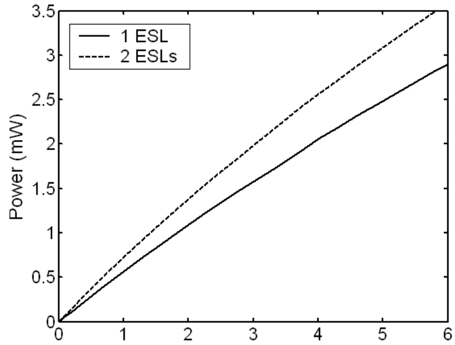

Fig. 3 L-I characteristics for RCLED with 1 ESL (solid line) and 2 ESLs (dashed lines).

IV. EXPERIMENTAL VERIFICATION

To verify theoretical data, the real device with structure shown on Fig. 1 was grown. The measured Spontaneous emission (SE) spectra are present on Fig. 4. The PL was measured by RPM2000 with using 532nm laser diode which output power is 7 mW at room temperature.

Results show improvement of SE spectra with introducing the ESL on both sides of active layer that verify our theoretical calculations.

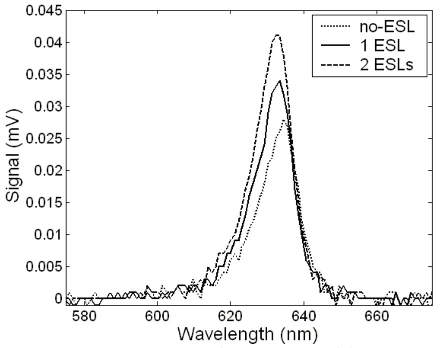

Fig. 4 Spontaneous emission spectra for RCLED with no ESL (dotted line), 1 ESL (solid line) and 2 ESLs (dashed lines) .

V. CONCLUSIONS

The thermal, electrical, optical, and modulation properties are analyzed for the 635 nm InGaAlP RCLED with different structures of active layer. Results show, inserting ESL layers in both sides of active layer increases the slope efficiency of L-I characteristic due to increasing the electron capture efficiency in the quantum wells. Theoretical result was verified experimentally and shows the external quantum efficiency in W/A.

ACKNOLEDGEMENT

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