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Delta doping: New technique to reduce current crowding problem in III-nitride LEDs

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Current crowding problem generally occurs in conventional III-nitride light emission diodes (LEDs) due to design geometry. This problem give rises to unequal heating and unequal light emission from LED dice. Current crowding problem can be reduced by using multi-finger design, where active area of LED device is divided into two portions and thus total emission from device increases. By delta doping we can reduce, current crowding problem in conventional III-nitride LEDs design. Current crowding problem vanishes almost in multi-fingered design with delta doped layer.

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1. Introduction

Due to direct band-gap, III-nitride materials has gained substantial interest as a promising material for light emitting diode (LEDs) and lasers diodes (LDs). At present, III-nitride based LEDs are used for variety of applications, including traffic signals, full colour displays, back lighting in liquid crystal display and solid state lighting. Mesa etched n-contact structures are commonly used in III-V nitride LEDs. Such mesa etched structures, rises current crowding and unequal heating of device [1]. Internal quantum efficiency (IQE) of LEDs is greatly affected by current crowding, and large portion of device remains inactive during operation. The current crowding effect is studied by different groups and different solutions are predicted to reduce current crowding [2-5].

As active area of device decreases, the current crowding problem in LED reduces. Low current crowding problem observed in multi-fingered chip design. Delta doping is found to be much effected method of doping for a certain region, without affecting the properties of device. Delta doping can be used (as an alternate to buried layer; Si technology) to obtained low resistance path in III-nitride LEDs and HEMTs [6- 13]. But the effect delta doping on current crowding was not yet studied. In this study the effect of delta doping on current crowding and device heating is studied, by ATLAS (M/S Silvaco).

2. Device structure

LED structure that we have simulated consists of 3.4 µm n-GaN layer ([Si] = 10^{18} cm^{-3}), $In_{0.2}Ga_{0.8}N$ (3nm)/$Al_{0.2}Ga_{0.8}N$ (100nm) single quantum well (SQW) active region followed by 500nm p-GaN capping layer ([Mg] = 10^{19} cm^{-3}). Fig. 1 show the cross section view of III-nitride LED used in simulation. Si delta doped layer, 1µm below n-contact was used in delta doped structures.

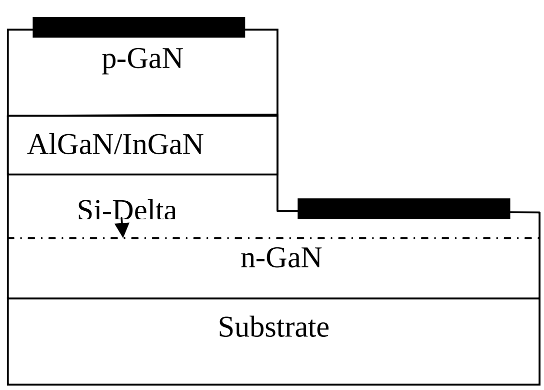

Fig.1. Schematic of III-nitride LED.

3. Results and discussion

Current flow lines of conventional LED, at forward bias of 7V are shown in Fig. 2. Current crowding problem is observed in the device, in between two contacting electrodes. Small current line passes through other edge, which make unequal emission from surface of device.

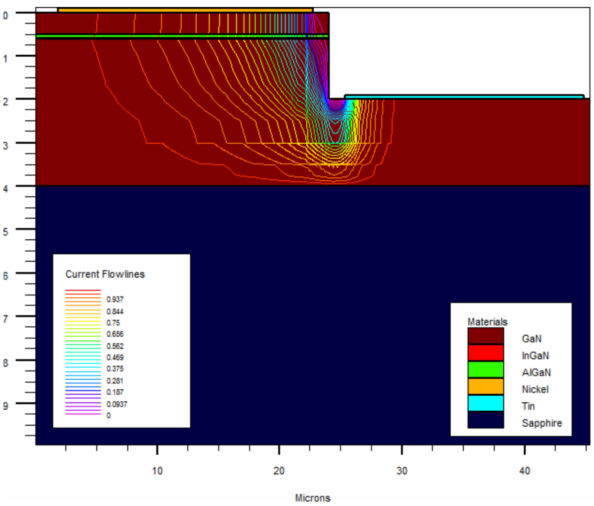

Fig.2. Current flow-lines in Conventional III-nitride LED.

Maximum heating is observed in current crowding area, which rises to non-uniform distribution of temperature. In this device maximum temperature rises to 347K at V_{anode} = 7V (36mA) as shown in Fig. 3.

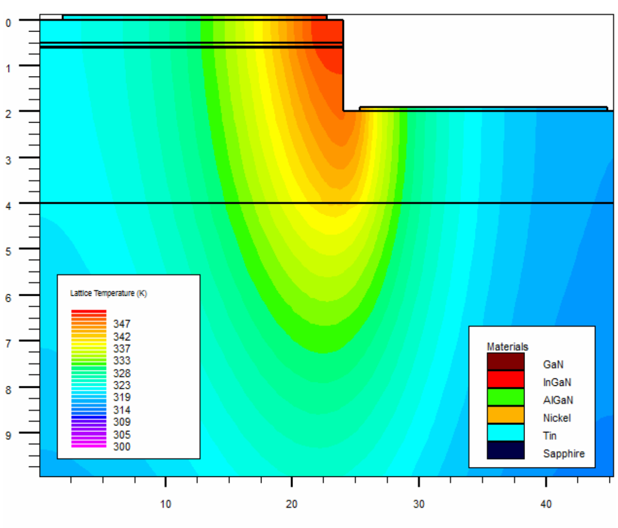

Fig.3. Temperature in Conventional III-nitride LED, forward bias at 7V.

Current flow lines in multi-fingered LED device are shown in Fig. 4. Maximum current flow lines passes through anode edges. Low current flow lines passes through middle of device. So an unequal emission is observed in multi-fingered design, where light is emitted from the edge of contact (anode). Maximum heating is observed in between anode and cathode electrode. Two high temperature region of maximum temperature 359 K are observed at V_{anode} = 7V (73mA) as shown in Fig. 5.

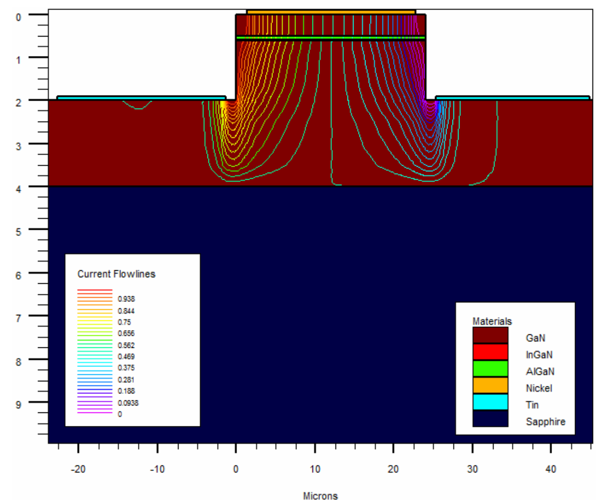

Fig.4. Current flow-lines in Multi-finger III-nitride LED.

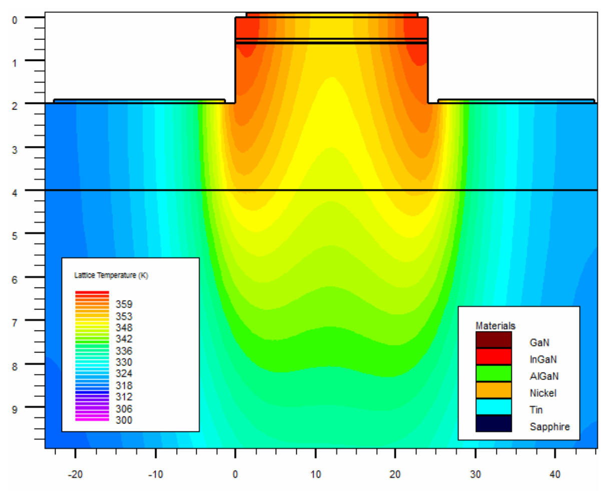

Fig.5. Temperature in multi-finger III-nitride LED, forward bias at 7V.

Current flow lines of delta doped LED without multi-finger design is shown in Fig. 6. While comparing it with Fig. 2, it is found that the current crowding reduces, with delta doped structure. Current flow lines in multi-finger device with delta doped structure are shown in Fig. 7. Current crowding problem vanishes almost in multi-finger device with delta doped structure. Significant current flow lines passes through middle of anode electrode and thus the total emission from device increases, resulting in improved external quantum efficiency.

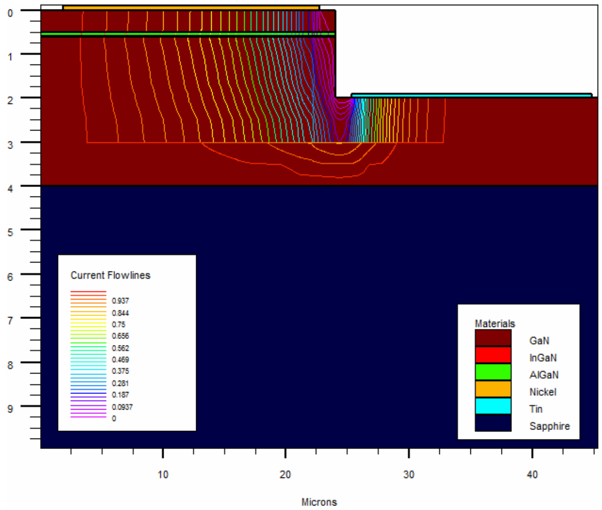

Fig. 6. Current flow-lines in conventional III-nitride LED with delta doping.

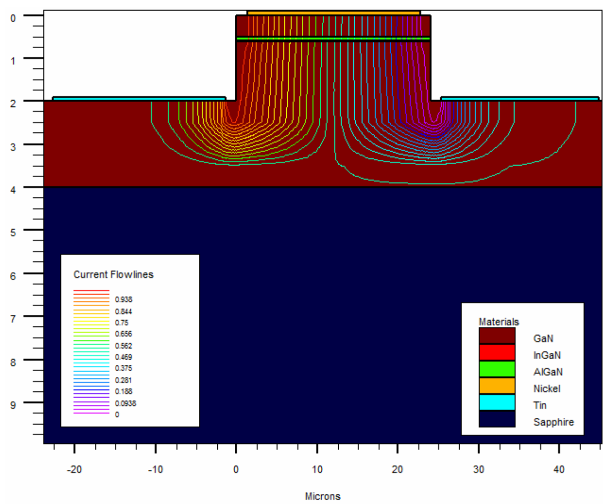

Fig.7. Current flow-lines in multi-finger III-nitride LED.

V-I characteristics of III-nitride LEDs are shown in Fig. 8.

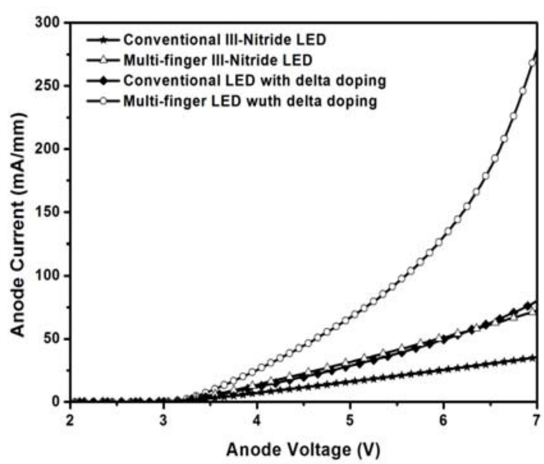

Fig.8. V-I characteristics of III-nitride devices.

It is observed that maximum current of 280mA is obtained in multi-fingered device with delta doped structure at V_{anode}= 7V. Lattice temperatures versus anode current for different LEDs design are shown in Fig. 9.

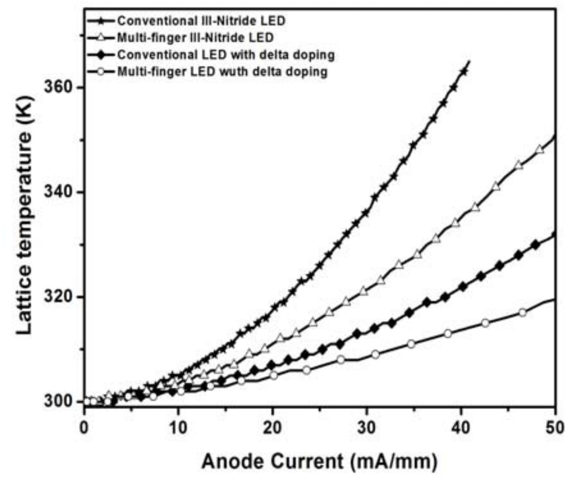

Fig. 9. Lattice temperature vs. Anode current of III-nitride devices.

It is observed that for same anode current conventional LEDs are getting heated, comparatively much larger than multi finger and delta doped design.

4. Conclusions

Current crowding problem in III-nitride LEDs are observed due to conventional mesa etched design. This makes large area of device inactive during operation. Moreover unequal distribution of current give rises to unequal heating of device. Using multi-finger design, we can reduce the current crowing problem in LEDs. In multi-fingered design the current crowding problem, finally vanishes by delta doping. So delta doped structure shows better external quantum efficiency and must be employed in LED manufacturing to get better results from the device.

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