

Improvement in enhanced spontaneous emission of Resonant Cavity Light Emitting Transistors via Inductively Coupled Plasma Etching Top Distributed Bragg Reflector

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Abstract

We report the improvement of light emission from resonant cavity light emitting transistor (RCLET) around 68% via Inductively Coupled Plasma (ICP) etching top distributed Bragg reflector (DBR). Due to the lateral feeding characteristics of RCLET, the radiative recombination takes place along the peripheral of the emitter. The smoothly etched sidewall achieved by ICP reduces the light scattering. Hence, the cavity quality factor (Q) increases. The enhanced recombination can be observed from reduced electrical gain in the family curve, an evidence of carrier lifetime reduction. The $10 \times 3 \mu\text{m}^2$ device shows the high optical bandwidth of 4GHz.

INTRODUCTION

Heterojunction bipolar light-emitting transistor (HBLET) is a novel three-terminal device which can simultaneously generate both electrical and optical output [1]. The quantum wells are inserted in the base region to enhance the recombination. With the tilted charge configuration, the carriers transit from the emitter into base and radiatively recombine in quantum wells. Those cannot recombine immediately are then swept into the collector region. By removing the slow carriers, the HBLET has demonstrated high-speed modulation up to 7GHz, which is prominent for short range communication transceiver module [2,3]. To push the HBLET toward the commercial application, not only the optical bandwidth but also the emission intensity should be further improved. One possible method to enhance the spontaneous emission is inserting resonant cavity at active region.

In this paper, the resonant cavity light-emitting transistor (RCLET) is demonstrated. With 35 pairs of bottom distributed Bragg Reflector (DBR) and 4 pairs of top DBR sandwiching the LET structure, the spectra show a narrow and enhanced spontaneous emission at 980nm. Because of the lateral feeding configuration in LET, the recombination around the edge of the emitter is stronger.

We use inductively coupled plasma (ICP) etch to create steep top DBR sidewall. The DC measurement shows that the device with ICP etched DBR has stronger light output as compared with the device made by wet etching. The light output intensity improves by 68%.

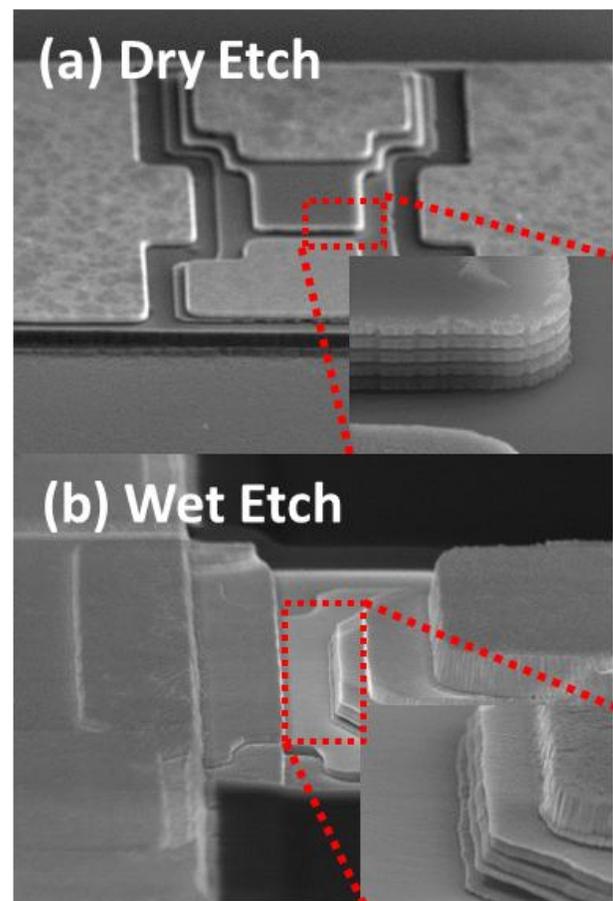


Figure 1. The electron scanning microscopic of resonant cavity light emitting transistor with (a) dry and (b) wet etching emitter process.

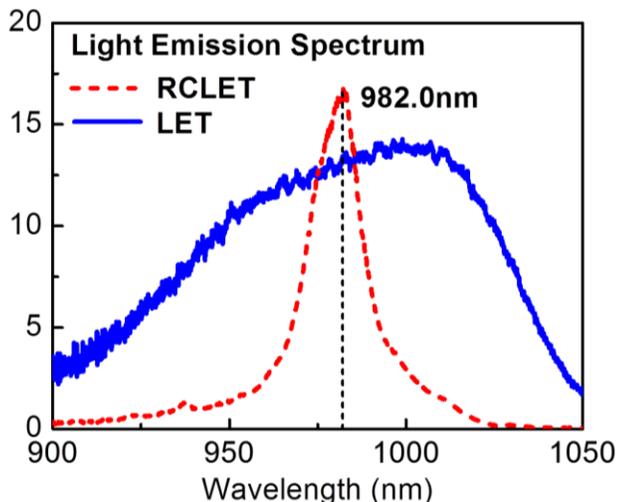


Figure 2. The spontaneous emission spectra of RCLET and conventional LET. The emission peak of RCLET is narrower due to the resonant cavity enhancement.

DEVICE FABRICATION

The epitaxial layers consist of 35 pairs of $\text{Al}_{0.12}\text{Ga}_{0.88}\text{As}/\text{Al}_{0.9}\text{Ga}_{0.1}\text{As}$ DBR reflectors, followed by 200\AA n^+ -GaAs sub-collector, and a 1000\AA undoped $\text{Al}_{0.12}\text{Ga}_{0.88}\text{As}$ collector layer. The base layer consists of 1100\AA p^+ - $\text{Al}_{0.05}\text{Ga}_{0.95}\text{As}$ with two undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{As}$ quantum wells, and a 500\AA n - $\text{In}_{0.49}\text{Ga}_{0.51}\text{P}$ emitter. On the top of the emitter, there are 4 pairs of $\text{Al}_{0.12}\text{Ga}_{0.88}\text{As}/\text{Al}_{0.9}\text{Ga}_{0.1}\text{As}$ used as a top DBR, and an n^+ -GaAs cap is grown as the contact layer. To increase the resonant cavity Q, the emitter etching is proceed by

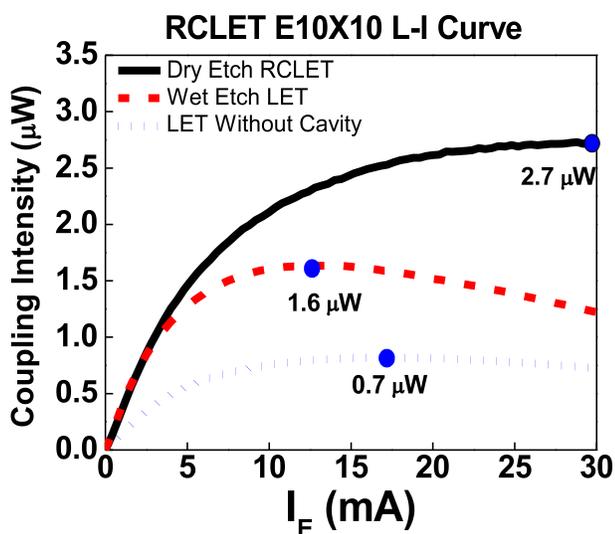


Figure 3. The emission intensity as a function of emitter current (I_E). RCLET with ICP dry etching enhances the spontaneous emission by 68% and at $I_E = 30\text{ mA}$ is 4 times stronger than the conventional LET.

inductively coupled plasma (ICP) dry etching step followed by a quick oxidation to seal the sidewall. Because of the selective etching between GaAs/InGaP, the dry etching can be controlled and stopped at InGaP layer. We also use dilute sulfuric acid ($\text{H}_2\text{SO}_4:\text{H}_2\text{O}_2:\text{H}_2\text{O}=0.5:5:100$) to etch the top DBR as comparison. After emitter etch, there are another two wet etching steps for base/collector mesa and isolation, three metallization steps for emitter/base/collector contacts, one polyimide passivation step, and one metal interconnection step, and then the device is done. Figure 1 shows the SEM image of the RCLET device before polyimide passivation. The sidewall of the top DBR is straight and smooth to minimize the scattering effect. On the other hand, the wet etching DBR shows a rough etching surface, which is due to different etching rate between GaAs and AlGaAs in DBR layers.

DEVICE CHARACTERIZATION AND RESULTS

Figure 2 shows the emission spectra of RCLET and conventional LET. The full width at half maximum (FWHM) of emission peak of RCLET is 16 nm at 982 nm while that of the conventional LET is 96 nm . The narrow emission reduces the chromatic dispersion, allowing higher bit rates transmission in short distance optical communication network. To investigate the influence of emitter etching process on RCLET performance, we measure the emission intensity and family curve of $10 \times 10\text{ }\mu\text{m}^2$ devices for comparison. The emission intensity as a function of the emitter current I_E is shown in Fig.3. The emission intensity of RCLET with ICP dry etching at $I_E = 30\text{ mA}$ is 4 times stronger than conventional LET, an evident improvement in emission efficiency. As compared to the device with emitter prepared by wet etching process, the emission of RCLET with ICP dry etching increases from

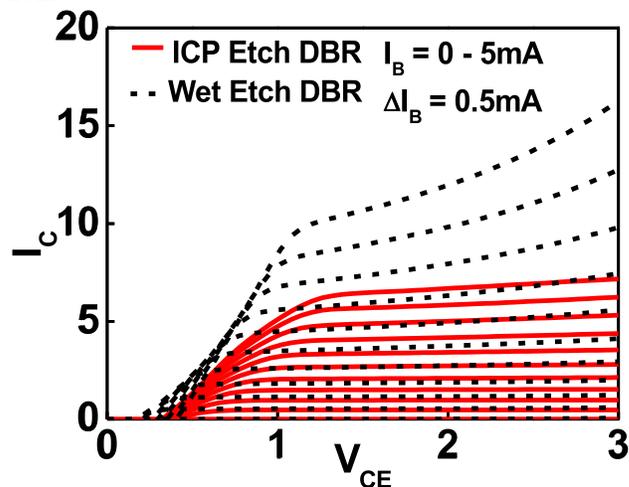


Figure 4. The common-collector family curve of devices with dry and wet etching process, respectively. The device with ICP etching shows lower electrical gain as compared with one with wet etching.

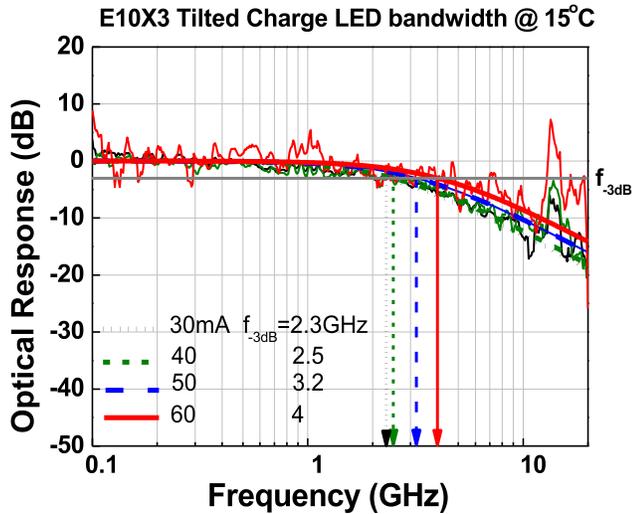


Figure 5. The optical response of RCLET with BC grounded (tilted charge LED configuration)

1.6 uW to 2.7 uW, a 68% improvement. The enhanced emission and large roll-off driving current show that more recombination takes place in the dry etched cavity. The base recombination is the crucial mechanism for bipolar transistor and light-emitting transistor operation, which affects the electrical gain. Figure 4 shows the family curve of the two $10 \times 10 \mu\text{m}^2$ RCLET devices with ICP and wet etched top DBR, respectively. The electrical gain, β , is 2.14 for wet etching device and is 1.418 for dry etching device at $I_B = 5\text{mA}$. The reduction of β and the increase in spontaneous emission indicate that there is more radiative recombination in the dry etched resonant cavity. Because of the lateral feeding configuration in RCLET design, the radiative recombination takes place along the peripheral of the emitter mesa. Thus, RCLET is more sensitive to the sidewall scattering issue than other photonic devices.

Figure 5 shows the frequency response of RCLET with base/collector short configuration (Tilted charge RCLED) at 15°C . The 3dB bandwidth of a $10 \times 3 \mu\text{m}^2$ device is 2.3GHz under 30mA emitter current. Although further increase in the emitter current will decrease the optical response, the bandwidth can be further pushed to 4 GHz with 60mA emitter current. From the single-pole response fitting, the transfer function can be expressed as

$H(f) = A/(1+jf/f_{3dB})$ where $f_{3dB} = 1/(2\pi\tau_B)$. The carrier lifetime, τ_B , is extracted to be 40 ps. As compared with conventional C-doped LED with bandwidth of 1GHz, the 4GHz bandwidth of RCLET operating at room temperature shows a great potential for commercial short distance communication system.

CONCLUSIONS

In summary, we present the fabrication and device characteristics of resonant cavity light-emitting transistor with dry and wet etching emitter process. Because of the smooth cavity sidewall, the device with ICP dry etching has higher cavity Q and thus shows stronger spontaneous emission and lower electrical gain as compared with the device made with wet etching process. From microwave measurement, the RCLET has bandwidth of 4GHz at 60mA, corresponding to recombination lifetime of 40ps.

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ACRONYMS

- ICP: Inductively Coupled Plasma
- DBR: Distributed Bragg Reflector
- RCLET: Resonant Cavity Light Emitting Transistor
- HBLLET: Heterojunction bipolar light-emitting transistor

