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The Effects of Light Output via Inductively Coupled Plasma (ICP) and Wet Chemical Etch on Distributed Bragg Reflectors in Resonant Cavity Light Emitting Transistors

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INTRODUCTION

Heterojunction bipolar light-emitting transistor (HBLET) is an unique three-terminal device which can simultaneously produce both electrical and optical output.[1] The quantum wells inserted in the base region is to enhance the radiative recombination. With the tilted charge configuration, the carriers transit from the emitter into base and radiatively recombine in quantum wells. Those injected electron did not recombine within the base transit time, are then swept into collector region. By removing the slow carriers, the HBLET or TCLED has achieved high speed modulation up to 7GHz, which is prominent for short communication transceiver module.[2,3]

In this paper, we report the first resonant cavity light-emitting transistor (RCLET) operated at room temperature. With 34 pairs bottom distributed Bragg Reflector (DBR) and 4 pairs top DBR sandwiching the QW-HBLET structure, the spectra show a narrow enhanced spontaneous emission at 980nm. Because of the lateral feeding configuration in LET, the recombination around the edge of the emitter is stronger. Inductively couple plasma (ICP) was used to create steep sidewall of top DBR. The measured DC-IV shows that device with ICP etching DBR has produced 68% stronger light output intensity compared with device made by wet chemical etching DBR.

DEVICE LAYER DESIGN AND ICP & WET ETCH PROCESS

The device epitaxial layers consist of 35 pairs of $Al_{0.12}Ga_{0.88}As/Al_{0.9}Ga_{0.1}As$ DBR reflectors, followed by Å n^{+}- GaAs sub-collector, and a 1000 Å undoped $Al_{0.12}Ga_{0.88}As$ collector layer. The base layer consists of 1100 Å p^{+}- $Al_{0.05}Ga_{0.95}As$ with two undoped $In_{0.2}Ga_{0.8}As$ quantum wells, and a 500 Å n- $In_{0.49}Ga_{0.51}P$ emitter. On the top of the emitter, there are 4 pairs of $Al_{0.12}Ga_{0.88}As/Al_{0.9}Ga_{0.1}As$ are used for a top DBR, and an n+- GaAs cap is grown for the emitter contact layer. To increase the resonant cavity Q, the emitter etching is proceed by inductively coupled plasma (ICP) dry etching step followed by 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 (H_2SO_4:H_2O_2:H_2O=0.5:5:100) etching the top DBR as comparison. After finishing emitter etch, 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, then the device is done. Figure 1 illustrates 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 CHARACTERISTICS AND RESULTS

Figure 2 shows the collector I-V of the two 10 x10 um^2 RCLET device with ICP and wet etch top DBR, respectively. Devices with ICP etching top DBR shows smaller electrical gain, indicating more radiative recombination taken place in the active region. Because of the lateral feeding configuration in RCLET design, the radiative recombination takes place along the peripheral of the emitter mesa. Thus, the sidewall scattering issue is more sensitive than other photonics. Figure 3 shows the light output of 10X10 um^2 device with dry and wet etching top DBR, respectively. The maximum light output of dry etching device increase 68% as compared with wet etching device. The inset of Fig. 3 shows the emission spectra of resonant cavity light emitting transistor. Compared with conventional light emitting transistor, the full wave half maximum (FWHM) of emission peak of RCLET is only 16nm at 982nm while the LET is 96nm. A narrower emission will reduce the chromatic dispersion, allowing for high bit rates transmission in short distance optical communication network. The fiber coupled light intensity measurement of RCLET and LET with the same device geometries are also compared as shown in Fig. 3. The light output of the RCLET is four times stronger than conventional one, which is attributed to the enhanced spontaneous recombination. When emitter current excesses 15mA, the light output intensity decreases, which might be due to heat or the limit hole carrier supply from base contact to resonant cavity region. Fig. 4 shows the frequency response of RCLET with base/collector short configuration (Tilted charge RCLED) at 15^{o}C. The 3dB bandwidth of a 10 x 3 μm^2 device is 2.3GHz at 30mA emitter current. Although further increase the emitter current will decrease the optical response, the bandwidth can be further push to 4 GHz when increasing emitter current to 60mA. The 4GHz bandwidth of RCLET operating at room temperature shows a great potential for commercial short distance communication system.

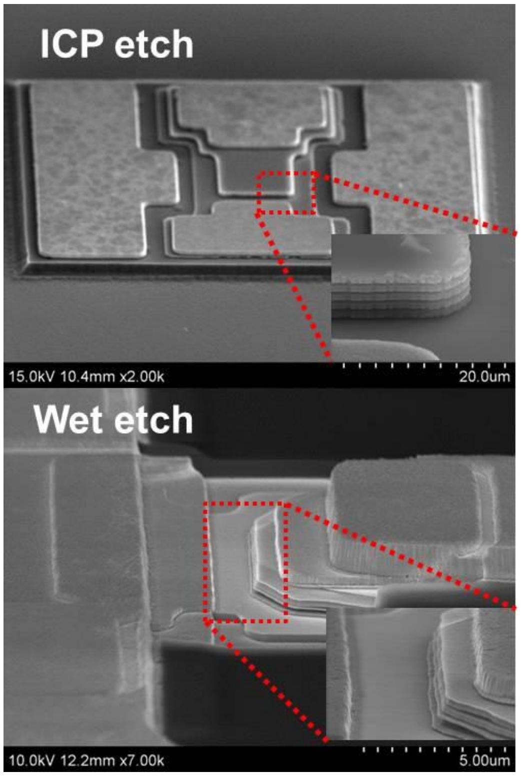

Figure 1. The scanning electron microscopic image of RCLET

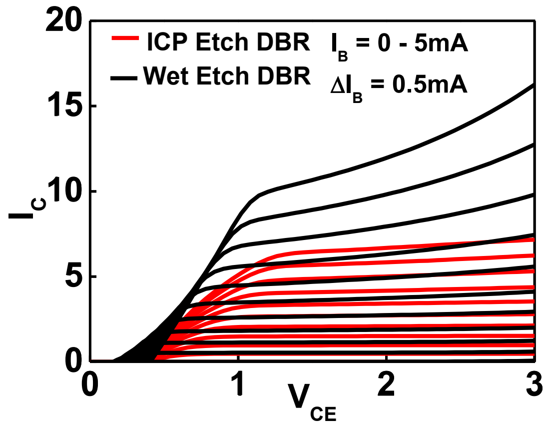

Figure 2. The Family Curve of RCLET with ICP and wet etching DBR.

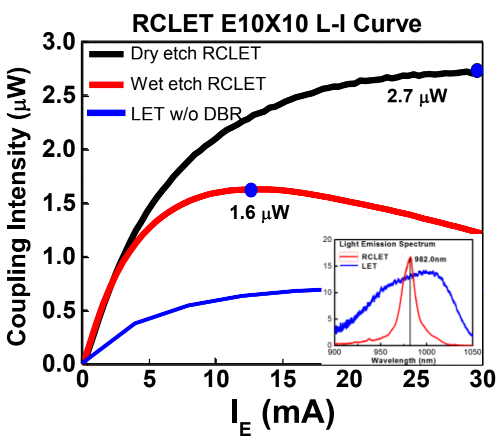

Fig. 3. The intensity versus emitter injection current of RCLET and LET

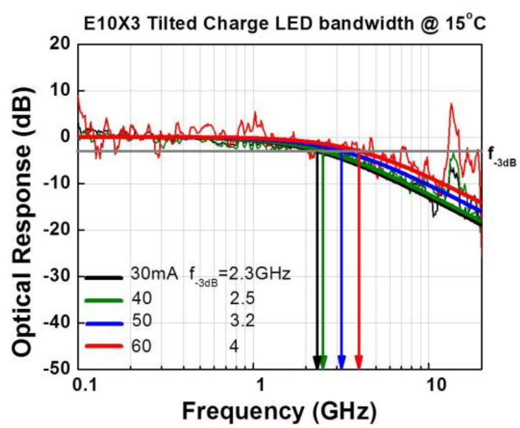

Figure 4. The frequency response of RCLET with 4 GHz bandwidth

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