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Characterization of $In_xGa_{1-x}As$ Tunnel Junction Light-Emitting Transistors

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INTRODUCTION

The III-V light-emitting transistors (LETs) function as three-port devices (an electrical input, an electrical output, and a "third-port" optical output) by incorporating quantum wells (QWs) in the base layer of heterojunction bipolar transistiors (HBTs) to enhance the radiative recombination [1][2]. If the base region is afforded adequate Q, the laser operation of the LET can be achieved, namely, the transistor laser (TL) [3]-[5]. As shown elsewhere [6], the recombination optical signal, via internal Franz-Keldysh (F-K) absorption [7], causes voltage-dependent breakdown and negative resistance in the TL collector characteristics [8]. Moreover, the highly-doped p^+-n^+ tunnel junction has been employed at the base-collector (BC) junction to enable the laser operation to be more effectively controlled by changes of voltages, which makes possible a direct voltage modulation laser along with an usual current modulation operation [9][10]. It is possible to realize voltage-operated switching and use it also in signal mixing and data processing [6].

In the present work we investigate the effect of different indium mole fraction of the $In_xGa_{(1-x)}As$ tunnel junction light-emitting transistors (TJLETs). The smaller band gap energy due to higher indium composition leads to stronger F-K absorption and direct tunneling probability when BC junction is reverse-biased. This results in the larger current gain and the less optical output enhancement. Figure 1 exhibits the layout design of the devices.

DEVICE CHARACTERISTICS AND RESULTS

Figure 2 shows the collector *I-V* and optical *L-V* characteristics of the emitter-metal-size $100\times100\mu m^2$ TJLET with the base current (I_B) varying from 0 to 80 mA. The indium mole fraction of the $In_xGa_{(1-x)}As$ tunnel junction is 0.025 and 0.05. The upward slope of the collector current when V_{CE} > 1.5V is the evident of tunneling effects. I_C increases as the function of V_{CE} owing to F-K (photon-assisted) absorption and direct tunneling (non photon-assisted). The collector *I-V* characteristics of the TJLET agree well in form with its optical output, as the optical *L-V* characteristics shown in Fig. 2(b). Reverse-biased BC junction supply more holes to the quantum well active region resulting in additional optical output enhancement. However, under stronger reverse-biased BC junction field (V_{CE}>2.5V), optical output is reduced by F-K absorption.

The directly tunneling probability can be obtained by using the Wentzel-Kramers-Brillouin (WKB) approximation [11]. The tunneling probability is given by

$$P_t \cong \left[-2\int_{x_1}^{x_2} \sqrt{2m^*(E_c - E_f)/\hbar^2}\, dx \right] \tag{1}$$

The more indium content at the $In_xGa_{(1-x)}As$ tunnel junction, the smaller band gap energy and leads to the greater tunneling probability. The tunneling probability is 2.64E-12 for x=0.025 and 4.21E-12 for x=0.05.

The F-K electroabsorption coefficient is given by

$$\alpha(\hbar\omega, E) = 1.0\times10^4\,(f/n)(2m_r/m)^{4/3}E^{1/3}\int_{\beta}^{\infty}\left|Ai(z)\right|^2 dz \tag{2}$$

$$\beta = 1.1\times10^5(2m_r/m)^{1/3}(E_g - \hbar\omega)/(E^{2/3}) \tag{3}$$

For x=0.05 tunnel junction, the smaller band gap energy leads to more photons reabsorption and more electron- hole pairs generation.

Figure 3 shows the electrical current gain and optical output when BC junctions are under four different reverse-biased junction field with I_B =40mA. The higher current gain growth and the less optical output enhancement of indium content x=0.05 tunnel junction are due to its smaller band gap energy and stronger F-K absorption and direct tunneling probability. The optical output reduction at V_{CB}=0.8V is on a ccount of the stronger F-K absorption under stronger reverse-biased BC junction field.

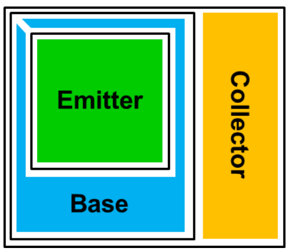

Fig. 1: Top view layout of the TJLETs.

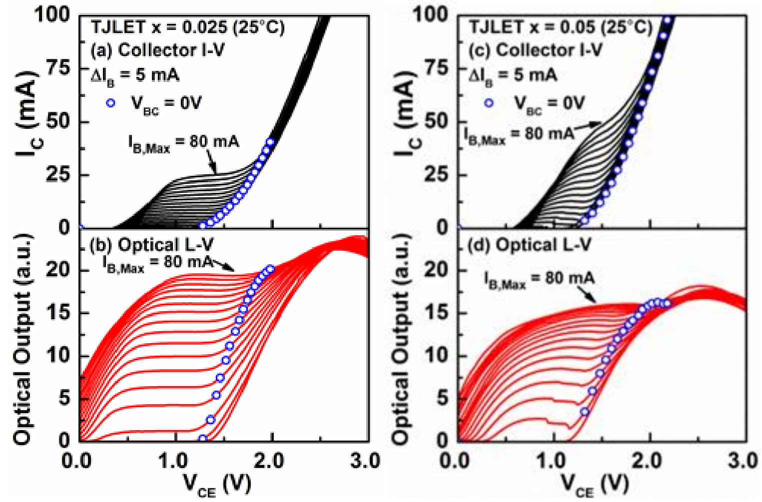

Fig. 2: (a) The collector *I-V* characteristics and (b) Optical *L-V* characteristics of an emitter-metal-size 100×100μm^2 TJLET (for $In_xGa_{(1-x)}As$ tunnel junction x=0.025). (c) The collector *I-V* characteristics and (d) Optical *L-V* characteristics of an emitter-metal-size 100×100μm^2 TJLET (for $In_xGa_{(1-x)}As$ tunnel junction x=0.05).

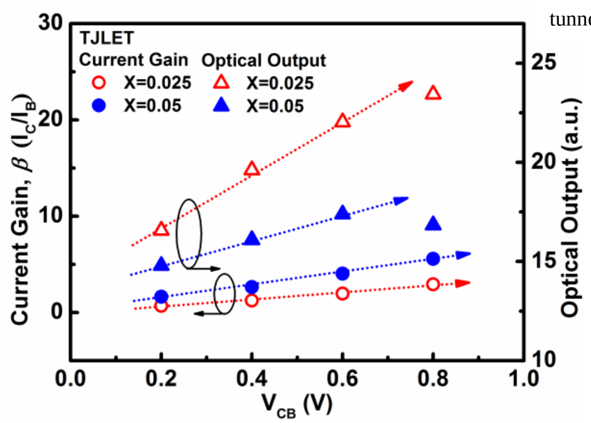

Fig. 3: The electrical current gain and optical output when BC junctions are under four different reverse-biased junction field and I_B=40mA.

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