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Author	Yasutaka Higa, Mikio Sorimachi, Takuya Nishinome, Hajime Iwasaki, Akihiro Matsutani, Tomoyuki Miyamoto
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The Reduction of Dumping Factor at Well-in-Well Quantum Well Lasers

Yasutaka Higa, Mikio Sorimachi, Takuya Nishinome, Hajime Iwasaki, and Tomoyuki Miyamoto
Photonics Integration System Research Center, P & I Lab., Tokyo Institute of Technology,
R2-39, 4259 Nagatsuta, Midoriku, Yokohama 226-8503, Japan
e-mail address: yasutaka.higa@ms.pi.titech.ac.jp

***Abstract*- A quantum well design for controlling of the carrier relaxation process and reducing of the gain damping effect was investigated for improvement of high speed direct modulation semiconductor lasers. The proposed Well-in-Well structure decreases the carrier relaxation time into an active well by carefully designed wave function which relates to the LO phonon scattering rate. The decrease of relaxation time and the increase of modulation bandwidth was analyzed numerically. The reduction of damping factor γ was also demonstrated by experimental measurement of the relative intensity noise spectrum.**

I. INTRODUCTION

Quantum well (QW) lasers have been progressed and the direct modulation bandwidth has become fast up over 20GHz. However, increase of the modulation bandwidth by structural optimization methods is limited by the damping effect of the optical gain. To suppress the dumping effect due to the finite carrier relaxation time, a tunnel injection quantum well (TI-QW) structure (Fig. 1(a)) was proposed [1,2]. The TI-QW structure can control the carrier relaxation time into an active well by designing the wave function which relates to the LO-phonon scattering.

In this paper, a Well-in-Well (WWell) structure is proposed for controlling the carrier relaxation time and dumping effect to improve the modulation bandwidth. The WWell has the same elemental functions as the TI-QW and a simple layer structure. It is noted the WWell is proposed to increase the LO phonon scattering by designing the quantum structure in detail and is different from the conventional GRIN-SCH which has similar potential steps. The electron relaxation characteristics dependence on the structure was analyzed numerically and the MBE-grown device was tested for clarifying the reduction of the damping effect via the RIN spectrum measurement.

II. CONCEPT AND ANALYSIS OF WWELL

Figure 1 shows a schematic model of conduction band diagram and electron wave functions of a single WWell structure. The WWell structure is composed of an inner active well that is sandwiched by outer wells. At the WWell structure, outer well structure controls the wave functions and makes large overlap of wave functions between the barrier region and itself, and also between an active well and itself. This large overlap leads a large scattering rate of electrons by LO phonon. Because the LO phonon scattering causes energy relaxation of the carriers, electron relaxation time is decreased by controlling the wave functions.

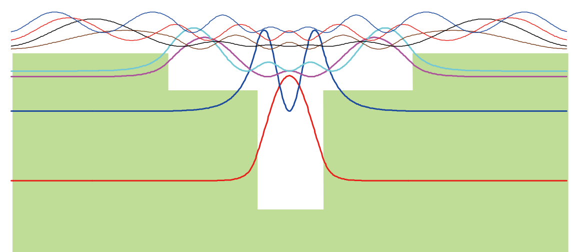

Fig. 1 The schematic model of conduction band diagram and electron wave functions of WWell structure.

Firstly, the theoretical analysis based on this LO phonon scattering rate was investigated. We composed the analysis model for this simulation, and investigated the carrier relaxation time and modulation bandwidth [3].

Figure 2 shows the dependence of electron relaxation time on outer well width at WWell structure. In the numerical analysis, the barrier or SCH layer thickness of one side was assumed to be 30 nm. It is noted that the structures whose outer well width was 0 nm and 30 nm correspond to the conventional QW structures of shallow and deep well depth, respectively. The relaxation time is reduced most when the outer well width is approximately 10nm. The minimum relaxation time was 3.7ps and corresponding K-factor was 0.15ns at typical laser parameter. At conventional InGaAs/GaAs QW laser for high speed direct modulation, reported K-factor was 0.24~0.29 ns [4,5]. Comparing with these values, we think that the K-factor can be reduced by the WWell structure.

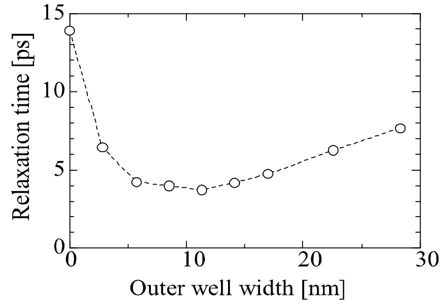

Fig. 2 Calculated relaxation time dependence on the outer well width of WWell structure.

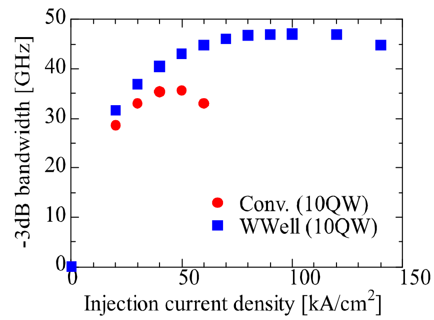

Fig. 3 Theoretical -3dB bandwidth of 10QW lasers.

Figure 3 indicates the calculated -3dB bandwidth of conventional QW and WWell lasers. The WWell laser structure was optimized to the fastest electron relaxation. The active region of both lasers was composed by 10QW and photon lifetime was set to be 1.3 ps. The result shown in Fig. 3 suggested that the WWell structure can expand the -3dB bandwidth because of the faster carrier relaxation. As shown in Fig. 3, the maximum bandwidth is expected to be increased from approximately 35GHz to 50GHz.

III. Mesuremtn of rerative intensity noise

A WWell laser wafer was grown by MBE system, and fabricated to ridge lasers for characterization of the relative intensity noise (RIN) characteristics. We prepared $Ga_{0.8}In_{0.2}As/GaAs$ conventional 3QW lasers and $Ga_{0.8}In_{0.2}As/GaAs/Al_{0.05}Ga_{0.95}As$ WWell 3QW

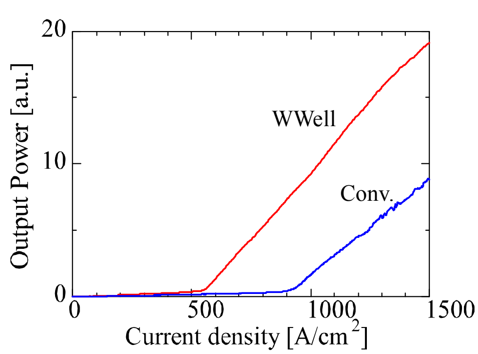

Fig. 4 The characteristics of injection current density versus output power of 4μm x 500μm ridge lasers.

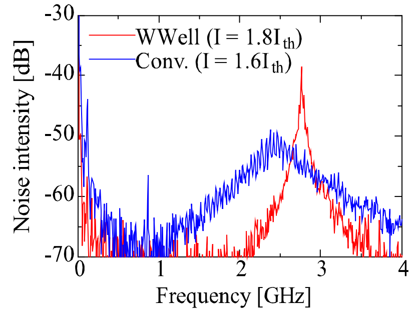

Fig. 5 Relative intensity noise spectrum of lasers.

lasers. Figure 4 shows the current density versus output power characteristics of these lasers. The difference of threshold current density is explained by the small fabrication error of the cavity width and the photon lifetime.

Figure 5 shows the result of RIN spectrum measurement. The peak of RIN spectrum of the WWell structure was larger than that of the conventional QW. This difference indicates that the damping factor of the WWell laser is smaller than that of the conventional QW laser from the theoretical relation shown below:

$$\frac{\mathrm{RIN}}{\Delta f} = \frac{4\Gamma R'_{sp}}{N_p} \cdot \frac{1}{\gamma^2}$$

It is noted that the difference of photon density is not enough to explain the 10dB difference of RIN peaks.

In conclusion, a novel quantum well active region “WWell” was proposed to reduce the electron relaxation time. By theoretical analysis, the shortening effect of electron relaxation and expanding effect of direct modulation bandwidth were studied. The reduction effect of damping factor was demonstrated by measurement of the RIN peak intensity. The WWell is advantageous to improve the direct modulation response of the semiconductor lasers by suppression of the gain damping.

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