UWB Analogous Optical Link Based on a Quantum-Dot-in-a-Well (QDWELL) Laser

Y. Ben Ezra, B.I. Lembrikov*
Department of Communication Engineering,
Holon Academic Institute of Technology,
52 Golomb str., P.O.B. 305,
Holon 58102, Israel
* contact person, e-mail borisle@hit.ac.il

***Abstract*— We investigated theoretically the application of a quantum-dot-in-a-well (QDWELL) laser diode under the optical injection for an ultra wideband (UWB) analogous opical link. The simulation results show the improvement of the optical link performance due to the optically synchronized carrier dynamics in a QDWELL laser at the modulation frequency of $10GHz$.**

***Index Terms*— quantum dot (QD), ultra wideband (UWB) communications, optical link, radio-over-fiber (RoF) technology.**

I. Introduction

Ultra wideband (UWB) radio-over-optical fiber (UROOF) technology attracted great interest due to broad bandwidth, low loss, light weight, high data rate, availability of low-cost transceivers, low transmit power, low power spectral density (PSD), and low interference [1]-[3]. Typically, directly modulated semiconductor laser diodes are used as a radiation source in a UROOF communication system [3]. Recently, a ridge waveguide InAs/InGaAs QD laser diode having a quantum dot-in-a-well structure (QDWELL) has been investigated both theoretically and experimentally [4]-[6]. It manifests a high performance for the modulation frequencies up to $7GHz$ limited by the relaxation oscillation (RO) frequency of the carriers in the QDWELL structure [4]. We have shown that the optical injection of QDWELL lasers synchronizes the carrier dynamics and enhances the QDWELL laser bandwidth and modulation frequency [7], [8]. In this paper, we investigated theoretically the influence of a QDWELL laser dynamics under an optical injection on the UWB analogous optical link (AOL) performance. We have shown that the modulation frequency can be enhanced up to the higher UWB frequency of $10GHz$.

II. Theoretical Model of an Optical Link Based on QDWELL Laser

The UWB high-speed AOL block diagram is shown in Fig. 1. It consists of a transmitter block (Tx) with a QDWELL laser diode, electrical/optical (E/O) converter, an optical fiber, optical/electrical (O/E) converter, and a receiver block (Rx) [3]. We introduced a QDWELL laser diode into the UROOF AOL model instead of a conventional vertical cavity surface emitting laser (VCSEL) and considered the direct modulation regime characterized by the simplicity and low cost. The rate equations for the electron and hole occupation probabilities in QDs $\rho_{e,h}$, the electron and hole densities in the QW $w_{e,h}$, and the photon density n_{ph} taking into account optical injection, the inhomogeneous broadening in QDs, the radiative losses and the separate Auger-related losses, and the nonlinear carrier scattering rates $S_{e,h}^{in,out}$ are given by [6].

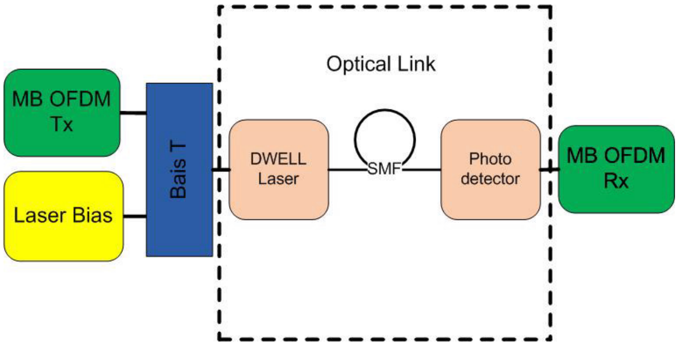

Fig. 1. Block diagram of the analogous optical link containing QD in the well (QDWell) laser

$$\frac{dn_{ph}}{dt} = n_{ph}\left[2\widetilde{W}Z_a^{QD}(\rho_e+\rho_h-1)-2\kappa\right]$$
$$+\frac{\beta}{A}2Z_a^{QD}R_{sp}(\rho_e,\rho_h)+\frac{2K}{\tau_{in}}\sqrt{n_{ph}n_{ph}^0}\cos\left(\Phi-2\pi\Delta\nu_{inj}t\right) \quad (1)$$

$$\frac{d\Phi}{dt} = \frac{\alpha}{2}\left[2\widetilde{W}(\rho_e+\rho_h-1)-2\kappa\right]$$
$$+\frac{K}{\tau_{in}}\sqrt{\frac{n_{ph}^0}{n_{ph}}}\sin\left(\Phi-2\pi\Delta\nu_{inj}t\right) \quad (2)$$

$$\frac{d\rho_{e,h}}{dt} = -\widetilde{W}A(\rho_e+\rho_h-1)n_{ph}-R_{sp}(\rho_e,\rho_h)$$
$$+S_{e,h}^{in}(w_e,w_h)(1-\rho_{e,h})-S_{e,h}^{out}(w_e,w_h)\rho_{e,h} \quad (3)$$

$$\frac{dw_{e,h}}{dt} = \frac{j}{e_0}$$
$$-2N^{QD}\left[S_{e,h}^{in}(w_e,w_h)(1-\rho_{e,h})-S_{e,h}^{out}(w_e,w_h)\rho_{e,h}\right]-\widetilde{R}_{sp} \quad (4)$$

where A is the in-plane area of the QW. The laser frequency ν and the injected light frequency ν_{inj} are very close: $\nu_{inj}/v \approx 1$; $K = \sqrt{T_{inj}n_{inj}/n_{ph}^0}$ is the injection strength, T_{inj} is the transmission coefficient of of the cavity mirror; n_{inj} is the injected photon density in the active region of the QD laser; $n_{ph}^{0}$is the steady-state photon density without injection $(K = 0)$. The input detuning $\Delta\nu_{inj} = \nu_{inj} - \nu_L$; $Z_a^{QD} = a_L A N_a^{QD}$ is the number of active QDs inside the waveguide, a_L is the number of self-organized QD layers; N_a^{QD} is the density per unit area of the active QDs of lasing subgroup, N^{QD} is the density per unit area of all QDs, 2κ are the optical intensity losses. $\widetilde{W} = |\mu|^2 \omega_L T_2 / (\varepsilon_0 \varepsilon_{bg} \hbar V^w)$ and $W = |\mu|^2 \sqrt{\varepsilon_{bg}} \omega_L^3 / (3\pi\varepsilon_0 \hbar c^3)$ are the Einstein coefficients for the coherent interaction and for spontaneous emission resulting from the incoherent interaction of the QD with all resonator modes [6], μ is the associated dipole moment of the optical transition, T_2 is the lifetime of the microscopic polarization; $V^w = Ah^w$ is the volume of the optical waveguide; ε_0 is the free space permittivity. The spontaneous emission rates in QDs and QW have the form, respectively $R_{sp}(\rho_e, \rho_h) = W\rho_e\rho_h$, $\widetilde{R}_{sp} = B^S w_e w_h$ [6], $\tau_{in} = 2L\sqrt{\varepsilon_{bg}}/c$ is the time for one round trip of the light in the cavity of length L; ε_{bg} is the static relative permittivity of the background medium, c is the speed of light in vacuum, L is the cavity length; j is the injection current density, e_0 is the elementary charge, B^S is the band-band recombination coefficient; α is the linewidth enhancement factor (LEF).The expressions for the carrier scattering rates $S_{e,h}^{in,out}$are presented in Ref. [6]. The corresponding carrier lifetimes have the form $\tau_{e,h} = \left(S_{e,h}^{out} + S_{e,h}^{in}\right)^{-1}$ [6].

III. Simulation Results

We solved numerically equations (1)-(4) for the case of the small UWB signal in the upper UWB frequency of $10GHz$ using the typical values of QDWELL laser parameters [6], [8]. The simulation results are shown in Figs. 2, 3. The electron (upper box) and hole (lower box) dynamics in a QW for a modulation frequency of 10 GHz is presented in Fig. 2. It is seen that the carrier dynamics in QW and QDs is synchronized due to the optical injection [8]. The UWB frequency of $10GHz$ modulated density of photons radiated from the QDWELL laser is shown in Fig. 3. The performance of the optical link based on a QDWELL laser is improved due to the optical injection.

IV. Conclusions

We investigated theoretically the performance of the AOL based on the optically injected QDWELL laser for the small UWB signals. The QW and QD carrier dynamics is synchronized due to the optical injection. The UWB AOL performance improves up to the higher UWB frequency of $10GHz$.

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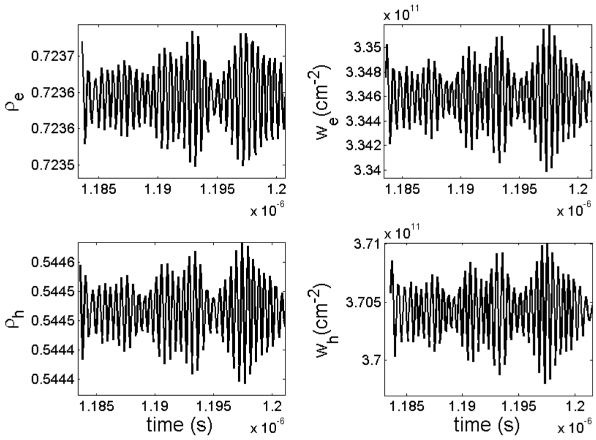

Fig. 2. Optically synchronized dynamics of the QW and QD carriers

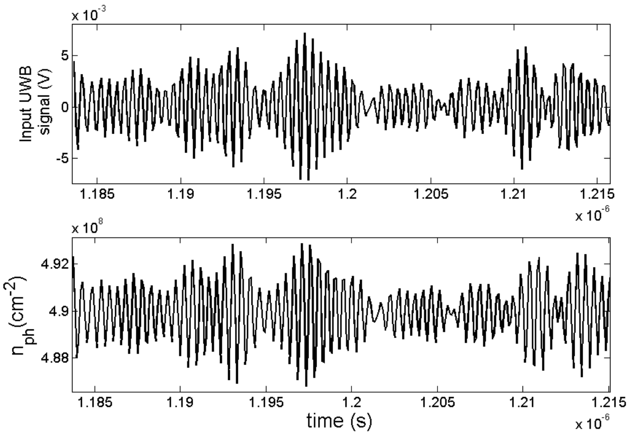

Fig. 3. The input UWB signal (upper box) and the directly modulated photon density n_{ph} (lower box)

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