Short Pulses from QD Laser Excited State

Nuran Dogru, S. Hilal Duranoglu Tunc, Ali Mumtaz Al-Dabbagh
Department of Electrical & Electronics, University of Gaziantep, 27310, Gaziantep, Turkey
dogru@gantep.edu.tr

Abstract: For the first time gain-switched short pulse generation with a width of 25-40 ps from excited state is demonstrated applying an external optical Gaussian beam to the excited state of InAs-InP-(113)B quantum dot laser.

I. INTRODUCTION

Short optical pulses with high response speeds and large peak power are in demand in many fields such as high-speed optical communication, medical applications, clock distribution, electro-optic sampling systems and so on [1]. Low cost directly adjustable lasers will play an important role in next generation telecommunications links. As a result, semiconductor lasers based on small-size heterostructure such as the quantum dot (Q-Dot) laser are very promising. The Q-Dot laser is one kind of semiconductor nanostructure that shows the merits of high-temperature stability, low-chirp operation, optical feedback resistance, and a low threshold current, which has led to widespread study compared with bulk-based or quantum well [2,3]. InGaAs-GaAs Q-Dot devices do not allow laser emission over 1.45 μm, which causes loss in long distance transmissions. In order to achieve standard long distance transmission, one uses long-haul optical transmission at a wavelength of up to 1.55 for this reason, one chooses InAs-InP-(113)B, with the InAs Q-Dot laser grown on an InP substrate that emits at a wavelength of 1.55 μm [2].

Mode-locked, Q-switched or gain-switching represent the most renowned techniques or methods for generating picosecond optical pulses in semiconductor Q-Dot lasers. The implementation of the gain-switching technique is simpler and better than Q-switching and mode-locking because it requires neither an external cavity nor saturable absorber. The gain-switched method seems to be more advantageous due to the simplicity of implementation and low production cost. Therefore, here it is presented, for the first time to our knowledge, gain-switched short pulse generation via excited state from InAs-InP-(113)B Q-Dot by applying an external optical beam to the excited state of Q-Dot.

II. THEORETICAL MODEL DESCRIPTION

Laser model used here is based on [4] that direct injection from the wetting layer (Wly) to the ground state (Grs) was introduced to reproduce the experimental results. The carrier and photon density in the two lowest energy levels, Grs and Exs, are used as a base for the model of the InAs-InP-(113)B Q-Dot laser and the active region consists of only one Q-Dot ensemble. The single mode rate equations are solved using the Runge-Kutta method. Inhomogeneous and homogeneous broadening are neglected in our calculations since we will just only try to show what the limits must be to generate short pulses from the InAs-InP-(113)B Q-Dot laser. The temperature effect and carrier loss are also neglected in the computation. It is supposed that carriers are directly injected from contacts to Wly, so the carrier dynamics are not considered in the barrier. It is assumed that only a single discrete Grs for electrons and a corresponding Grs for holes are formed inside the Q-Dot and that the charge neutrality always holds in each Q-Dot.

III. RESULTS AND DISCUSSIONS

In our simulation, a 1.55-μm InAs-InP-(113)B Q-Dot laser suitable for telecommunications is used. Gain saturation parameter is considered to be as 1×10^{-16} cm^{-3} for Grs and Exs and the values of other laser parameters were obtained from [2,5].

In our simulation, threshold current for the Grs and Exs without optical beam irradiating the Exs were calculated 8 mA and 61 mA, respectively. The total threshold current for the Grs and Exs together (Grs+Exs) was close to the threshold current value of the Grs, which was equal to 8 mA. Gain-switched output pulses with a pulse with of 76.78 ps and peak power of 82.56 mW is given in Fig.1(a) for an AC peak current (I_{rf}) current of 20 mA. Since applied current magnitude is less than the threshold current of Exs, generated pulses are due to only Grs lasing. Therefore, pulse width (full width half maximum-FWHM) and peak power of the Grs photons are also 76.78 ps and 82.56 mW. When the current is increased, the Exs lasing appears around 85 mA and it contributes the output pulses with Grs together. Fig. 1(b) shows simultaneous emission from both states as an I_{rf} current of 100 mA giving a FWHM of 302.26 ps and a peak power of 369.33 mW. A shoulder appearing in the output pulse is caused by lasing of Grs. Our results showed that peak power and FWHM increases with increasing I_{rf}. The reason for the increase in the FWHM is that Grs photon density decreases slowly after reaching the maximum value. However, it can be observed from the figure that Exs photon density decreases very fast giving a shorter output pulse compared with that of Grs. We can say that the long pulses in the InAs-InP (113)B lasers are emitted from the InP ground state. In order to obtain short pulses with a high peak power Exs lasing must be sustained eliminating Grs lasing. However, Exs lasing appears at high injection currents. If any way both Grs lasing is suppressed and threshold current of Exs is reduced, it is possible to generate shorter pulses at low injection currents due to Exs. For that reason we applied an external Gaussian beam to Exs. When optical beam is applied to Exs, according to magnitude of applied current, threshold currents of Grs and Exs can be zero and also photon density of Exs can be greater than that of Grs at zero current.

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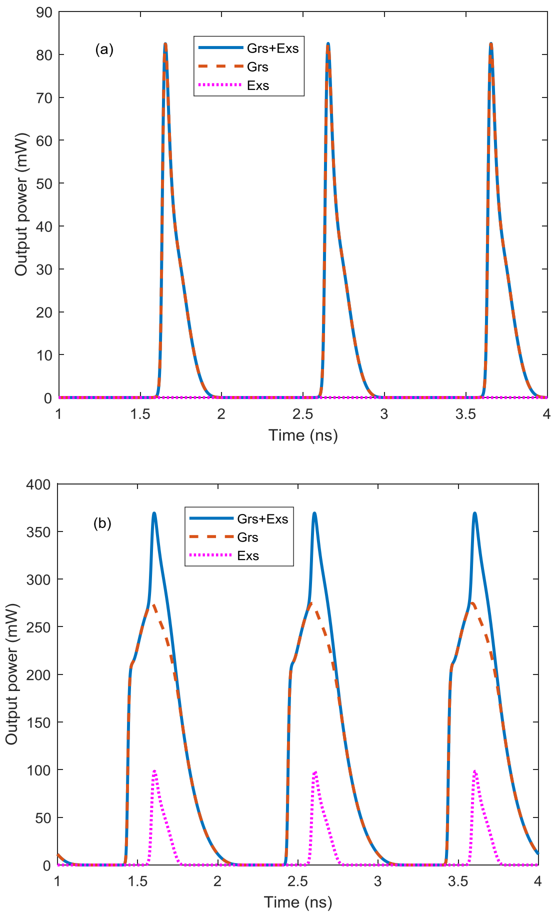

Fig.1. Output pulses without optical beam (a) I_{rf}=20 mA, (b) I_{rf}=100 mA

For an I_{rf} current of 20 mA, FWHM and peak power of pulses are found as 31 ps and 663.24 mW for a Gaussian peak power of 20 mW (see in Fig.2(a)) and as 38.7 ps and 979.2 mW for peak power of 50 mW. Generated pulses are due to lasing of Exs. However, if the current is increased for example to 50 mA and to100 mA for a peak power of 20 mW, FWHM and peak power are calculated as 34 ps and 939 mW for 50 mA and 41.9 ps and 1.1 W for 100 mA (see in Fig. 2(b)). In this case generated pulses are caused by both lasing of Grs and Exs. If the peak of optical beam increases, Exs photon density becomes much greater than that of Grs and since Exs transition photons have narrow width FWHM of output pulses also become narrow.

IV. CONCLUSION

Gain-switched short pulses were obtained with a width of 25-40 ps by applying an external optical beam to the excited state of InAs-InP-(113)B quantum dot laser. These results are important to achieve long-distance optical transmissions

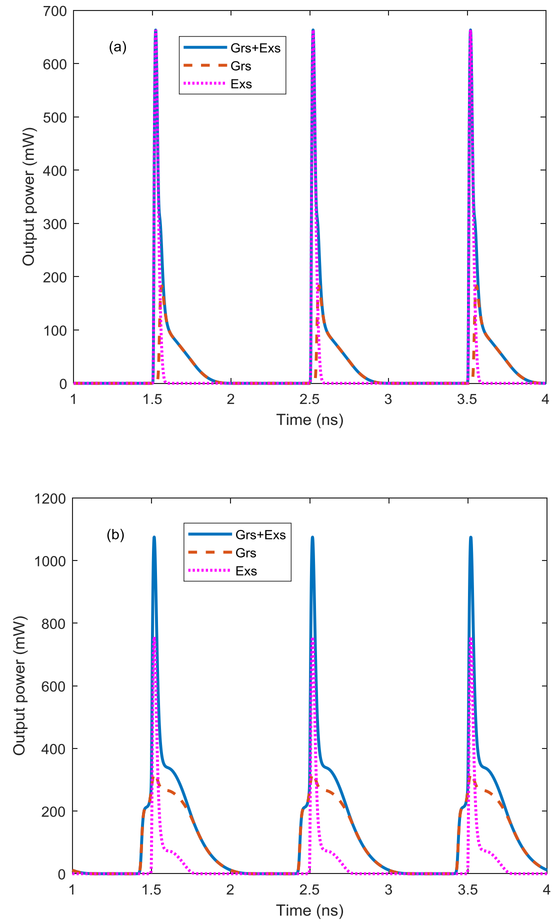

Fig. 2. Output pulses with a Gaussian peak power of 20 mW: (a) I_{rf}=20 mA, (b) I_{rf}=100 mA

using quantum dot lasers and semiconductor optical amplifiers.

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