Quantum dot twin stripe lasers as emitter and receiver in chaotic encrypted communication systems

Quantum dot twin stripe lasers as emitter and receiver in chaotic encrypted communication systems

J. Pozo[1], A. Corradi[1], E. Smalbrugge[1], T. de Vries[1], R. Nötzel[2], D. Lenstra[3], M.K. Smit[1]

[1] OED group and [2] PSN group, COBRA, Technische Universiteit Eindhoven, The Netherlands.
[3] Faculty of Electrical Engineering, Mathematics and Computer Science, Delft University of Technology, The Netherlands.

The complex nonlinear and chaotic regimes observed in laterally coupled diode lasers – or twin stripe lasers– make this device a real contender for the emitter and receiver in chaotic encrypted communication systems, since the chaos is produced on chip and no other elements have to be added to the set-up. The main problem until now was to be able to synchronize two of those devices, due to the difficulty of fabricating a pair similar enough. Our approach is to use Quantum Dots for the active region of the twin stripes, which allows for the use of shallow etching to electrically isolate both stripes due to the zero dimensional confinement of the Quantum Dots. In this paper we present the first time that a pair of twin stripe lasers has been synchronized together with an observation of transitions to chaos such as those found in single-stripe lasers subject to external influences.

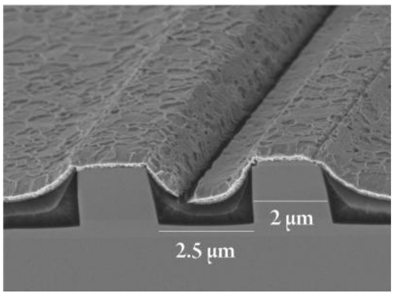
Introduction

Non-linear dynamics in Quantum Dot (QD) lasers have attracted the attention of the research community for over a decade. These interesting non-linear dynamic features can not be only studied in detail but also exploited. Encryption schemes for hiding messages in chaotic signals have also attracted attention to a great extent in order to transmit information securely. But to date these encryption systems have had two major issues: (1) although chaos on a laser chip already has been proven experimentally [1], the fabrication of reproducible chaotic lasers is still a major issue; (2) also, traditionally, optical chaos has been created by externally influencing a laser in complicated set-ups making difficult the use of the system for commercial applications. Our approach is to simplify the system and increase its reproducibility by producing the chaos 'on chip', without adding extra components to the set-up. For that purpose, we use twin-stripe lasers.

Device details

By using InAs/InGaAsP/InP (100) QD material [2] operating at 1.5 μm to fabricate devices consisting of two laterally coupled non-linear oscillators, or twin-stripe lasers, we have the advantage, due the zero dimensional confinement of the QDs, of achieving evanescent coupling between the stripes with no lateral carrier diffusion through the active region. In this material, lateral carrier diffusion, through thermal carrier excitation to the wetting layer or the barriers, takes place over up to 100 nm.

A SEM image of the resulting device can be observed in figure 1 (right). The resulting devices are 4 mm long with two ridge waveguides with a width of 2 µm each, separated by 2.5 µm. The fabricated lasers have then been characterized showing good performance with a threshold current of 200 mA in each stripe at 285 K and an output power of up to 8 dBm per stripe and per facet.



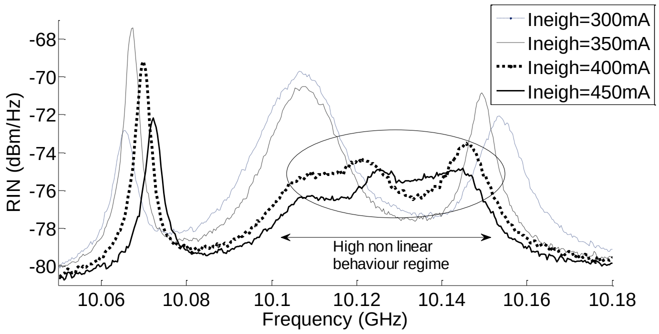


Figure 1 (right) SEM image of one of the facets of the twin-stripe laser. (left) RIN spectra of the twin stripe laser corresponding t a fix value for I_{main} (400 mA) and 4 values of I_{neigh}.

Dynamic Characterization

The dynamics of the lasers are influenced by the evanescent coupling between the stripes, and altering parameters such as the separation between the stripes –in the fabrication process– or the bias current in either one of the stripes, transitions to chaos similar to those found in single-stripe lasers subject to external influences have been observed [1,3].

For the easier understanding of the dynamic characterization, in the rest of this article we will name the stripes as main stripe –the one from which the light is collected– and neighbour stripe. In figure 1 (right) the relative intensity noise (RIN) spectra of the output of the main stripe have been plotted as a function of the bias current on its neighbor stripe (I_{neigh}). In that figure it is possible to observe how a variation in I_{neigh} has a major effect in the dynamical behaviour of the sample around the resonant peak of the cavity –10 GHz, corresponding to a cavity length of 4 mm. It is observable how there is a transition by operating the neighbour stripe from 350mA to 400mA. In the curve corresponding to 400 mA and 450 mA it is observable a region with high non linear behaviour in the region of frequencies between 10.1GHz and 10.15 GHz. While this could be the evidence of a chaotic point of operation, it is necessary to observe some measurements in the time domain, which, while they do not represent a formal proof of chaotic operation, they can show a high non-linear signal that could still be use as a carrier wave for chaotic encryption [3].

In figure 2, the time responses of the twin stripe lasers are plotted in 2 different points of operation. In that figure I_{neigh} has been fixed at 400mA and a swept in bias current in the main stripe has been performed.

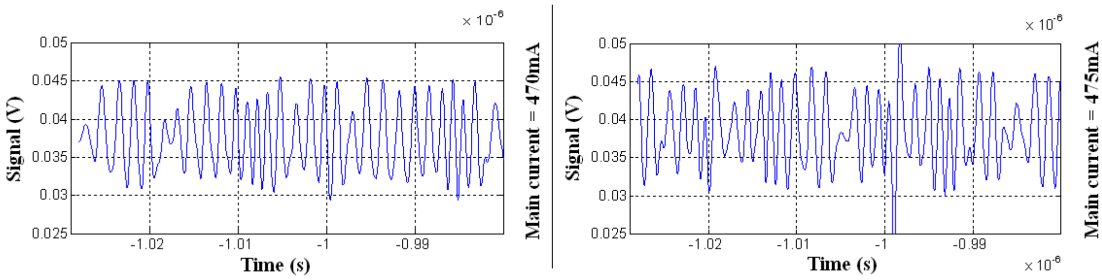


Figure 2 Time responses of the twin stripe corresponding to a fix value of I_{neigh} (400mA) and 2 different values of I_{main}.

For the measurement of the signal response a photodiode with 2.5 GHz bandwidth has been connected to a digital oscilloscope. It has been observed how the bias of the main stripe, I_{main}, has a big effect in the time response of the laser. In addition, the signal on the right hand side of figure 2 corresponding to I_{main} = 475 mA resembles the unpredictable behaviour observed experimentally in previous published work [3 - 5].

Synchronization experiments

The synchronization of a pair of chaotic lasers, a master and a slave, is not trivial. In order for two lasers to dynamically synchronize, they need to have similar behaviour and also similar geometry and structure. In the section about the device details it was mentioned how the use of QD material made easier the fabrication of the device. This is an advantage in order to make sure that both lasers will have identical geometry, but it can also constitute a disadvantage, since the QD material is non uniform and therefore it may derive on differences in the structure of the devices that will difficulty the synchronization.

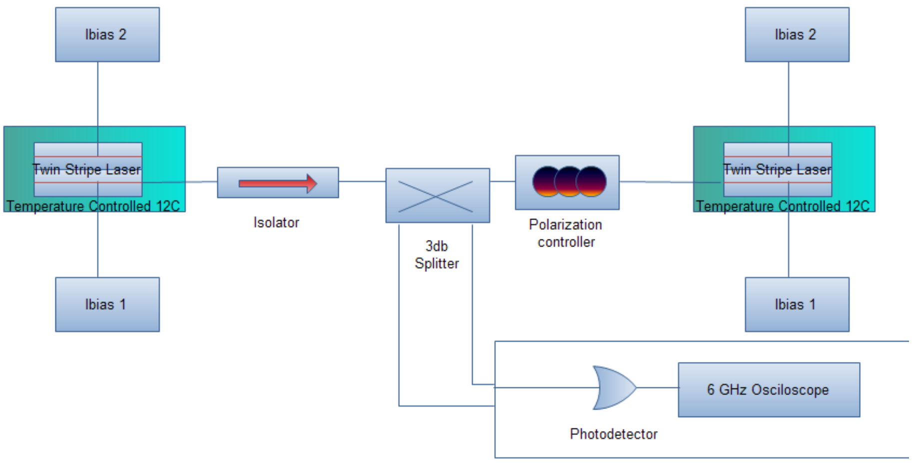


Figure 3 Synchronization set-up.

Figure 3 has a diagram of the experimental set-up used for the synchronization experiment. In this diagram we will consider as master laser the one on the left hand side and slave laser the one on the right hand side. Both lasers have a very accurate temperature control at 12.00 ^{0}C by means of a water cooler and a peltier + thermistor. The output light from the master is coupled into a SMF and connected to a 3 dB beam splitter. An isolator is placed between the master twin stripe laser and the beam splitter to avoid any feedback light. The beam splitter will send half of the power to an analysis kit –with an oscilloscope and a photodetector– while the other half will go to the slave laser in order to produce the synchronization. In order to guarantee that the light arriving to the slave laser has the right polarization a polarization controller has been used. The output light of the slave laser will also travel through the same SMF and arrive to the 3-dB splitter, where half of it will go to the analysis kit and the other half will unsuccessfully try to reach the master laser, and will be reflected out by the isolator.

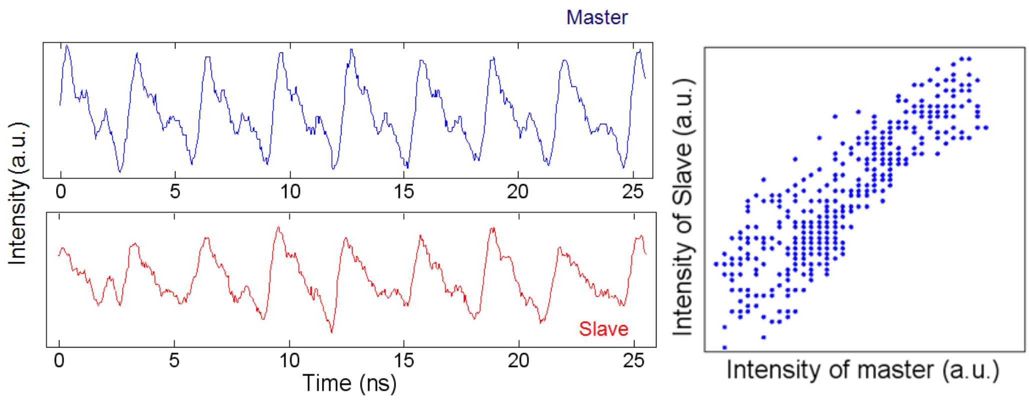


Figure 4 (right) Time traces from master and slave laser, (left) x-y plot of the time traces on the right for the observation of the correlation of both siugnals.

Figure 4 shows the first results obtained in the synchronization experiments. On the right it can be observed the time traces from a master and a slave. The master and slave lasers are operated in identical bias conditions –400 mA for both the main and neighbour stripe. On the right hand side we can observe the correlation plot of the two signals. Its quasy diagonal shape shows certain level of synchronization of the stripes, which still needs to be improved by proper amplification of the light travelling from the master to the slave laser, but still represents the proof of principle that both lasers can effectively synchronize.

Conclusion

In this paper we show that using QD material for the fabrication of laterally coupled lasers, it can not only simplify the fabrication of electrically isolated stripes, it is also possible to produce chaotic devices capable of synchronizing.

References

[1] M. Yousefi et al.: New Role for Nonlinear Dynamics and Chaos in Integrated Semiconductor Laser Technology, Phys. Rev. Lett, vol. 98, 044101, 2007.

[2] S. Anantathanasarn, et al., Lasing of wavelength-tunable (1.55 μm region) InAs/InGaAsP/InP (100) quantum dots grown by metal organic vapor-phase epitaxy, Appl. Phys. Lett., vol. 89, 073115, 2006.

[3] I. Fischer et al., Synchronization of chaotic semiconductor laser dynamics on subnanosecond time scales and its potential for chaos communication, Phys. Rev. A, vol. 62, 011801, 2000.

[4] A. Gavrielides, T. Erneux, V. Kovanis, P M Alsing and T B Simpson, “Subharmonic transition in an optically injected semiconductor laser: theory and experiments” Quantum Semiclass. Opt. 9, pp. 575-585, 1997.

[5] Liu, H.-F.; Ngai, W.F.,” Nonlinear dynamics of a directly modulated1.55 μm InGaAsP distributed feedback semiconductor laser”, IEEE J. Quant. Electron., vol. 29, pp. 1668 – 1675, 1993.