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## Quantum-Dot InAs/InGaAsP/InP (100) Twin-Stripe Lasers

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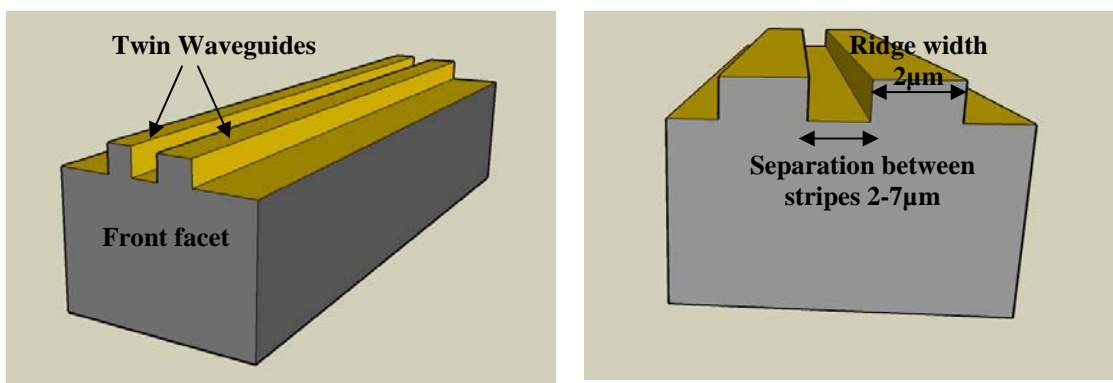
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*The interesting non-linear dynamic features observed in quantum-dot (QD) lasers operating at 1.5  $\mu\text{m}$  can be now deeply studied and exploited by using InAs/InGaAsP/InP (100) QD material to fabricate devices consisting of two laterally coupled non-linear oscillators, or twin-stripe lasers. The use of this material for the fabrication of twin-stripes allows for the use of shallow etching to electrically isolate both stripes due to the zero dimensional confinement of the QDs. The fabricated lasers are then characterized showing outstanding static performance in terms of output power.*

### Introduction

Encryption schemes that hide messages in chaotic signals have attracted the attention of the research community in recent years as a mean to transmit information securely. While no encryption system is entirely secure, the main advantage of chaotic encryption is based on the fact that it works on hardware level, and therefore can be combined with software level cryptography systems. For chaotic encrypted communication, two identical chaotic lasers need to be in the system, one in the emitter and one in the receiver. While chaos on a laser chip already has been proved experimentally [1], the fabrication of reproducible chaotic lasers is still a major issue.

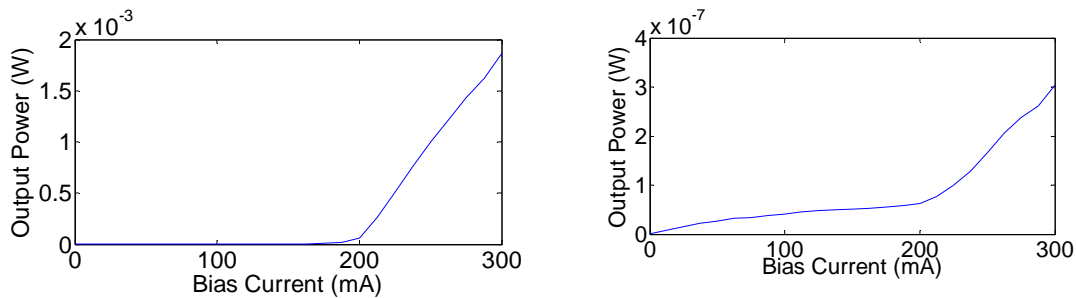


**Figure 1.** Diagram of a twin stripe laser. Angle view on the right and front view. The waveguides have to be electrically isolated even of the small separation between them since the only couple desired is optical and not electrical.

Just after the metalization, before the plating step, a Voltage-Current (V-I) diagram was measured to explore the resistivity and diode-like performance of the future lasers. The results were very satisfactory as shown in the figure 2 (left). Figure 2 (right) shows a picture of the resulting chip.

## Device Characterization

After the succesful fabrication of the twin stripe lasers, the devices have been cleaved and the resulting chips have been mounted on copper chunks. The lengths chosen for the basic characterization steps has been 4mm. In terms of static performance, the devices show low threshold current, i.e. 200 mA for a 4mm-long device as shown in the output power – current (L-I) diagram in figure 3 (right). That figure also shows an output power measured, once coupled in fiber, of 2mW at 1.5 times the threshold current. This amount of output power for QD material is among the best found in the literature.

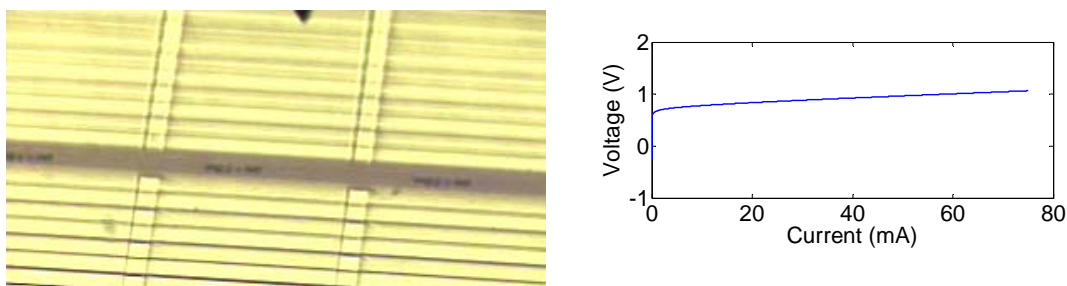


**Figure 3. (right) L-I diagram of a 4mm-long twin stripe laser at 288K when only one stripe is biased. (left) L-I diagram of one of the stripes when the neighbor stripe is being biased. 4% of the light is successfully coupled from one stripe to the other.**

For good performance of the QD laser, the light has to be coupled succesfully in the neighbor stripe. To explore that behaviour, the light out in one of the stripes was measured while biasing the neighbour. We found that 4% of the light was succesfully coupled in the stripes. Figure 3 (left) shows an L-I diagram of the light coupled.

In order to evaluate the optical spectrum of the laser, the output light was studied in an optical spectrum analyzer. Figure 4 (right) shows the optical spectrum of the laser biased at 1.5 times the treshold current, while figure 4 (left) shows the spectrum of the light coupled in the twin stripe.

A twin stripe laser consists on two active stripes close enough to allow optical coupling between them, but, at the same time, electrically isolated to avoid undesired carrier diffusion between them —as shown in figure 1. Our approach is to fabricate twin stripe lasers using InAs/InGaAsP/InP (100) Quantum Dot material [2,3]. One of the main advantages of this material for the fabrication of twin-stripes, as a result of the zero-dimensional confinement in the quantum dots, is that lateral carrier diffusion only occurs due to effects such as thermal carrier excitation to the wetting layer and only takes place over lengths of up to 100nm. We chose a separation between the stripes is varied in a range of 2-7  $\mu\text{m}$ , therefore shallow etching can be used in the fabrication process to separate both stripes with no undesired carrier diffusion taking place between them.

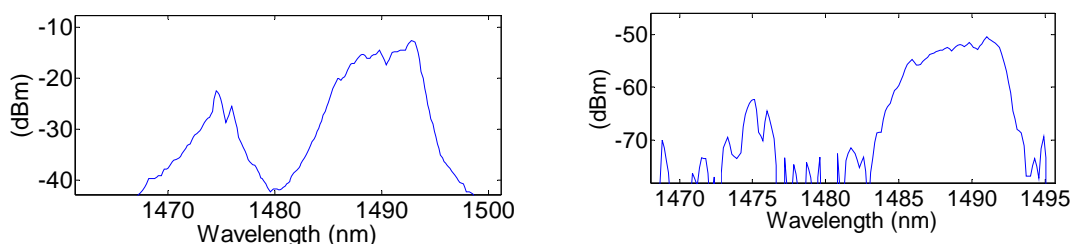


**Figure 2. (right) Picture of topview of wafer once processed, the horizontal bars represent each of the stripe which they are coupled in pairs, each stripe separated 2 $\mu\text{m}$  from its twin, the vertical lines are the cleaving sections, allowing for multiple of 1mm devices. (left) V-I diagram of the wafer after the metallization step.**

### Twin stripe fabrication process

For the fabrication of the twin stripe lasers, QD material has been used, grown on n-type InP (100) substrates by metal-organic vapor-phase epitaxy (MOVPE), as presented in [2,3]. The QD wavelength is tuned into the 1.5  $\mu\text{m}$  region through insertion of ultrathin GaAs interlayers. In the active region five InAs QD layers are stacked, separated by 40-nm InGaAsP layers with a bandgap corresponding to a wavelength of 1.25  $\mu\text{m}$  (Q1.25).

For the fabrication of the twin-stripes with a ridge width of 2 $\mu\text{m}$ , optical lithography has been used in order to define the structures —waveguides, metal contact and plating to increase the conductivity and provide good carrier distribution over the dot areas. The most delicate part of the fabrication has been the alignment of the different masks, since, in order to have good optical coupling between the stripes, the waveguides had to be separated only 2-7  $\mu\text{m}$ ; the way chosen to proceed was to use two different metalization steps, one for each stripe; as a consequence, when aligning any of the metal masks, the smallest displacement (in the nm range) could result on the shortcircuit of the stripes.



**Figure 4. (right) L-I diagram of a 4mm-long twin stripe laser at 288K when only one stripe is biased. (left) L-I diagram of one of the stripes when the neighbor stripe is being biased. 4% of the light is successfully coupled from one stripe to the other.**

## Conclusion

In this paper we showed the fabrication and basic characterization of QD - twin stripe lasers. The lasers show good static performance, and the optical coupling between the stripes has been achieved. The next step will be to study of the effect of detuning and coupling parameters in the spatio-temporal behavior, especially in transitions to chaos such as those found in single-stripe lasers subject to external influences.

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