

Laser à boîtes quantiques InAs/GaAs de 1.3- μ m insensible à la température et à la rétroaction, soumis à la modulation d'amplitude multi-niveaux

Temperature and feedback insensitive 1.3- μ m InAs/GaAs quantum dot lasers subject to pulse amplitude modulation

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Abstract/Résumé

This work reports on a high-efficiency InAs/GaAs distributed feedback quantum dot laser. The large optical wavelength detuning at room temperature between the lasing peak and the gain peak causes the static, dynamic, and nonlinear intrinsic properties to all improve with temperature, including the reflection insensitivity and modulation performance. Results highlight the potential of the large optical mismatch assisted single-frequency laser for the development of uncooled and isolator-free high-speed photonic integrated circuits.

Ce travail porte sur un laser à boîtes quantiques à réaction distribuée InAs/GaAs à haute efficacité. Le grand désaccord de longueur d'onde optique à température ambiante entre le pic laser et le pic de gain entraîne une amélioration des propriétés intrinsèques statiques, dynamiques et non linéaires avec la température, y compris l'insensibilité à la réflexion et les performances de modulation. Les résultats mettent en évidence le potentiel de ce laser monofréquence reposant sur un large désaccord optique pour le développement de circuits intégrés photoniques à haut débit fonctionnant sans contrôleur de température et sans isolateur optique.

1 Introduction

Recently, high efficiency 1.3 μ m semiconductor lasers have been widely emphasized and used in optical interconnections between large data centres and in systems with high transmission capacity over short distances. [1,2] In particular, distributed feedback (DFB) semiconductor lasers with single-frequency behaviour play a crucial role in a variety of applications, including high-resolution LIDAR systems [3], high-speed supercomputers and optical data centres. [2] Due to their narrow linewidth and large modulation bandwidth [2,5], DFB lasers are spatially and spectrally single-mode and are useful for WDM to support the ever-increasing data transmission rates in this big data era. [4,5]

The development of highly efficient quantum dot (QD) lasers is more conducive to the integrated interconnection of optical chips. The 1.3 μ m QD DFB laser has even more potential for short-range, high-speed, high-capacity photonic integrated chips. [6] Generally, the high workloads in data centres create a high temperature environment for the chips and require significant investment to keep them operating properly. If a stable performance of the QD DFB laser over a wide range of temperature conditions can be achieved, a significant reduction in the energy consumption of the silicon optical chip can be expected. [7] Designing for the wavelength mismatch of the optical gain peak and the DFB lasing peak allows the DFB to operate stably at higher temperatures. [8] Typically, InAs/GaAs and InAs/InP QD lasers report spectral linewidths in the range of 110 to 500 kHz at room temperature. [9-11] Exploring low linewidth QD DFB lasers at high temperatures will further advance their use in data centres. On the other side, the various active and passive conversion and regeneration interfaces in the laser transmission system can lead directly to optical feedback. It is shown by

research on the dynamics of external optical feedback that these unwelcome reflections can lead to strong laser instabilities and reduce transmission performance. [12,13] Given that developing an on-chip optical isolator that has low loss and sufficient isolation remains a challenge, it is an important to develop feedback insensitive sources. [14] The QD lasers exhibit a strong potential to be applied to isolator-free PICs owing to their high tolerance for chip-scale back-reflections. [15] Therefore, this study provides guidance using high performance single frequency lasers that can be applied to uncooled integrated systems with good transmission characteristics without optical isolators.

2 Device description

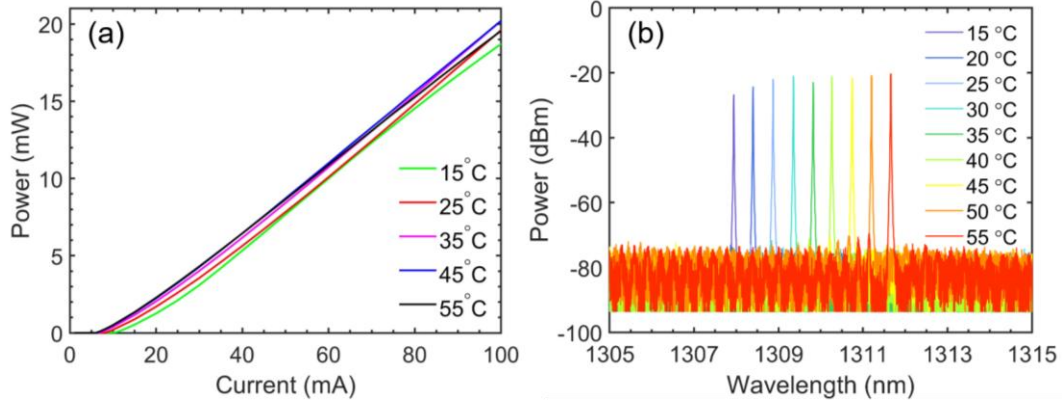


Figure 1 (a) Power-current characteristics with temperature ranging from 15°C to 55°C and (b) Optical spectra of the QD DFB laser from 15°C to 55°C ($2 \times I_{th}$).

The QD DFB laser under study was grown on a GaAs substrate. The active region contains eight periods of QD layers, each separated by p-type GaAs spacer. The cavity length of the DFB laser is 0.75 mm. The cavity facets are asymmetric, with an antireflection (AR) coating of reflectivity about 3% in the front and a high-reflection (HR) coating of reflectivity about 95% in the rear, respectively. InAs QD layers were grown on GaAs and covered by GaAs. Then top GaAs layer was processed to form grating for distributed feedback. [9] Figure 1 (a) depicts the power current characteristics at different temperature from 15 to 55 °C. The threshold current decreases as the temperature increases hence showing a strong temperature stability. The optical spectra at different temperature are shown in Figure 1 (b). The wavelength mismatch between the DFB lasing wavelength and the gain peak is about 30 nm at 15 °C. In addition, the optical spectra show the consistent side-mode suppression ratio (SMSR) of over 50 dB over the full temperature range of 15 °C to 55 °C. These results confirm that wavelength mismatching is an effective method to design uncooled single-frequency sources.

3 Linewidth measurement

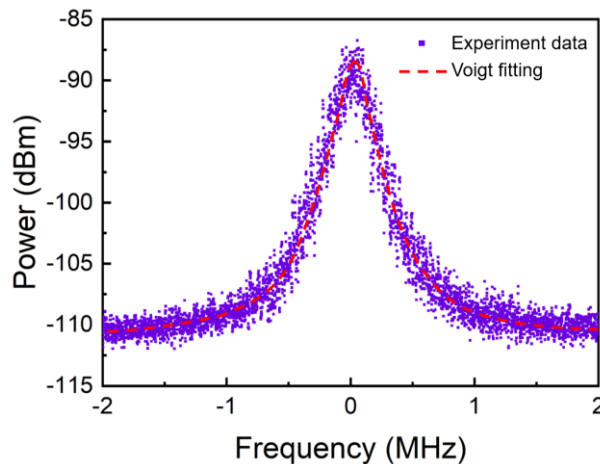


Figure 2 RF spectrum of QD DFB laser recorded at 55°C ($2 \times I_{th}$) and the corresponding Voigt fitted spectrum.

The self-heterodyne interferometric apparatus was used to measure the spectral linewidth. The light from the QD DFB laser passes through two optical isolators and part of the signal is sent to a 100 MHz frequency-shifted acousto-optic modulator (AOM), while the other part travels through a 25 km fibre optic coil. This relatively long fibre length provides a time delay that is more than adequate for the coherence time of the laser. Then, the light from the two channels was combined and fed into the polarisation controller for matching the polarisation in the two arms. At the output of the interferometer, the resulting beat centred on the AOM frequency is recorded with a photodiode (PD) and sent to an electrical spectrum analyser (ESA). Figure 2 displays the RF spectrum recorded at 55°C ($2 \times I_{\text{th}}$). The full width at half maximum extracted from the Voigt profile (red) leads to a minimum linewidth of 251 kHz. The narrow linewidth at high temperatures proves that this QD DFB laser is highly temperature tolerant. It is expected to have high performance high temperature transmission characteristics.

4 Modulation experiments

To investigate the modulation performance of the QD DFB laser at high temperatures, we performed pulse amplitude modulation experiments on it at 55°C . Besides, the reflection sensitivity was considered in the direct modulation system. Figure 3 represents the set-up for direct modulation with optical feedback. The QD laser is directly modulated by the digital generator with a pseudo-random binary sequence (PRBS) and a bit sequence length of 2^7-1 and the applied modulation format is Pulse Amplitude Modulation 4-level (PAM4) as shown in light blue part. The emission is divided into two paths, the feedback path (orange part) and the output path (green part). On the feedback path, 90% coupled power is sent to the back-reflector (BKR) that consists of a mirror and a variable optical attenuator (VOA). The latter is used to change the feedback strength, which is defined as the ratio of returned power to the free-space output power. The other 10% of the coupled power is isolated and then amplified by a semiconductor optical amplifier (SOA). At the end, a variable optical attenuator (VOA) is used to tune the received power of the error detector in order to analyse the bit error rate (BER) performance. A high-speed oscilloscope (OSC) is used to capture the eye diagram. The PD converts the optical signal into an electrical signal before entering BER tester or OSC.

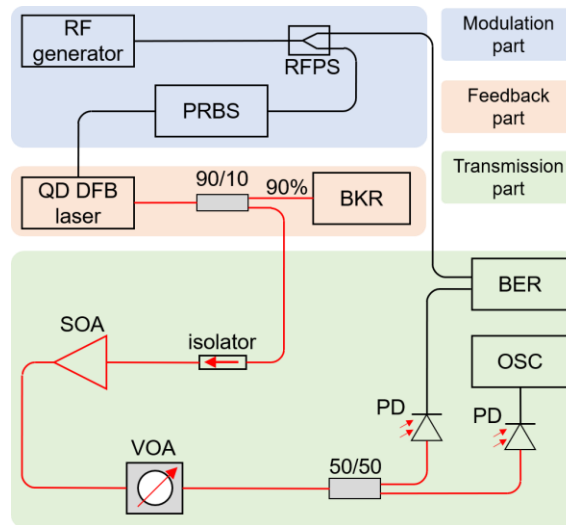


Figure 3 Schematic of the experimental setup. Light blue part: modulation set-up, orange part: feedback set-up, green part: transmission set-up. The black lines show the electrical circuit and the red lines show the light path.

High-speed response of the QD laser is carried out at $6 \times I_{\text{th}}$ and the modulation rate is 6 Gbps. The emission from the QD laser is divided into two paths, the feedback path and the output path. In the feedback path, 90% of the coupled power is sent to a back-reflector (BKR). In the output path, the light is finally introduced to the bit error rate (BER) instrument. The BERs of the QD laser with and without feedback after back-to-back (B2B) are plotted in Figure 4. It can be found that the BER can reach below 10^{-7} with no feedback and -15 dB feedback strength (I_F). When the feedback strength is increased to -12 dB, the BER is minimally close to 10^{-4} . The BER is below the hard decision forward error correction (HD-FEC) 5×10^{-3} at received power greater than -5 dBm. When the feedback strength increases to -5 dB, such large feedback has a very strong impact on the BER,

making it drift around the HD-FEC. In fact, there is not quite so much feedback in short distance data transmission, so the actual BER will meet the HD-FEC requirements at the modulation rate of 6 Gbps. So, the QD DFB laser retains its excellent transmission characteristics at the temperature of 55 °C.

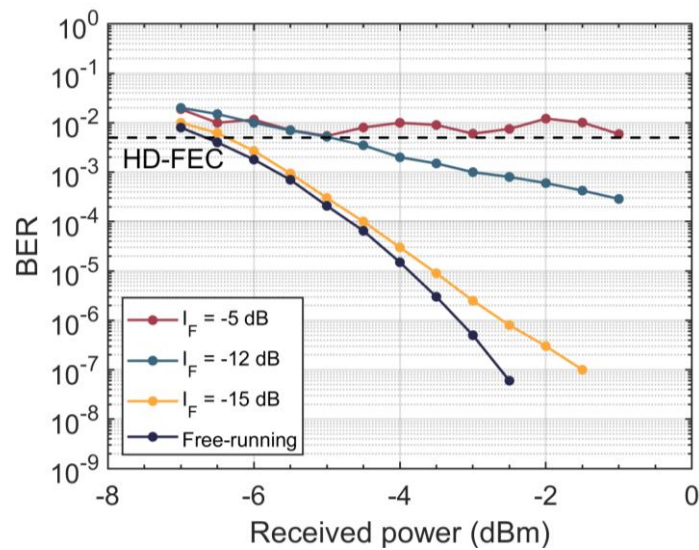


Figure 4 BER plots for back-to-back (B2B) with and without feedback for the QD laser at 55 °C and $6 \times I_{th}$. The modulation rate is 6 Gbps.

5 Conclusion

We demonstrated high temperature stable and low linewidth quantum dot DFB lasers and performed pulse amplitude modulation experiments with and without different feedback conditions. The QD laser was able to modulate at the rate of 6 Gbps at 55 °C and could tolerate strong feedback. Such results facilitate the development of uncooled silicon photonic chips for short distance communication links.

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