White Paper

Quantum dot laser

QD Laser, Inc.

1. Introduction

Semiconductor lasers in a wavelength range around 1310 nm, which are widely used as light sources for intra- and inter-data center optical communications, support evolution of the Internet and SNS. In recent years, it has also been introduced as a light source for silicon photonic circuits called silicon photonics, which is compact and capable of high-speed operation. In addition, a new application of silicon photonics “LiDAR” (Light Detection And Ranging) is emerging to realize autonomous driving and advanced robotics.

The requirements for semiconductor lasers for these applications are high reliability in high temperature environments and high tolerance against external optical feedback. We are developing and manufacturing quantum dot lasers that can meet these demands (Fig. 1). This article introduces the features of our quantum dot lasers.

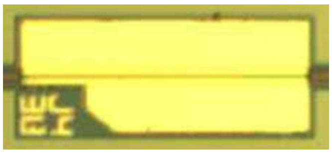

Fig. 1. Quantum dot laser

2. Feature of quantum dot laser

Quantum dot lasers are manufactured using the Molecular Beam Epitaxy (MBE) method. The MBE method is an epitaxial growth technique of crystals on a substrate in a growth chamber under ultra-high vacuum by evaporating elements from cells. We have realized high performance quantum dot lasers by deepening our understanding of crystal growth physics through many years of research and development.

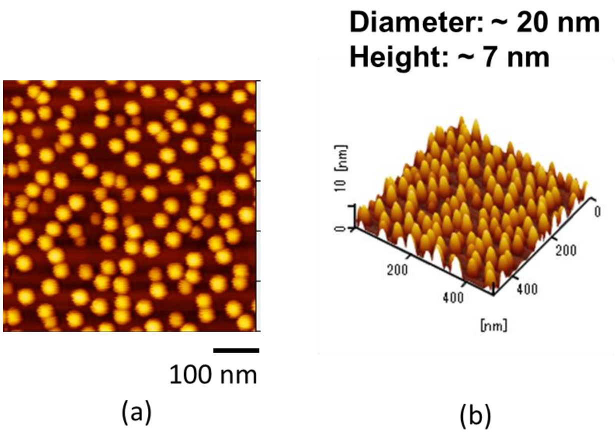

Fig. 2. Atomic force microscope image of InAs quantum dots on GaAs substrate: (a) top view, (b) bird’s eye view

The features of our quantum dot laser are (1) stable operation and high reliability in high temperature environment, and (2) excellent optical feedback tolerance.

The features of each are explained below.

(1) Stable operation and high reliability in high temperature environment

A major feature of silicon photonics is that it enables a compact and low-cost optical transmitter / receiver by utilizing the CMOS process. If the light emitted from a semiconductor laser is directly coupled to a silicon photonic circuit without using a lens, the optical coupling loss will increase, but the cost can be further reduced by reducing the number of components, and the package can be more compact. Therefore, one of major requirements for a semiconductor laser is high output power to compensate the optical loss.

Figure 3 shows the typical light-current characteristics of a quantum dot DFB (Distributed Feed Back) laser. High optical output power of 90 mW at 25°C and 40 mW at 85°C is obtained. Figure 4 shows the lasing spectrum at 85°C. The submode suppression ratio, which is an index showing the stability of the optical output power, is larger than 50 dB. This indicates the quantum dot DFB laser operates with low noise at high temperatures.

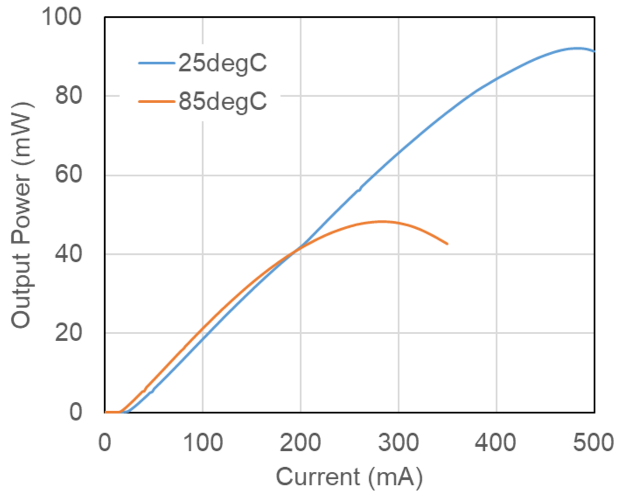

Fig. 3. Light-current characteristics of quantum dot DFB laser

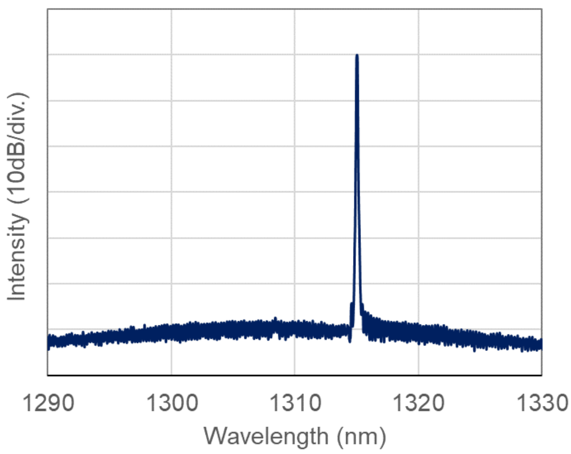

Fig. 4. Lasing spectrum at 85℃

Figure 5 shows the results of the reliability test. MTTFs (Mean Time To Failure) at 85°C and 95°C are estimated to be 280,000hours and 112,000hours, respectively, that is sufficiently reliable for practical use. When dislocation is generated in an active layer of a “quantum well” laser due to stress by current or light during operation, the dislocation propagates in the continuous active layer plane, resulting in rapid degradation. On the other hand, in the case of a “quantum dot” laser, each quantum dot is spatially separated and the dislocation does not propagate to the surroundings, so it is considered to be highly reliable.

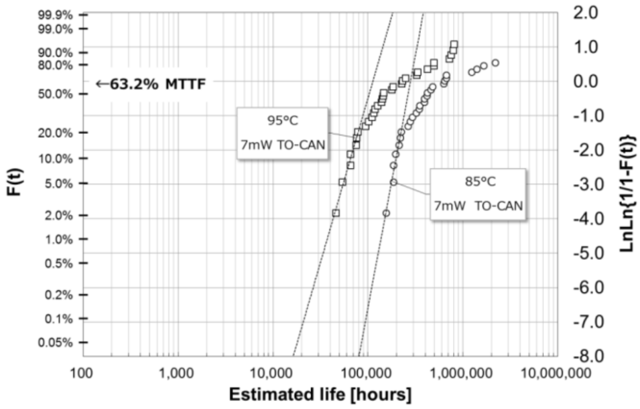

Fig. 5. Weibull reliability plot

(2) Excellent optical feedback tolerance

When a quantum well laser is used for optical fiber communication, the light reflected and returned at the connection point of the optical fiber makes the light intensity inside the laser unstable and may increase noise. To solve this issue, an optical isolator is placed between the laser and the optical fiber, but in silicon photonics, a light source that does not require an isolator is desired in order to reduce the number of components and assembly costs.

Figure 6 shows the measurement results of optical feedback tolerance [1]. The vertical axis shows RIN (Relative Intensity Noise), which means that the noise of the light source increases toward the top of the graph. Optical feedback noise of quantum dot lasers is superior to quantum well lasers even when the optical feedback increases. This result indicates quantum dot lasers have excellent optical feedback tolerance, it is expected to realize silicon photonics that do not require an optical isolator.

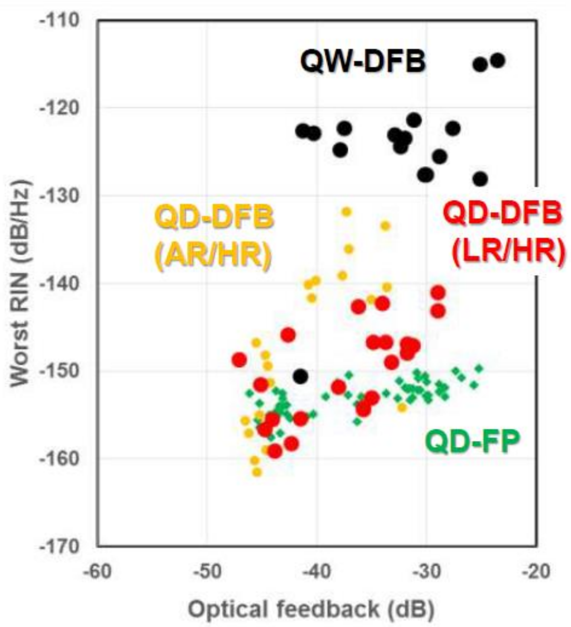

Fig. 6. Optical feedback vs. RIN.
QW-DFB: Quantum well DFB laser,
QD-DFB: Quantum dot DFB laser,
QD-FP: Quantum dot Fabry-Perot laser

3. Applications

3-1. Optical interconnect

Silicon photonics applied to data centers are becoming multi-channel and faster to increase the transmission capacity. It is expected that electrical communications between circuit boards and ICs will be replaced by optical interconnects. In order to achieve this, it is necessary to place the semiconductor laser close to the IC that generates heat, so the quantum dot lasers with high reliability at high temperatures are suitable for this application. In addition, quantum dot lasers have excellent optical feedback tolerance, which makes it possible to create ultra-thin optical modules that eliminate isolators and optical lenses (Fig. 7).

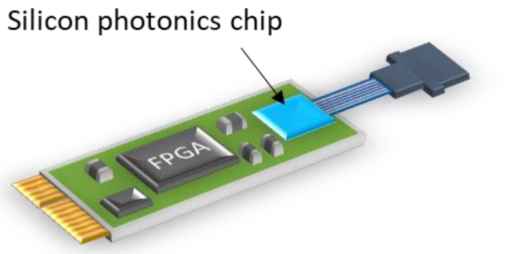

Fig. 7. Ultra-thin optical module

In order to increase the transmission capacity, a combination of high-density laser array and parallel optical waveguide is attractive. A problem that the laser elements are arranged close to each other is the heat generated by the laser raises the temperature of the entire element, resulting in reduction in optical output power. Since the quantum dot laser operates stably even in these high temperature environments, it is possible to suppress the decrease in optical output power of the high-density laser array.

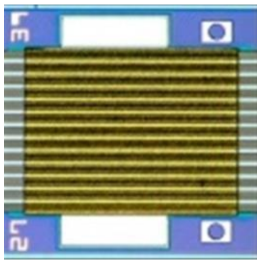

Fig. 8. High-density quantum dot laser array

3-2. LiDAR

LiDAR is a technology that detects the distance and speed of an object by irradiating the outside with pulsed light or continuous light and measuring the intensity and phase of the reflected light from the object with a photo detector. In order to apply it to highly automated driving and robotics, it is desired to improve the performance and reduce the size of LiDAR. Also, it is necessary to bring the detector and the light source close to each other or integrate them. However, when light is incident on the quantum well laser from the outside, the optical output power of the laser becomes unstable, the signal-to-noise ratio deteriorates, and the detection sensitivity decreases. To solve this issue, it is necessary to install optical lenses and an optical isolator in front of the laser light source, which increases the cost of components and assembly. Since quantum dot lasers have excellent optical feedback tolerance, it is expected that lenses and isolators will not be required in front of the laser. Also, in the case of LiDAR for autonomous driving, operation in a high temperature environment is required, so the features of quantum dot lasers with excellent environmental resistance can be utilized.

4. Summary

We introduced the quantum dot laser of QD Laser, Inc. The high reliability of quantum dot lasers in high temperature environments and the robustness against external optical feedback are suitable for light sources of silicon photonics, and contribute to the creation of customers' unique products.

Reference

[1] K. Mizutani, et al., "Isolator free optical I/O core transmitter by using quantum dot laser", proc. 2015 IEEE 12th International Conference on Group IV Photonics (GFP), pp.177-178, 2015.