InGaN Self-Assembled Quantum Dot Laser

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Overview

- QD Lasers
  - Advantages and Challenges
  - QD Emission
- Methods of Growth
  - MBE Stranski-Krastanow Growth Mode
  - Two-Flow MOCVD
- Results
- Commercial Application

Quantum Dot Laser [1]

Advantages

- Lower threshold voltages
- Narrower emission spectra
- Less-temperature dependent

Challenges

- Broad distribution of QD size
- Low density of QD

QD Emission [1]

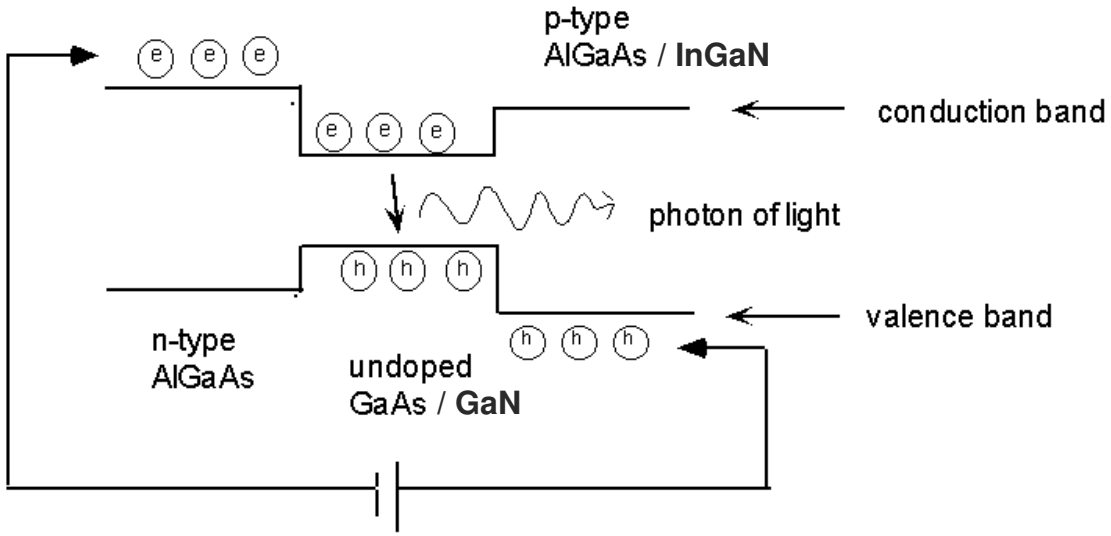


Figure taken from: http://www.wtec.org/loyola/nano/fh05_16.gif

- Electron hole recombination occurs in the confined quantum well
- A photon of light is emitted as a result. Varying dot size and composition can change the wavelength observed.

Growth Methods [2]

- Stranski-Krastanow Growth Mode – GaN dots on AlN layer using MBE
  - High temp (800 ˚C) results in higher crystalline quality, but lower InN concentration
- Two-Flow MOCVD
  - Lower growth temp (500 ˚C) increase InN concentration but lower crystalline quality

Stranski Krastonow Growth Mode [3]

- S-K MBE – QD form from strain induced island formation due to mismatch of crystal lattice

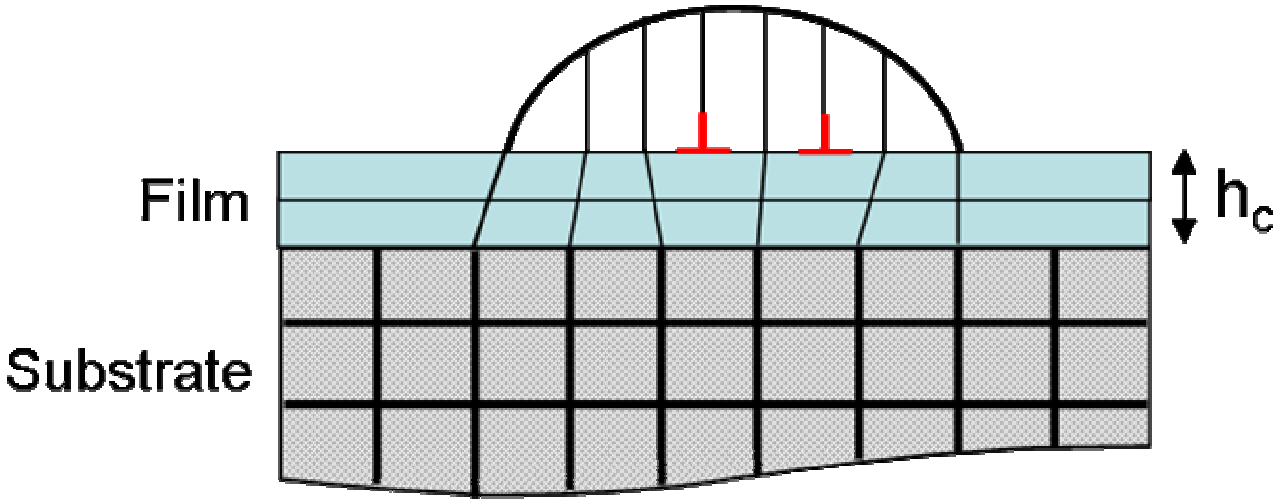


Figure taken from: http://upload.wikimedia.org/wikipedia/en/b/bd/DislocatedIsland.png

Two-Flow Atmospheric MOCVD [4]

- Main flow of TMG, TMA, TMI, NH_3, H_2: reactant gas
- Subflow of N_2, H_2: brings reactant gas into contact with substrate

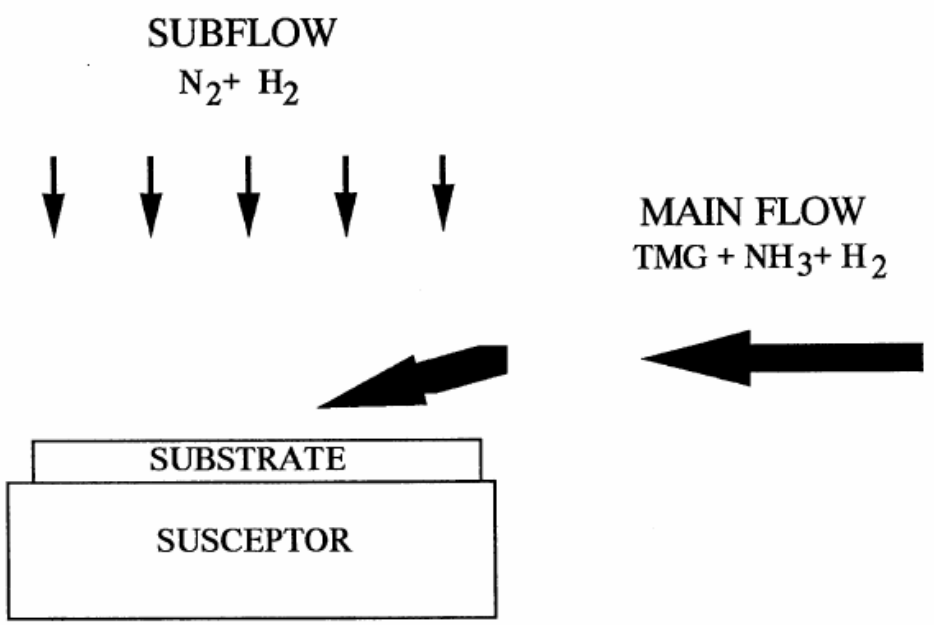
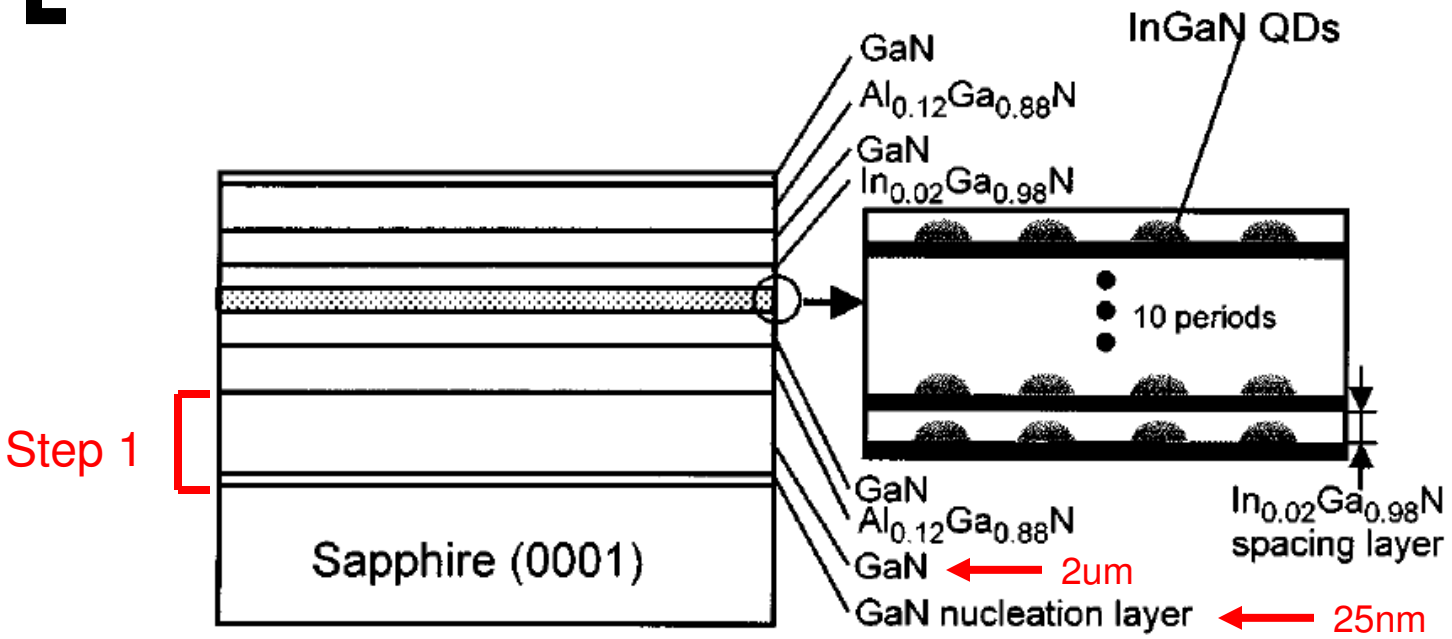


Fig. 2. Schematic principle figure of two-flow MOCVD.

Figure taken from: [4]

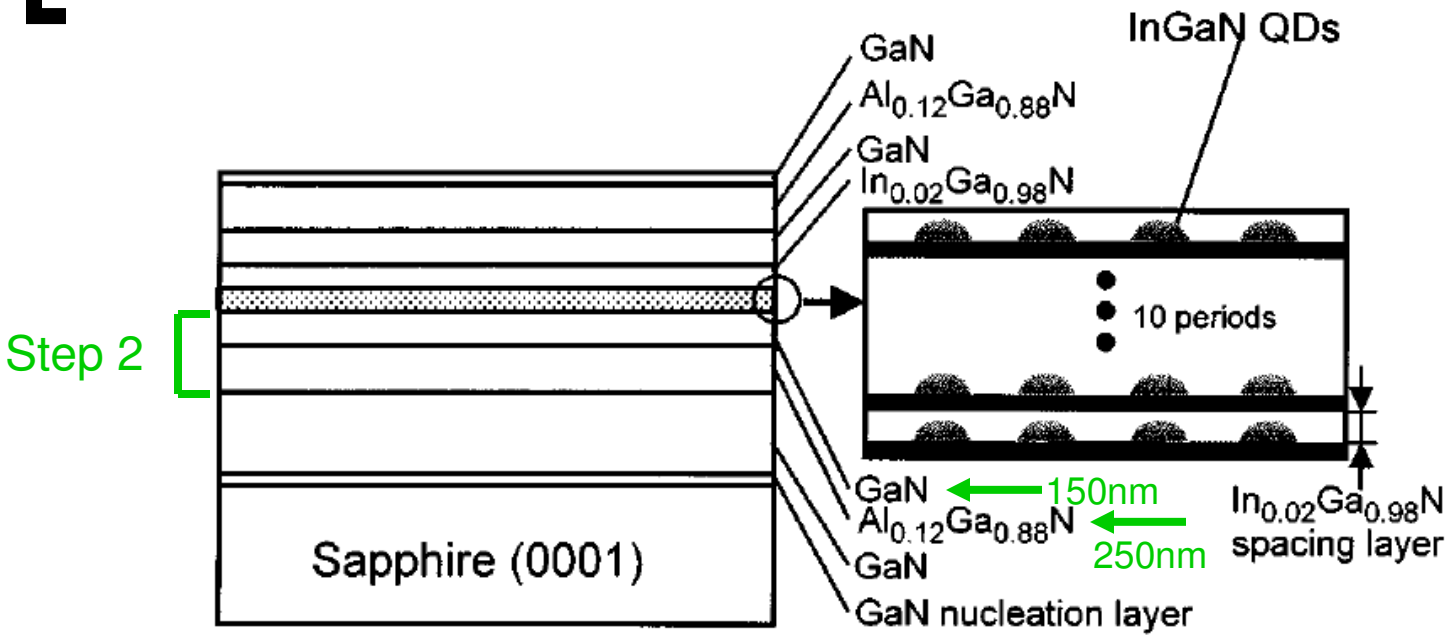
Growth Step 1-GaN Growth [5]



Schematic of stacked QD laser structure [5]

- 25 nm GaN nucleation layer grown at 500 ˚C
- 2um GaN layer grown at 1075 ˚C
- Buffer layer makes the 2um GaN layer surface smooth. Without the buffer layer, island growths are observed. [4]

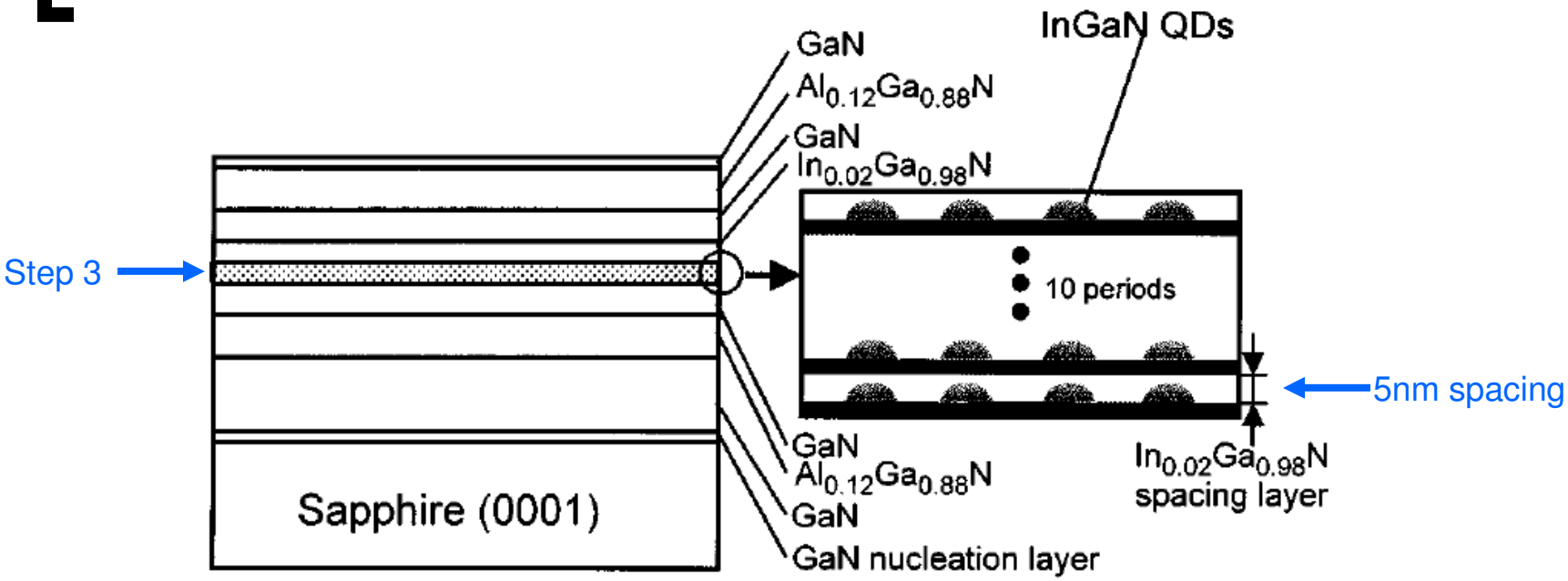
Growth Step 2-Cladding [7]



Schematic of stacked QD laser structure [5]

- 250nm $Al_{0.07}Ga_{0.93}N$ grown at 1092 ˚C
- 150nm GaN grown at 1092 ˚C

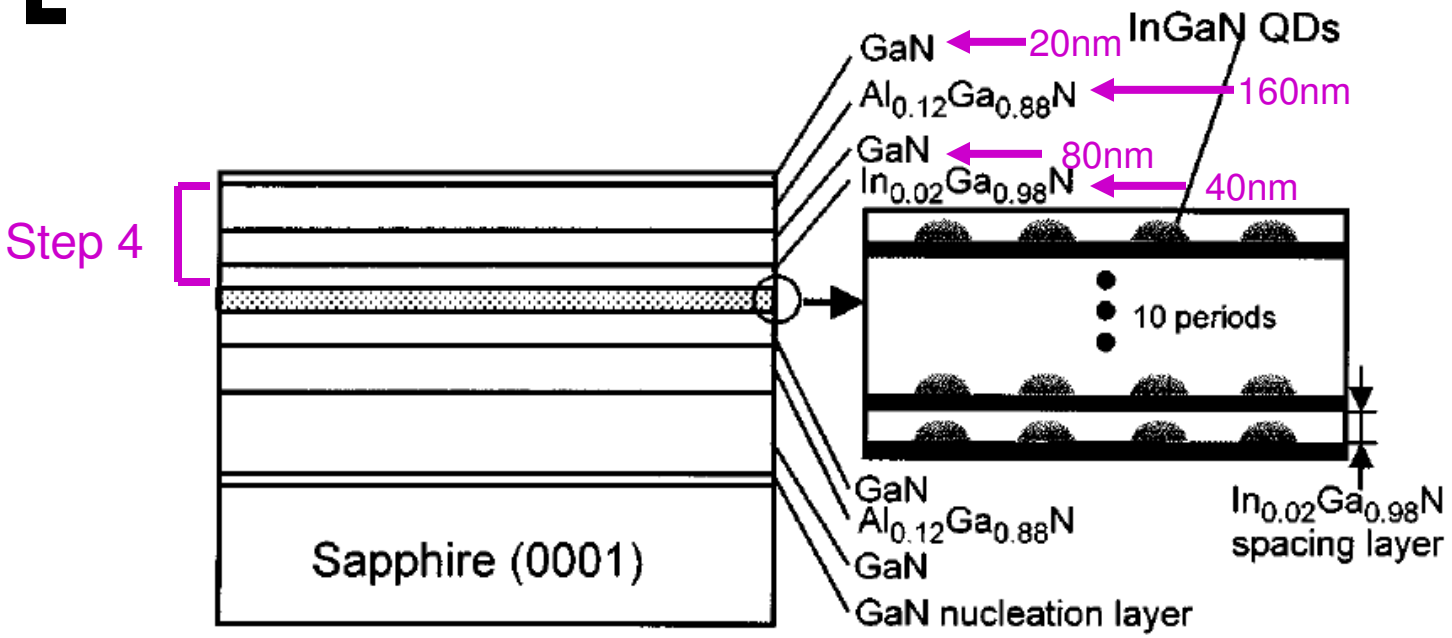
Growth Step 3-Vertically Stacked QD [5]



Schematic of stacked QD laser structure [5]

- InGaN QD layer grown at 740 ˚C.
- InGaN QD formed for wide range of coverage, indicating phase separation as cause for QD
- 5nm $In_{0.02}Ga_{0.98}N$ grown at 740˚C to recover smooth surface, allowing 10 multilayer dot structure [6]

Growth Step 4-Cladding [7]

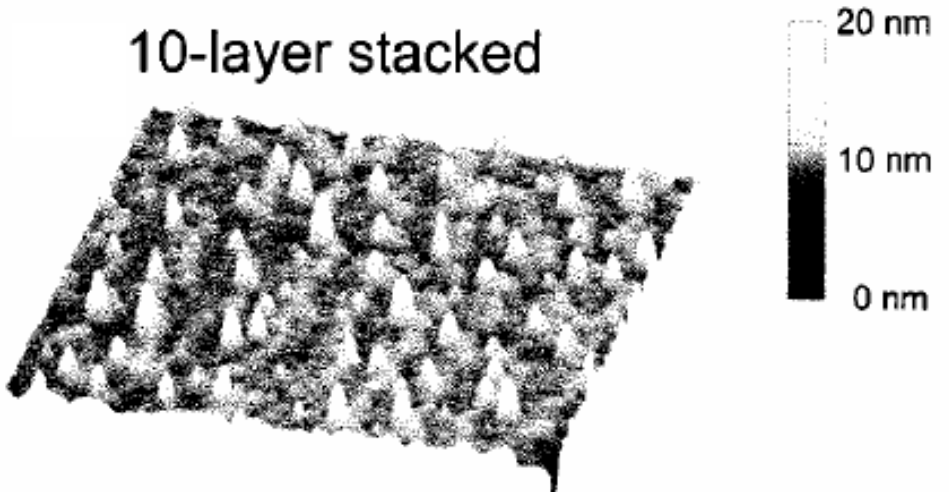


Schematic of stacked QD laser structure [5]

- 40nm $In_{0.02}Ga_{0.98}N$ at 770 ˚C
- 80nm GaN at 1075 ˚C
- 160nm $Al_{0.07}Ga_{0.93}N$ and 20nm GaN at 1092 ˚C

Results [5]

- InGaN coverage of 11.6ML
- Average diameter and height of 19.5 and 4.5nm
- QD density of $6 \times 10^{9} cm^{-2}$ per layer

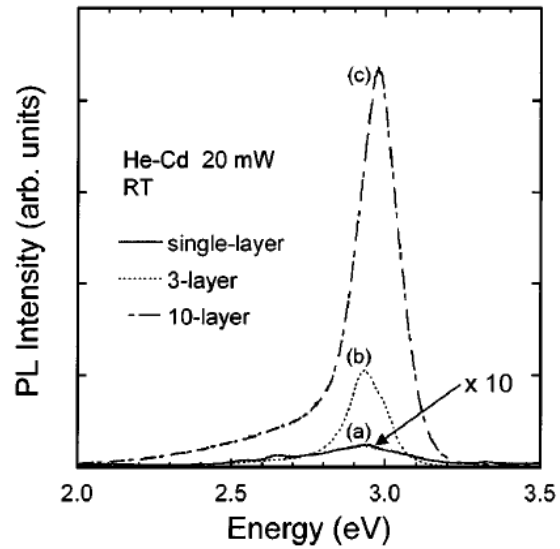


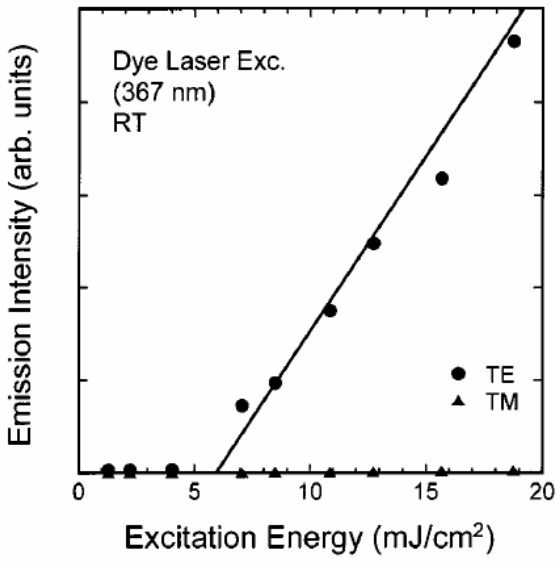
AFM image of 10-layer stacked InGaN QD [5]

Results [5]

- Photoluminescence of 10-layer QD structure is 180 times the single structure

- Threshold energy of 6mJ/cm^2 is observed at room temperature





[5]

Commercial Application [8]

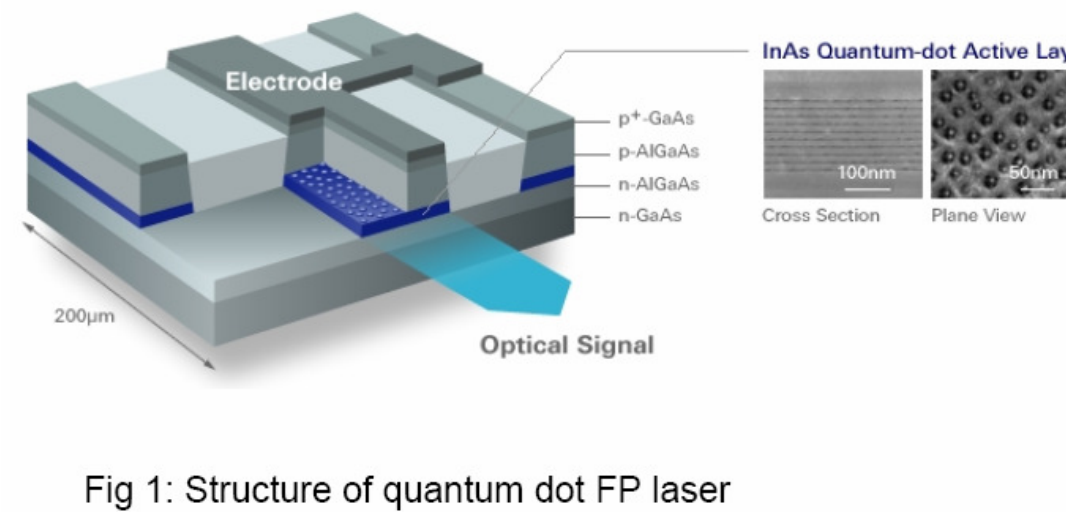
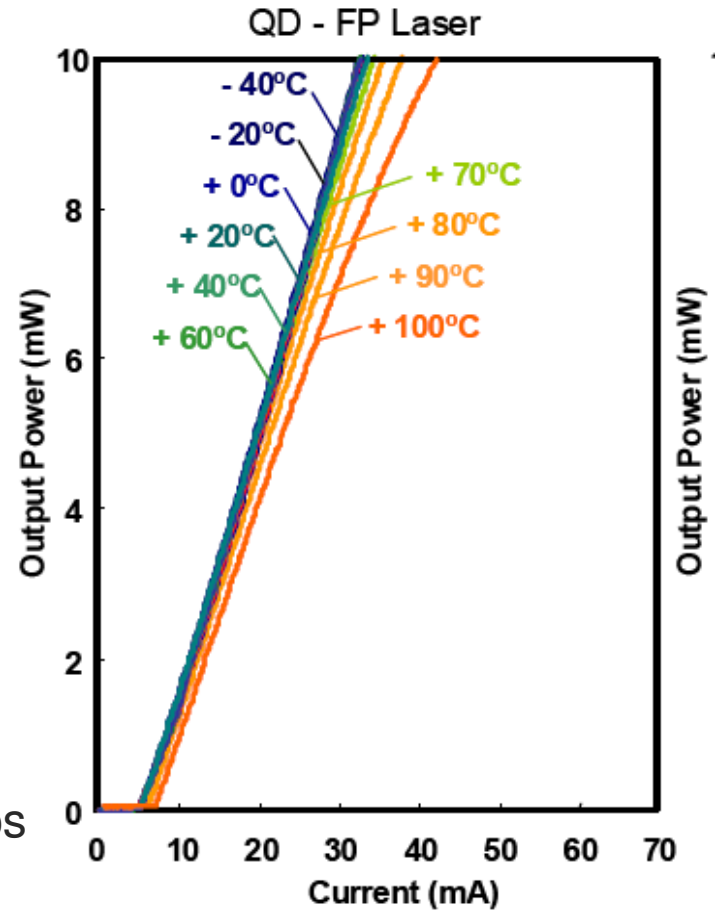


Fig 1: Structure of quantum dot FP laser



Optical telecom module with small form factor, lower power consumption at 1310nm/1.25-10 Gbps speed, and operational temperature insensitivity from -40 to 100 ˚C

http://www.qdlaser.com/20080225_PR_eng.pdf

References

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[5] K. Tachibana, T. Someya, Y. Arakawa, *IEEE J. of Selected Topics in Quantum Electronics*, vol. 6, No. 3, May/June 2000

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[7] K. Tachubana, T. Someya, Y. Arakawa, R. Werner, and A. Forchel, *Appl. Phys. Lett.*, vol. 75, pp. 2605-2607, 1999.

[8] "QD Laser Inc. Unveils Quantum Dot Lasers Featuring Temperature Insensitivity Operational from - 40 to 100 ℃ for Optical Telecom Applications", *QD Laser*, Tokyo, Japan, 28 Feb 2008