Extended Abstracts of the 2017 International Conference on Solid State Devices and Materials, Sendai, 2017, pp857-858

PS-7-05

Design THz Quantum Cascade Lasers Toward High Output Power Near Liquid Nitrogen Temperature Operation

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Abstract

For utilization of the real THz applications by semiconductor base QCLs, the performances balance of their output power and operation temperature are required for the recent devices. Here we demonstrate our fabricated THz QCLs toward high output power with liquid nitrogen Dewar condenser to approach the sub mW order average output power relative compact size portable THz source unit.

1. Introduction

THz quantum cascade lasers (QCLs) [1,2] are promising high output power semiconductor THz sources to over Watt [3] order peak power with narrow bandwidth. Based on the long time bottom neck of limited operation temperature below 200 K [4], it is still quite limited to the compact size THz applications which caused by the large cooling system and low duty cycle with low power. On the other hand, output power is one of the most critical parameters for real THz applications. Here we are trying to achieve a balance between operation temperature and high output power. We demonstrate one our fabricated high temperature operation QCLs devices combined with the 77 K liquid nitrogen Dewar condenser as a compromised compact portable THz source unit. They showed a few mW peak power with few ten µW average power operation. Analysis of the temperature operation of design by Non-Equilibrium Green's Function (NEGF) method is discussed. Further improvement of the active region, waveguide, and will be discussed device fabrication toward high operation temperature THz QCLs to larger power operation in order to exhibit the best performance of the compact 77 K Dewar system. Our latest THz QCLs recently delivered 250 mW peak power and 2.2 mW average power at 10 K, and gave the 10 mW peak power with 0.1 mW average power at 78 K.

2. Method and Results

Here we introduce a Dewar condenser cooling system with our recent fabricated metal-metal waveguide (MMW) variable height active structure THz QCLs with the premier a few µW average power and mW order peak power. *Fig.* 1 shows the diagram and photographs of our recent high temperature operation MMW variable height active structure design THz QCLs [5] and the liquid nitrogen Dewar construction with an inside focusing parabolic mirror and hemisphere Si lens. They demonstrated a maximum peak output power 3.1 mW and average output power 6.2 µW from this liquid nitrogen Dewar construction. The QCLs samples are combined with hyperhemispherical Si lens in front of operated mesa and an adjustable inside parabolic mirror in order to focus the output of THz QCLs and give the near collimated THz wave outside the measurement Tsurupica windows from the widely diverged MMW QCLs.

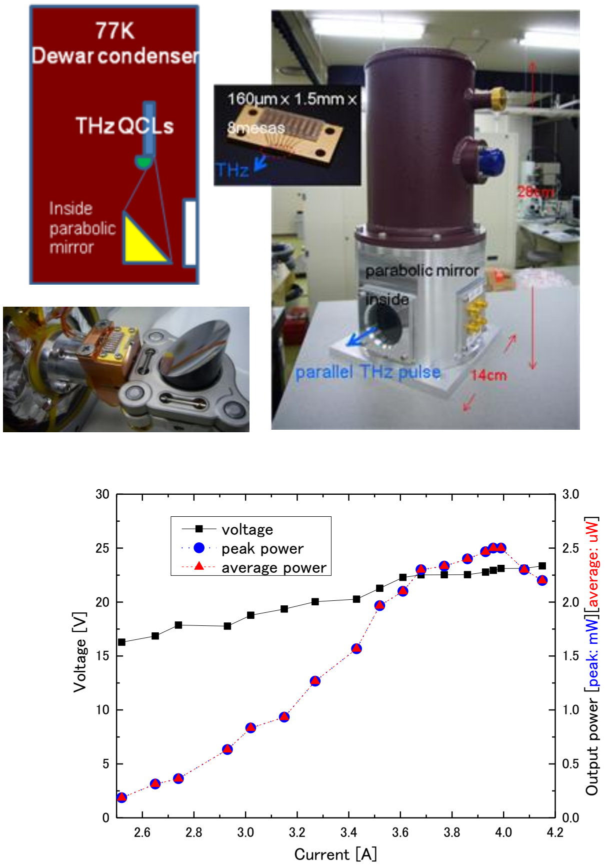
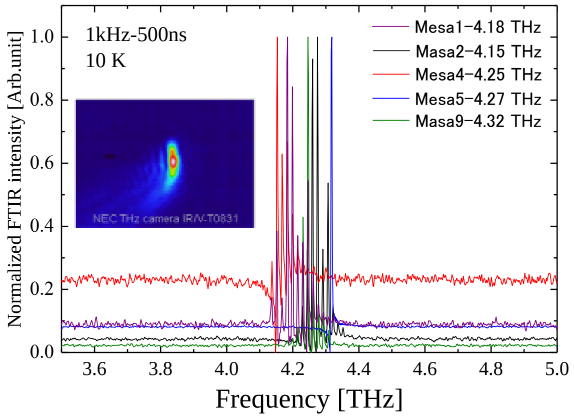


Fig. 1 Photographs of Dewar condenser with typical L-I-V curves.

Based on the results, we further improved the devices toward larger output operation by using an active region design with larger injection and more vertical optical emission and by adopting a semi-insulated surface plasma (SI-SP) waveguide with longer cavity length in order to get better far field patterns and lager output power. We achieved the maximum peak power of 250 mW and average power of 2.2 mW at 10 K, with regular mesa size of ridge width 200 µm and cavity length 2 mm (*Fig.* 2). But at 78 K, this device output 10 mW peak power and 0.1 mW average power with duty cycle 0.1%. The output power decreased more than our expectation. The temperature performance of this design was simulated by Non-Equilibrium Green's Function (NEGF) method. The reduction of optical gain is consistent with experimental results. The large optical gain structure at low temperate results in increased leakage pass at elevated temperature and rapidly reduce the output power.



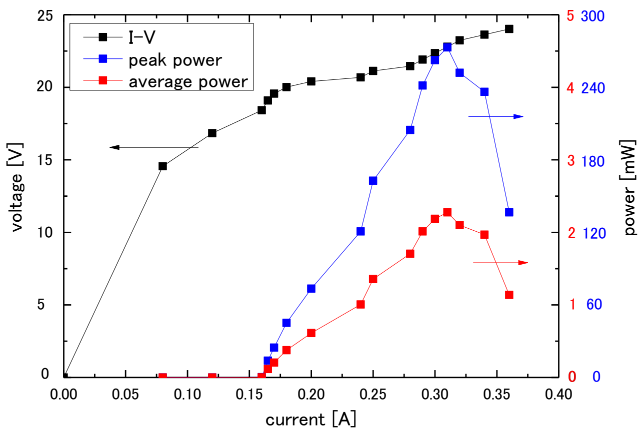


Fig. 2 Laing spectrum, THz camera image, and one typical L-I-V curves of our recently large output THz QCLs at 10 K operation.

3. Conclusions

Here we demonstrate our previous fabricated high temperature operation THz QCLs devices combined with the 77 K liquid nitrogen Dewar condenser as a compromised compact portable THz source unit. Then further improve the devices toward larger output operation and achieved the peak output power 250 mW and average power 2.2 mW at 10 K. And the 10 mW peak power with 0.1 mW average power at 78 K. The following works are considering the optimization of the required output power and temperature operation at the same time from both active region and waveguide design with larger mesa size and duty cycle operation; to toward the liquid nitrogen temperature operation with mW order average power.

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