様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科学研究費助成事業　　研究成果報告書

令和　３ 年　 ６ 月　 ８ 日現在

機関番号：８２４０１
研究種目：若手研究
研究期間：2019～2020
課題番号：１９Ｋ１５０５２

研究課題名（和文）Development of low-frequency terahertz quantum cascade lasers for high-speed wireless communications applications

研究課題名（英文）Development of low-frequency terahertz quantum cascade lasers for high-speed wireless communications applications

研究代表者

王　利（WANG, LI）

国立研究開発法人理化学研究所・光量子工学研究センター・研究員

研究者番号：５０８０４０３５

交付決定額（研究期間全体）：（直接経費）　　3,200,000円

研究成果の概要（和文）：1.非平衡グリーン関数に基づく完全理論量子輸送をシミュレーションプラットフォームとしてパッケージ化し、テラヘルツ量子カスケードレーザの量子輸送を予測 2.1200層の積層GaAs/Al0.2Ga0.8As量子井戸の改良技術最新のCu-Cu金属導波路加工を採用することで、185Kで1.8THzの発振を実現。

研究成果の学術的意義や社会的意義
Terahertz wave has many new applications in chemical and medical. This study is to develop a terahertz wave source based on quantum cascade laser using GaAs semiconductor quantum wells.

研究成果の概要（英文）：1.Full theory quantum transport based on non-equilibrium Green's function is packaged as a simulation platform, to predict the quantum transport in terahertz quantum cascade laser. 2.Improved technique in GaAs/Al0.2Ga0.8As quantum well with 1200 stacked layers is shown .By employing an latest Cu-Cu metals waveguide processing, the lasing of 1.8THz at 185K is achieved.

研究分野：quantum semiconductor

キーワード：THz-QCL

様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９（共通）

１．研究開始当初の背景

Low-frequency terahertz wave (*f*:0.5∽2THz; λ:600∽150μm) gains very strong interests because of its unique advantages in the wireless communications. Terahertz data links could increase data transfer 1000 times faster than the existing microwaves wireless technology (microwaves are what we use now for cellular and Wi-Fi). It will ultimatly beat out the upcoming 5G millimeter frequencies as the 5G cannot be able to cope due to the fast growth of the Internet of Things (IoT) in the very near future. However, until now, it still lacks the commercial viable technique to generate terahertz light to meet this requirement.

２．研究の目的

THz-QCLs has been treated as the most (even only) promising terahertz radiation sources at this low-frequency region. This device has realized the lasing frequency as low as 1.2*THz* in experiments since 2006, however, the operating temperature are still too low <110K. In general, the thermal-electric cooling temperature of 230*K* is considered as the critical point, at which the THz-QCLs device can work without heavy and big gas cooling system and this will extremely be benefit for coherent integrations in real applications. In this proposal, the main motivation is finding new device designs to lift up the operating temperature of low-frequency (<2THz) THz-QCLs in experiments.

３．研究の方法

By proposing a quantum transport model to describe the QCL and predict designs with high-optical gain at high-temperature. and then develops high-quality stacked quantum wells structures based on GaAs/AlGaAs semiconductors as the gain mediums. Finally, with reliable processing of waveguide fabrications, the lasing at high-temperature is expected.

４．研究成果

(1) Full theory quantum transport based on non-equilibrium Green's function is packaged as a simulation platform, to predict the quantum transport in terahertz quantum cascade laser. And the working mode in computing is with parallel. The optical gain of room-temperature operation is predicted by proposing a specific design, in which using GaAs/Al0.2Ga0.8As. Figure 1 shows the interface of the packages which shows spatial and energic mappings of quantum states, current density and also the optical gain at the active region. Figure 2 shows the design based on 3-well for low-frequency operation at 1-2THz, (b) shows the ministep concept proposed here to create clean levels. The corresponding optical gain at 300K is predicted more than the waveguide loss.

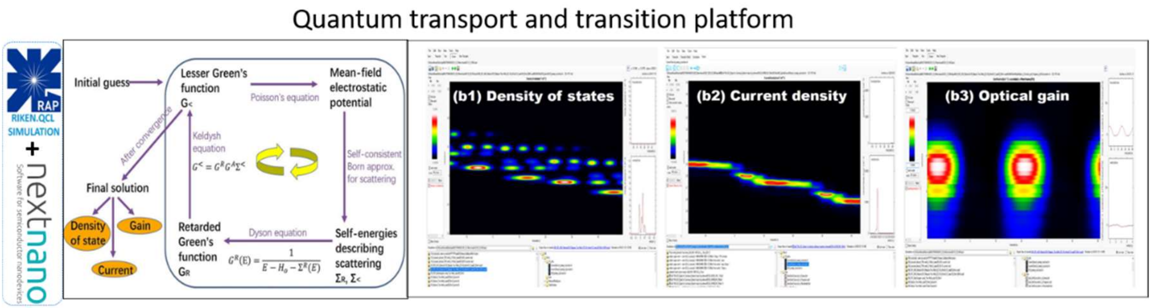

Fig.1　THz-QCL simulation package

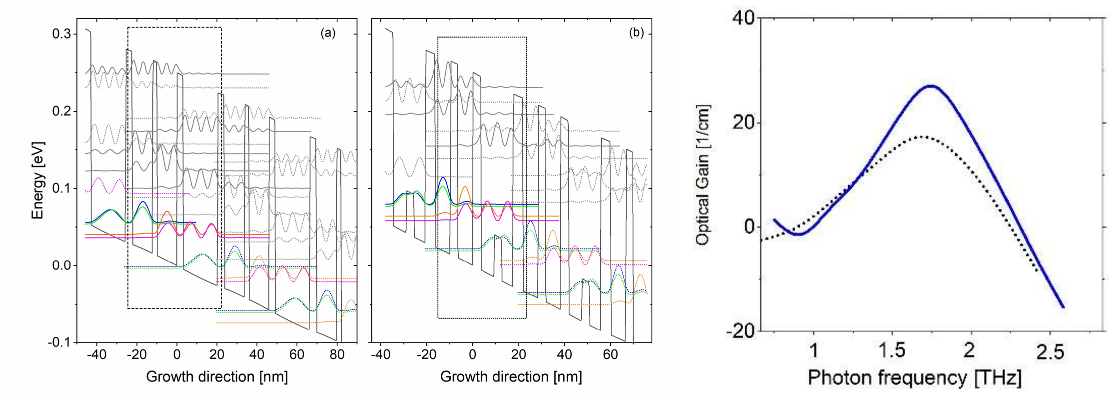

Fig.2 THz-QCL proposed and the optical gain

(2) Improved technique in GaAs/Al0.2Ga0.8As quantum well with 1200 stacked layers is shown, the thickness of each layer is well controlled within 1% fluctuation. And the Al% composition in barrier is within 5% deviation as expected.

(3) By employing a latest Cu-Cu metals waveguide processing, the lasing of 1.8THz at 185K is achieved, as shown in Fig. 3.

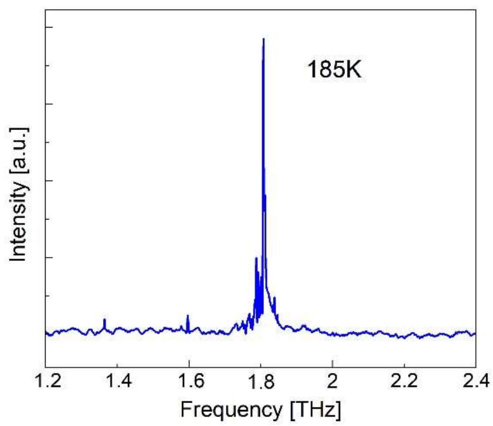

Fig. 3 The lasing spectrum of 1.8THz at 185K

５．主な発表論文等

〔雑誌論文〕　計2件（うち査読付論文　2件／うち国際共著　1件／うちオープンアクセス　2件）

１．著者名 Li Wang, tsung-tse Lin, Ke Wang, thomas Grange, stefan Birner & Hideki Hirayama	４．巻 9
２．論文標題 short-period scattering-assisted terahertz quantum cascade lasers operating at high temperatures	５．発行年 2019年
３．雑誌名 Scientific Reports	６．最初と最後の頁 9446 1-7
掲載論文のDOI（デジタルオブジェクト識別子） なし	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

１．著者名 Li Wang, Tsung-Tse Lin, Ke Wang, and Hideki Hirayama	４．巻 12
２．論文標題 Parasitic transport paths in two-well scattering-assisted terahertz quantum cascade lasers	５．発行年 2019年
３．雑誌名 Applied Physics Express	６．最初と最後の頁 082003 1-5
掲載論文のDOI（デジタルオブジェクト識別子） なし	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 －

〔学会発表〕　計2件（うち招待講演　0件／うち国際学会　1件）

１．発表者名 Li Wang, Tsung-Tse Lin, Ke Wang, and Hideki Hirayama
２．発表標題 Experimental and theoretical study of piezoelectric polarization in GaN/AlGaN terahertz quantum cascade lasers
３．学会等名 Infrared Terahertz quantum workshop (ITQW)（国際学会）
４．発表年 2019年

１．発表者名 Li Wang, Tsung-Tse Lin, Ke Wang, and Hideki Hirayama
２．発表標題 Near- and far-infrared quantum cascasde lasers based on GaAs and GaN materials: devices design and MBE growth
３．学会等名 電子デバイス研究会(ED)
４．発表年 2019年

〔図書〕　計0件

〔出願〕　計0件

〔取得〕　計1件

産業財産権の名称	発明者	権利者
量子カスケードレーザー素子	Li Wang, Hirayama	同左
産業財産権の種類、番号	**取得年**	**国内・外国の別**
特許、ＰＪＲＫ１９０１３	2020年	国内

〔その他〕

－

6．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

7．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計1件

国際研究集会	開催年
Infrared Terahertz quantum workshop (ITQW)	2019年～2019年

8．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関