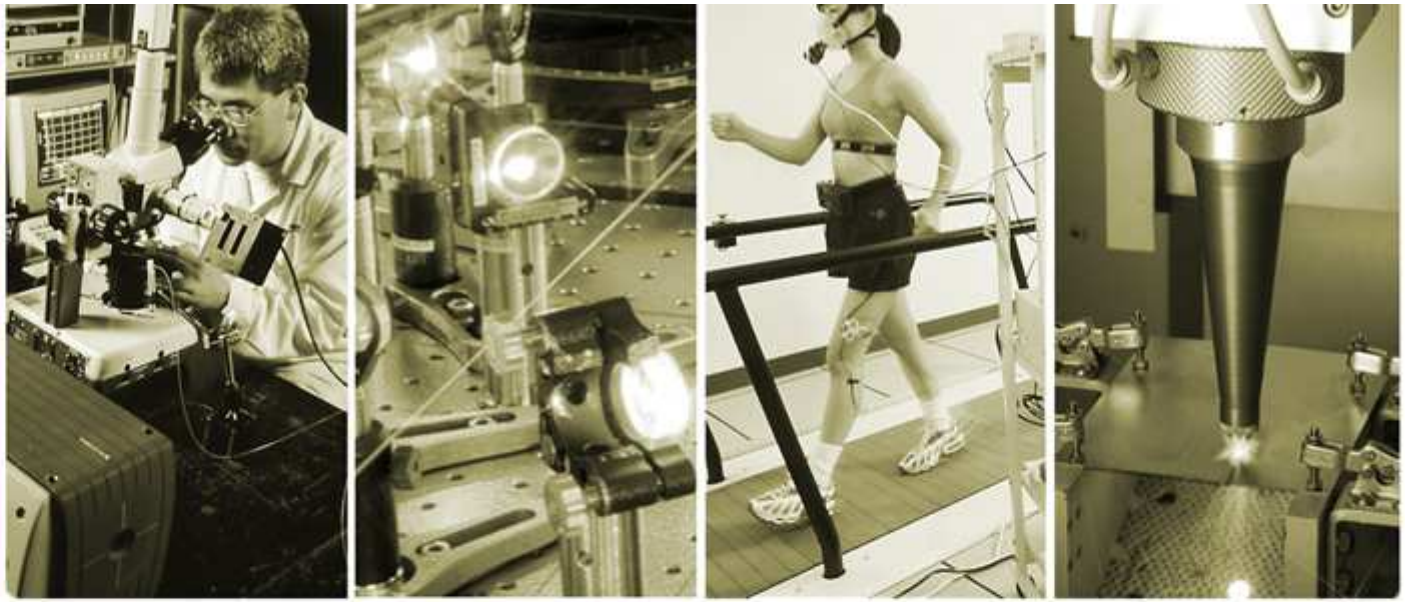


HAMAMATSU

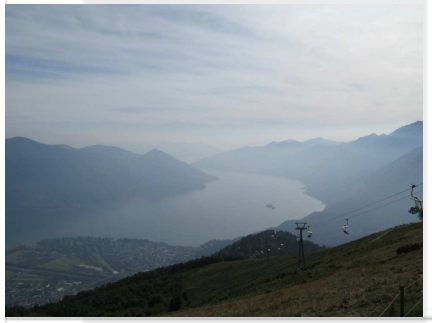
Quantum Cascade Lasers Development at HAMAMATSU, and Their Applications

- T.Edamura, N.Akikusa, A.Sugiyama, T.Ochiai, K.Fujita,

S.Furuta, A.Ito, M.Yamanishi, and H.Kan

HAMAMATSU Photonics

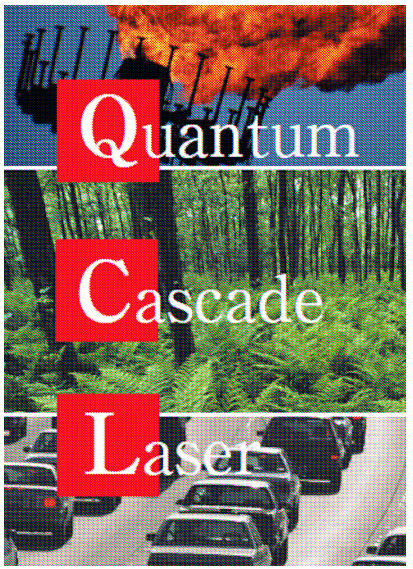
Central Research Laboratories, HAMAMATSU PHOTONICS

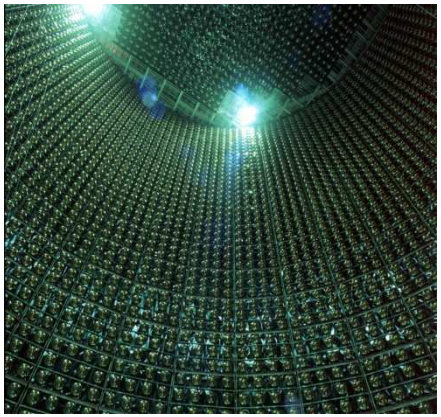


IQCLSW2008, Monte Verita, Sep./14-19/2008

Today's outline

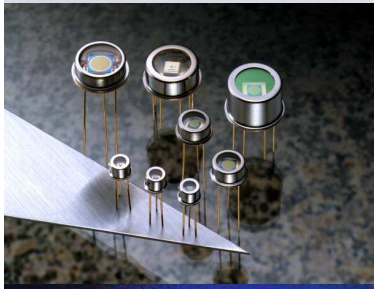
- Commercial QCL products
  - QCL selection guide
  - MOVPE growth
- Recent progress
  - SPC with simple ridge structure
  - Indirect-pump (IDP) scheme
  - Fiber out module
- Applications (Laser Absorption Spectroscopy)
  - Movie 1) pure N_2O, 2) exhaust gas(diesel engine) : NO
  - ambient air @Hamamatsu
- Summery





Super-KAMIOKANDE (20inch PMT)

Neutrino Cherenkov detector



Where is HAMAMATSU

Nagoya

Tokyo

Osaka

Hamamatsu

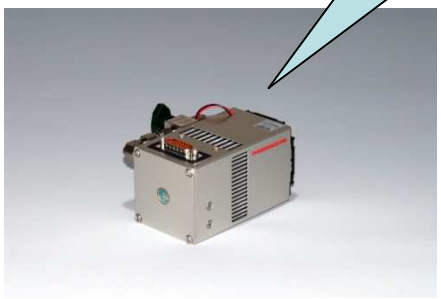
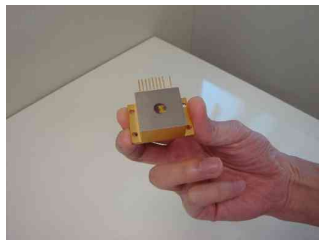
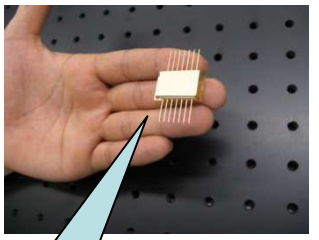
between Tokyo and Osaka

Our QCL History

QC laser chip → cryogenic temperature

start @2002

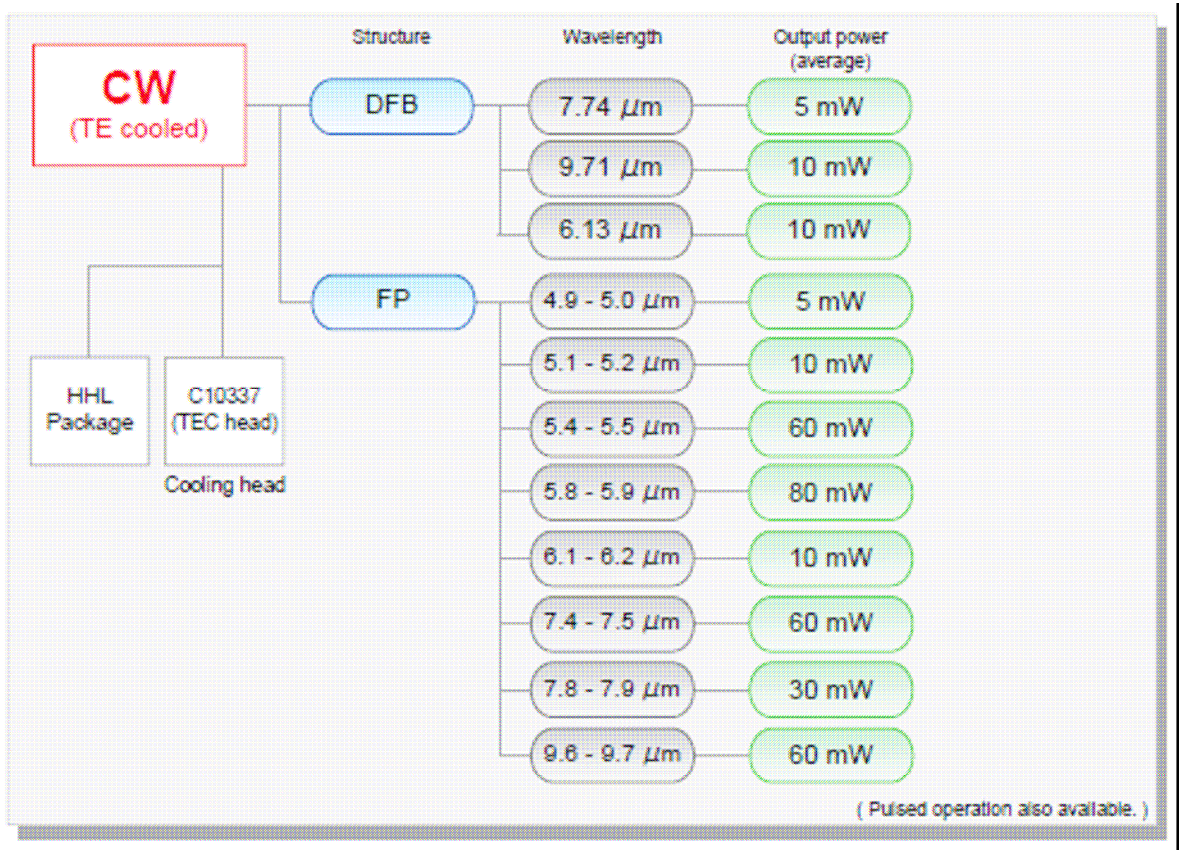
TE cooler type
Palm-top size

1st GEN	2nd GEN	3rd GEN	Next GEN
			
Metal-dewar 77K-pulsed, CW FP(multi-mode)	TE-cooled CW DFB(single-mode)	HHL package	Butterfly

Finger-top size !!

Commercial Products

◆Selection guide (TE cooled CW-QCL)



pulsed operation also available

E-mail：laser-g@lsr.hpk.co.jp　　FAX：(81)53-484-1302

9.7um(1030cm^{-1}) CW-DFB

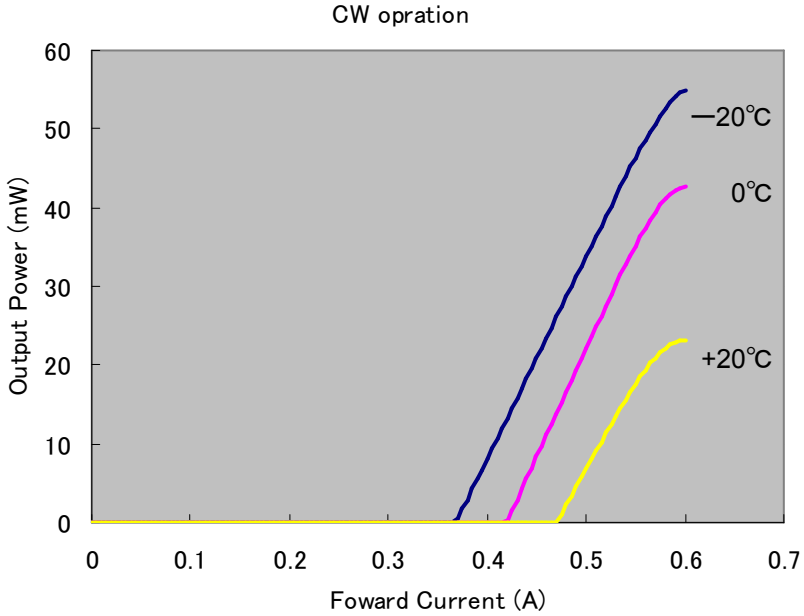
S/N;2645-A511-16

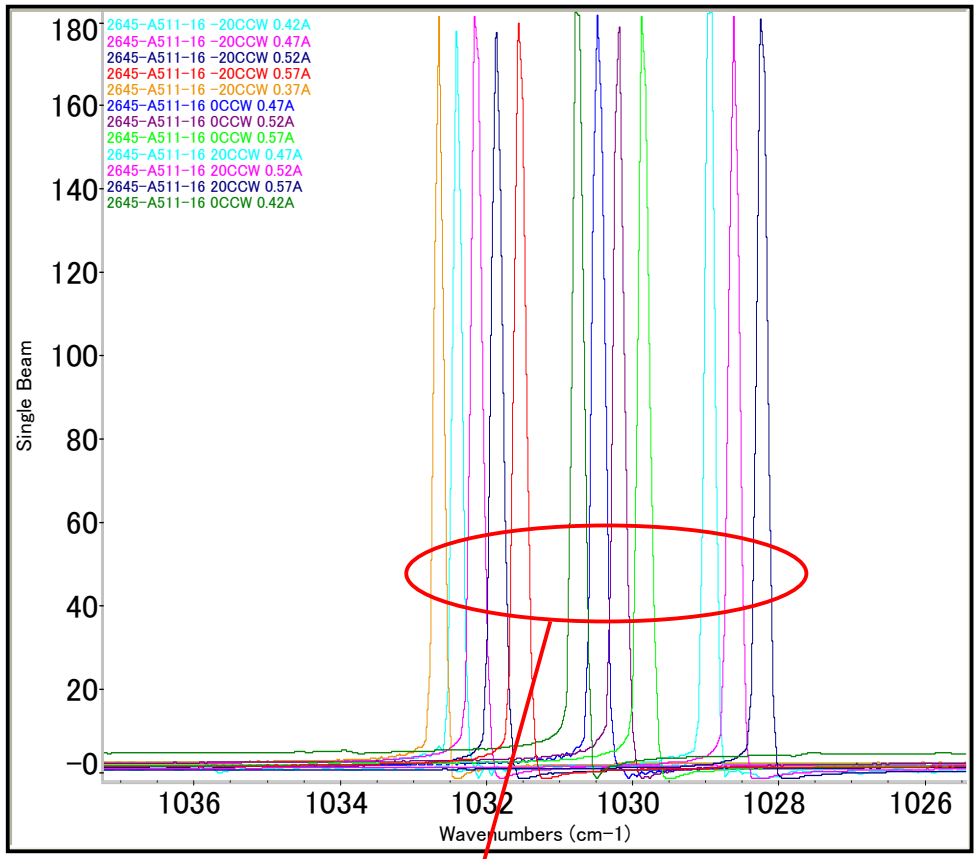
Type of laser

- Cleaved-Cleaved facet, DFB
- Center of emission wavelength = 9.70 μm, single-mode

Characteristics

- Maximum output power at 20℃ : 20mW
- Threshold current at 20℃ : 0.47A





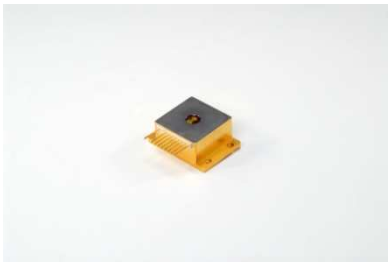
Data were taken bu the use with FTIR, resolution: 0.125cm-1.

tuning range : ～5cm^{-1} (-20 to +20℃)

Accessories

◆Laser head and drivers

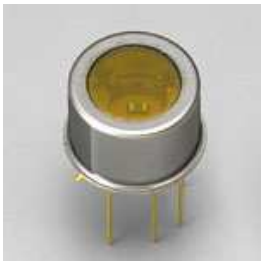
TE-cooling head with
ZnSe collimate lens



HHL package

Set-up example

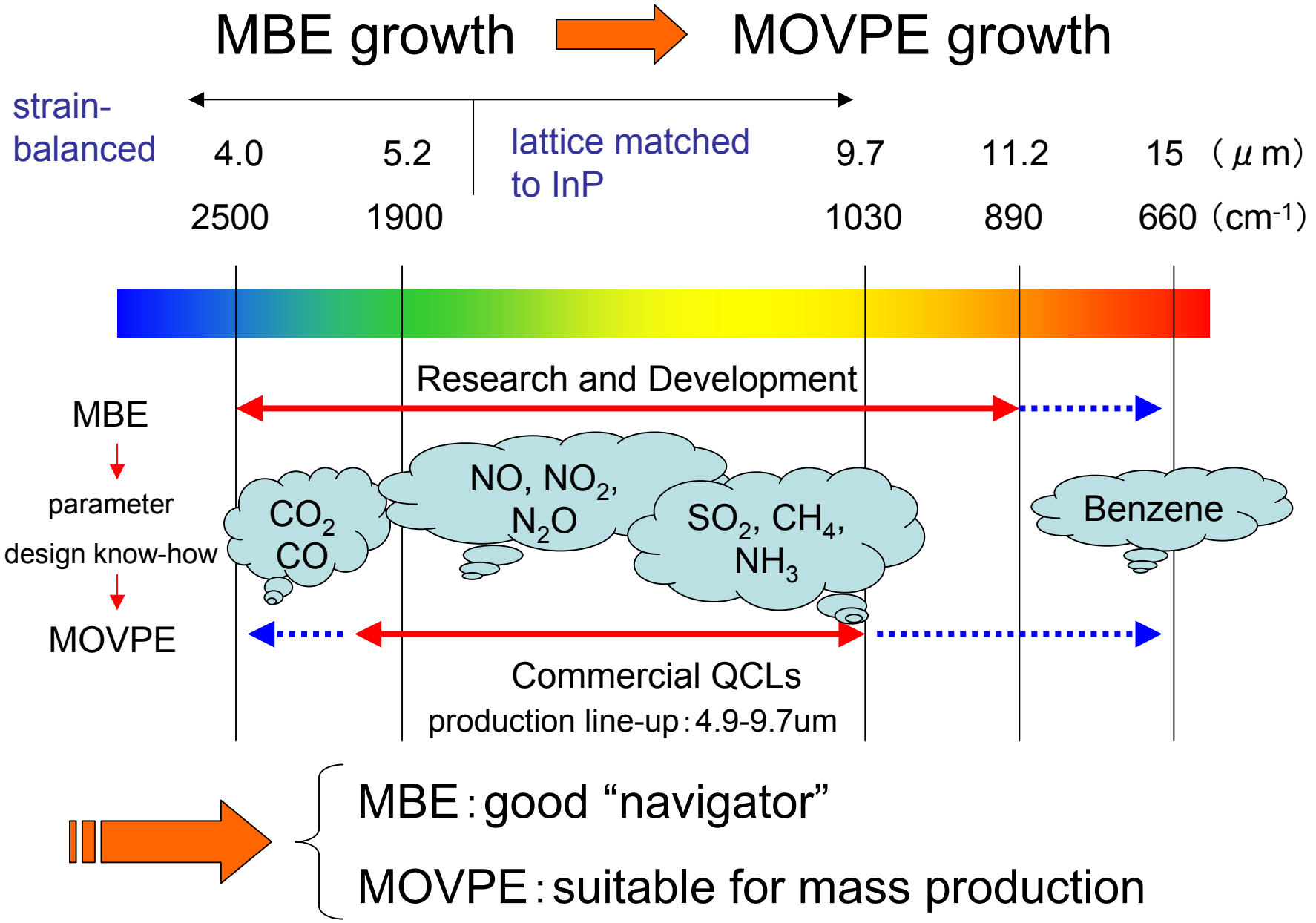
◆Mid-IR detectors : MCT(P3257 series) λ =2～11.5 μ m, ϕ =1mm



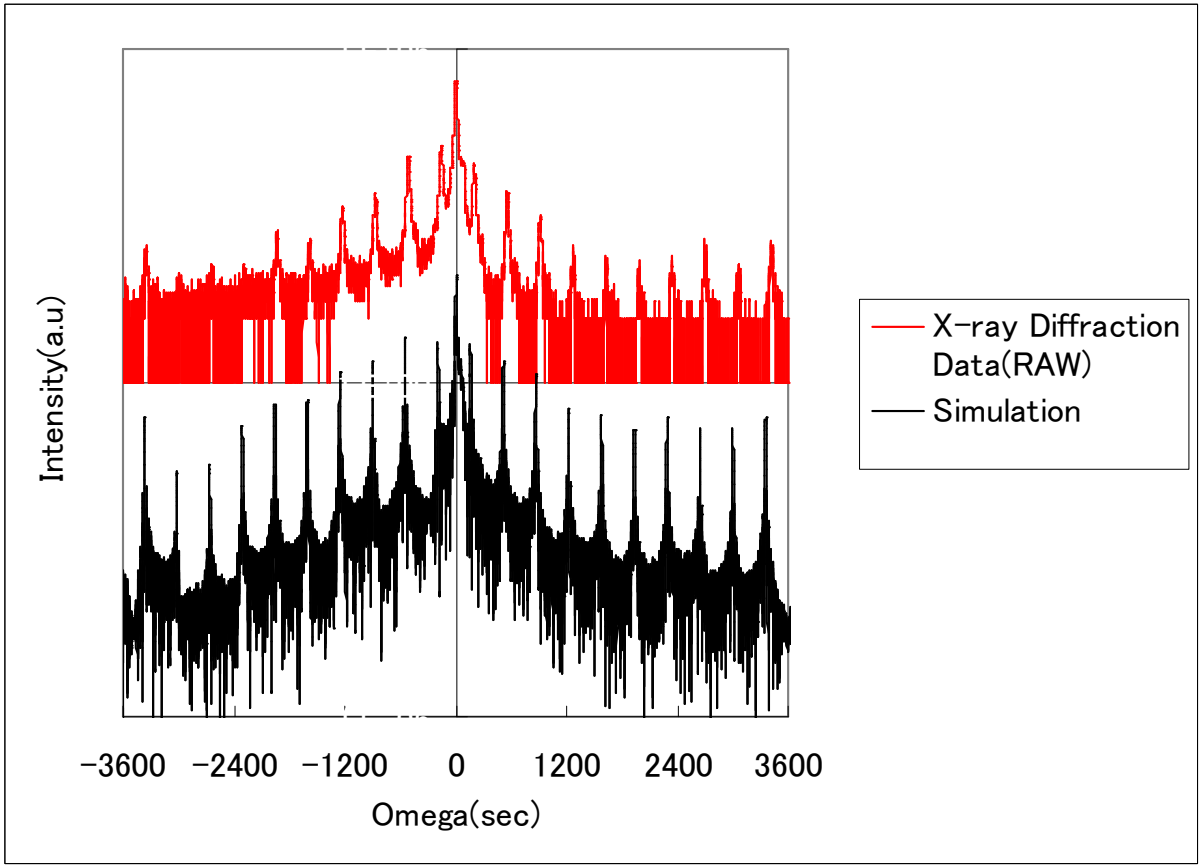
TE-cooled type

un-cooled type

amplifier module

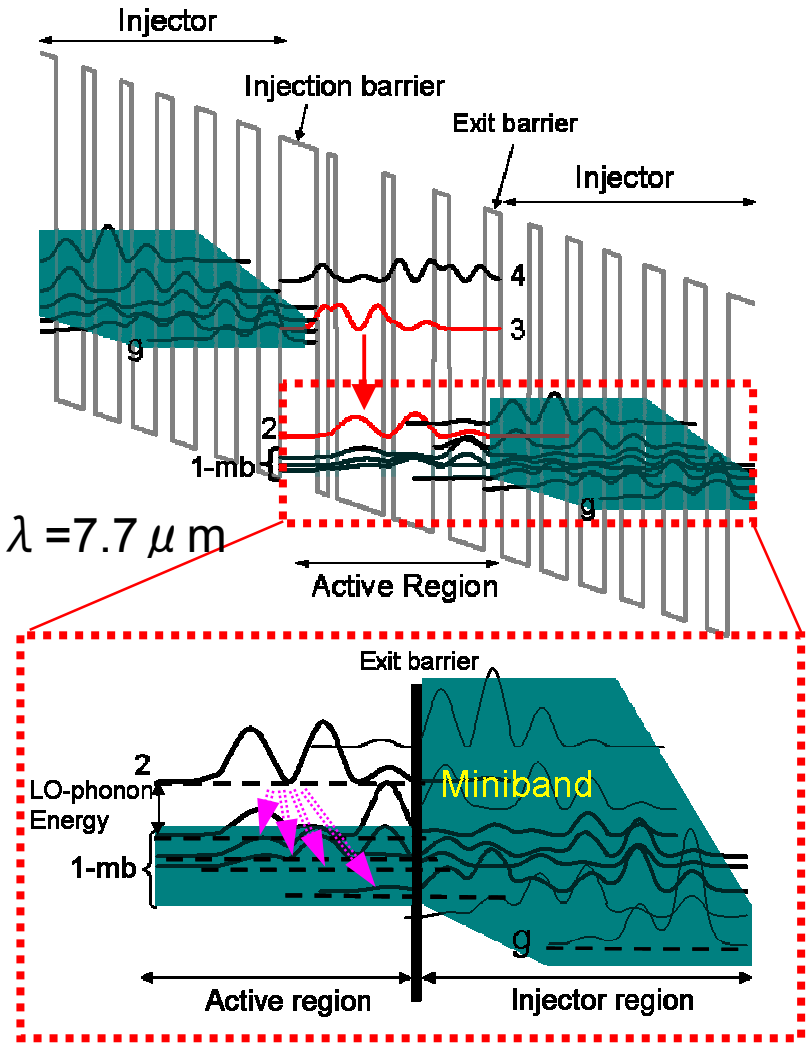


XRD (strain-balanced structure) : 5.2 μm



well controlled layer thickness, interface quality, material composition, and uniformity

Single Phonon resonance - Continuum depopulation structure: *SPC*-depopulation structure



- bound to bound vertical transition
- electrons at lower lasing state 2 are very quickly depopurated to the mini band (1-mb)
  - → via LO-phonon scatterings
  - → τ_2=0.18ps, τ_3=1.45ps
- efficient extraction to Injector miniband by miniband relaxation

⇒ lead to good device performance

- The energy separation between subband 2 and miniband 1-mb is not always required to match strictly with LO-phonon energy.

⇒ large allowance for thickness fluctuations

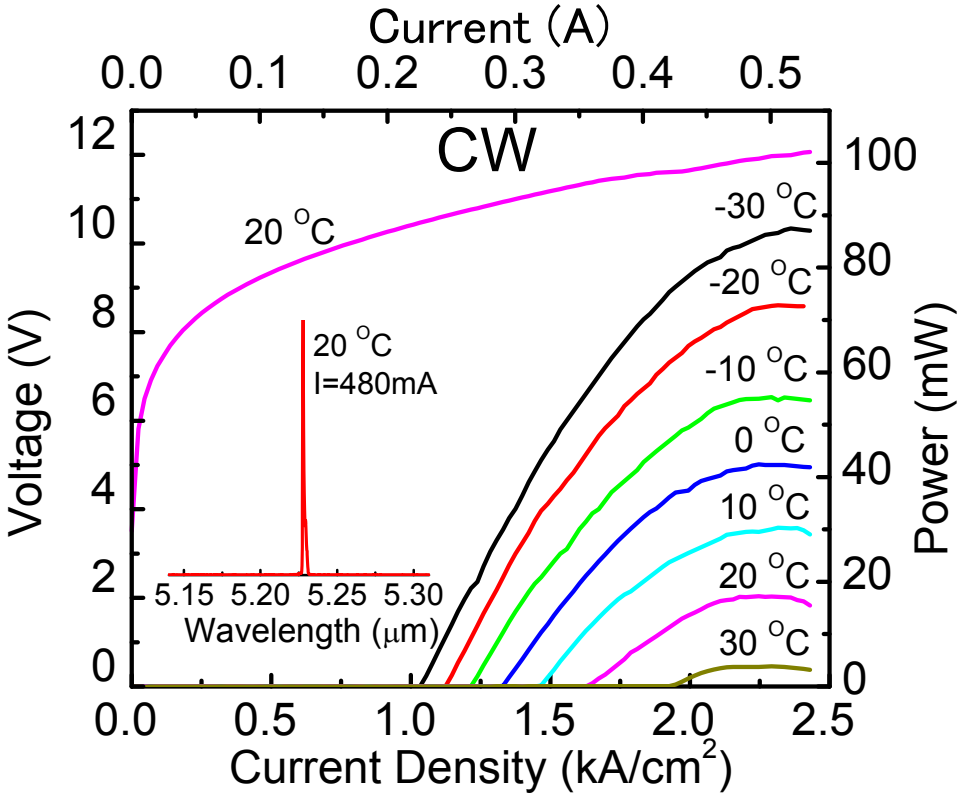
K.Fujita et al., APL91(2007)141121.

SPC with simple ridge structure

◆Optimized SPC design

Simple ridge structure

- epi-side up mount / Cu heat-sink
- high-mesa ridge structure (no BH)
- without HR coating



λ =5.2 μ m, +20℃, CW operation

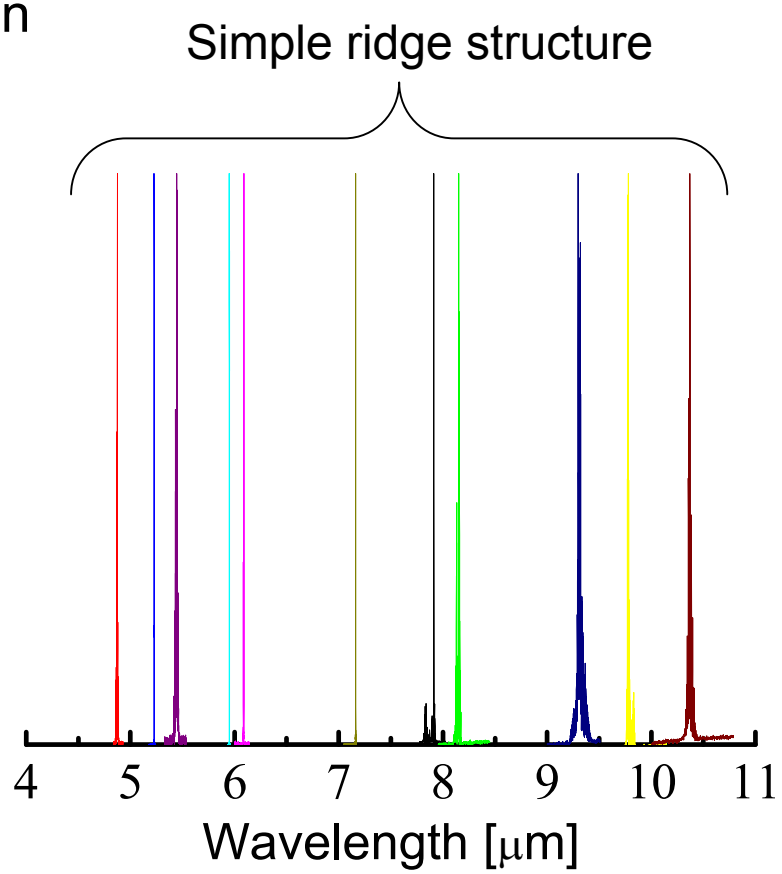
J_{th}=1.6kA/cm^2, P=17mW

This simple structure saves us from complex processing steps such as InP re-growth and HR coatings.

suitable for mass production

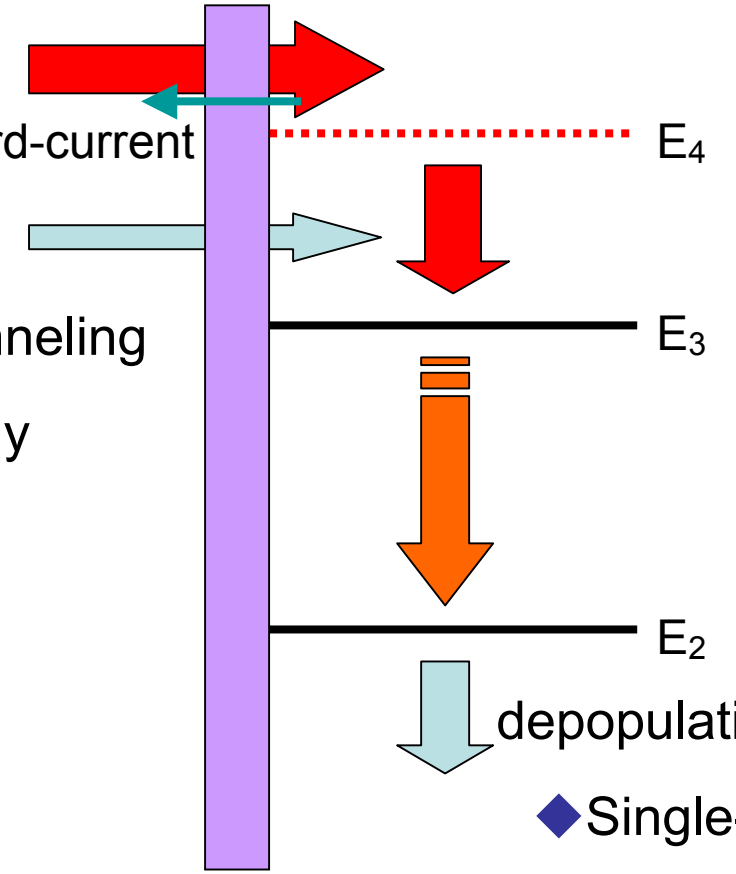
The wavelength range of SPC-QC Lasers

◆RT-CW operation



We have achieved RT-CW operation in the wavelength range of 4.8 – 10.5 μ m, grown by MOVPE.

Indirect-pump (IDP) scheme



◆Resonant Tunneling

→ directly

our new pump scheme

◆Indirect-pump (IDP)

Poster presentation

→ Sep./18, Yamanishi et al.

depopulation process → many ideas

◆Single-Phonon

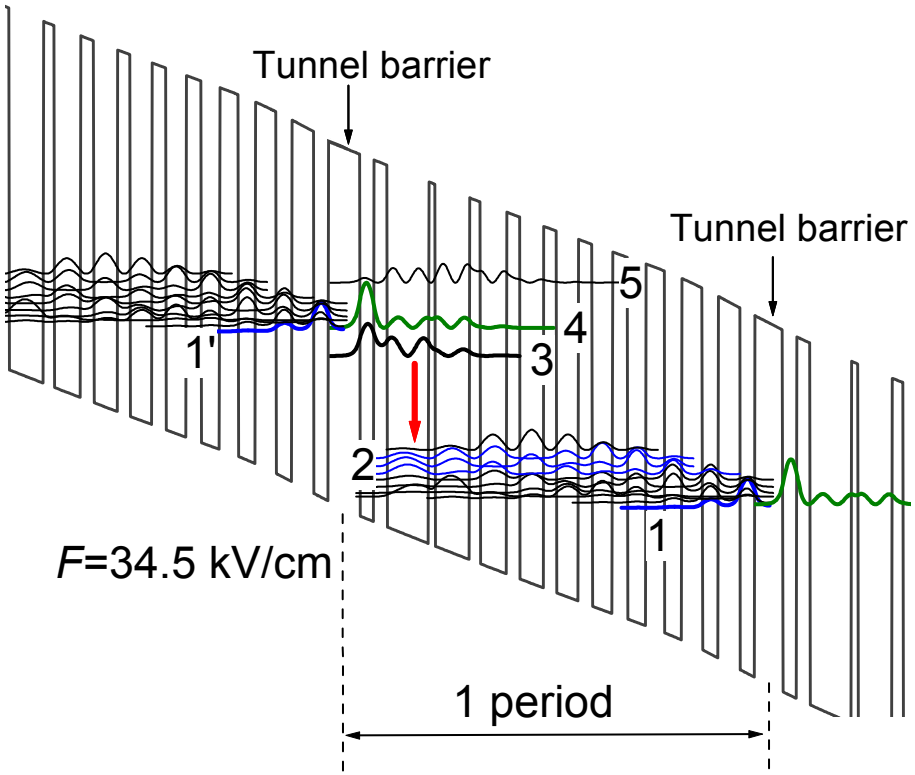
◆Double-Phonon, Multi-Phonon

◆BTC

◆SPC

IDP structure

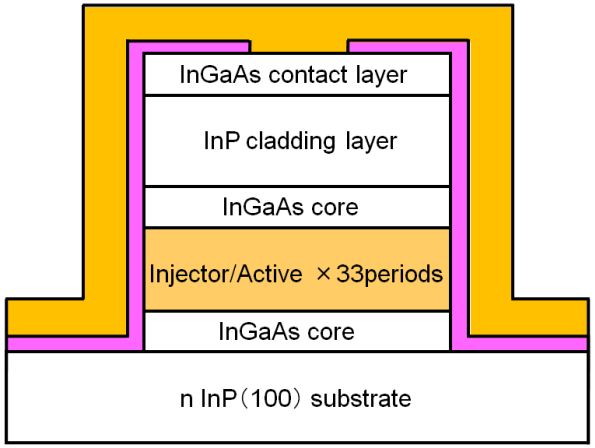
◆Energy band diagram



$\hbar\Omega_{41'}$ =7.0 meV
E_{43}~40 meV
E_{32}~160 meV (λ~8 μm)
E_{21}~60.0meV

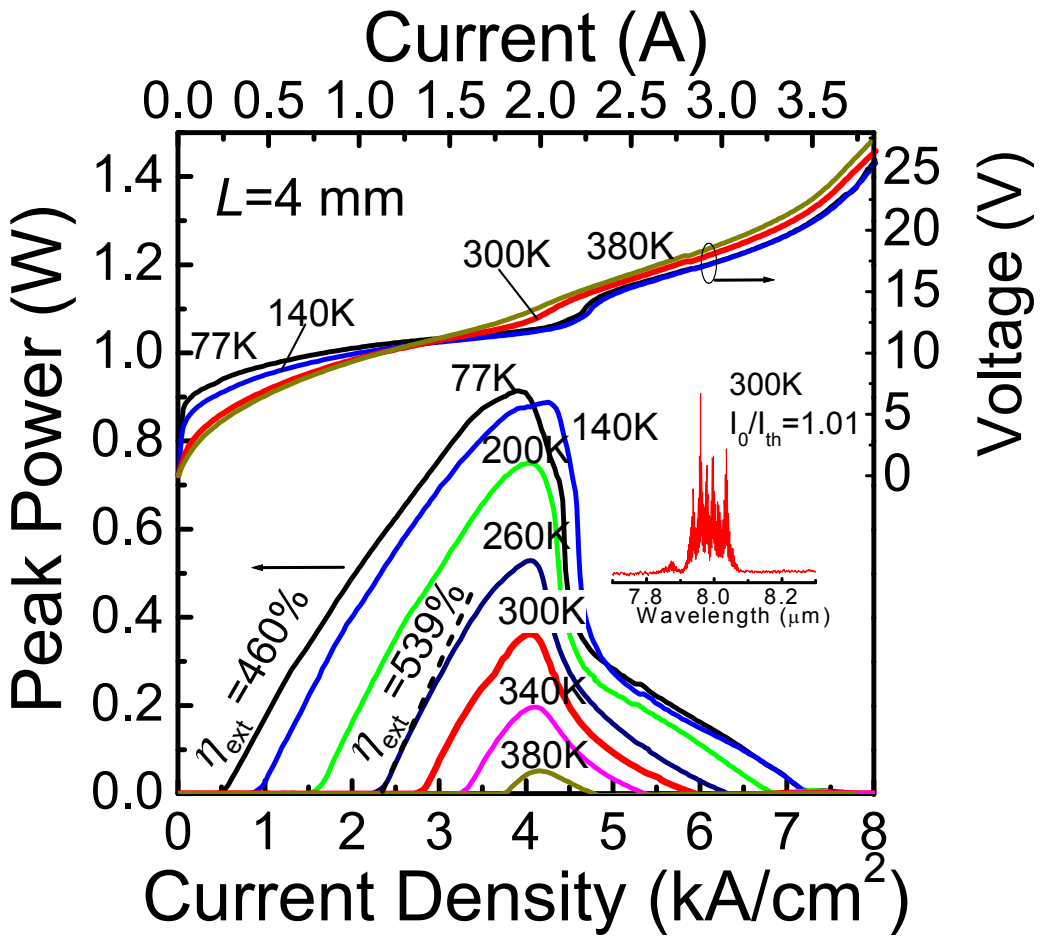
τ_{420}=3.0 ps (<<τ_{410})
τ_{430}=0.27 ps
τ_{30}=τ_{320} =1.5 ps

◆Device structure



- epi-side up mount
- high-mesa ridge structure
- without HR-coating

I-V-L (pulsed operation)



L=4mm, w=12 μ m

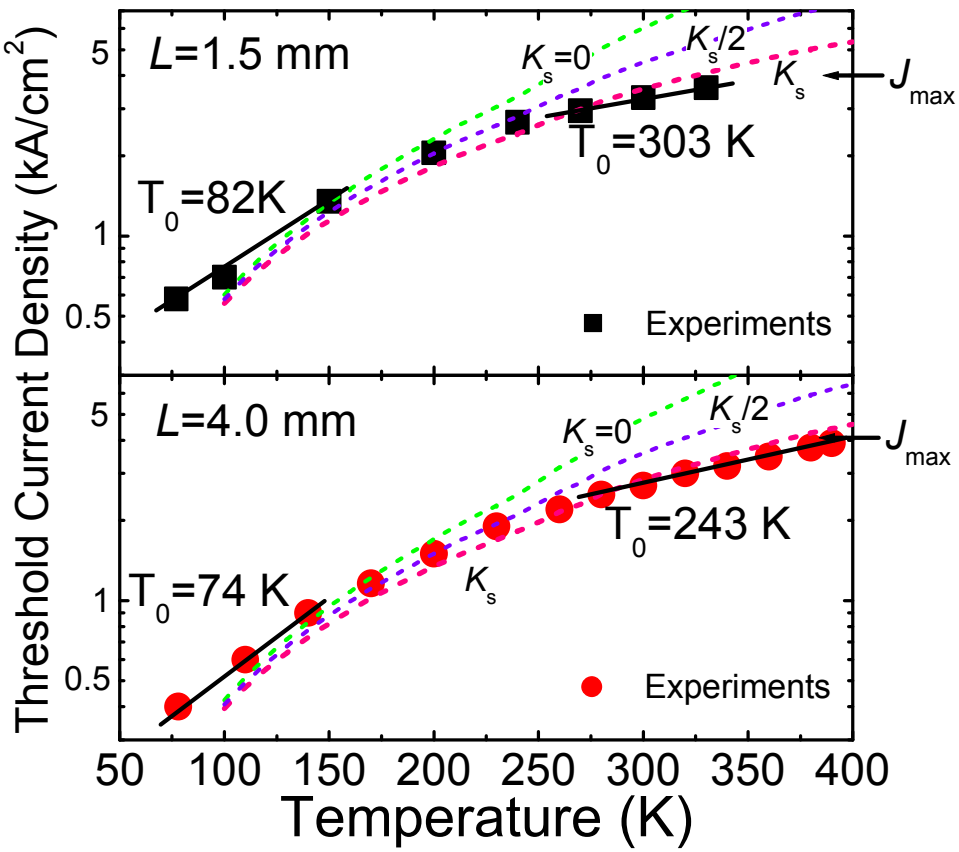
50ns/1kHz pulsed operation

J_{th}=2.7kA/cm^2 @300K

P_{peak}=362mW @300K

Low threshold current density and high peak output power

High T_0-values



L=1.5mm → T_0=303K

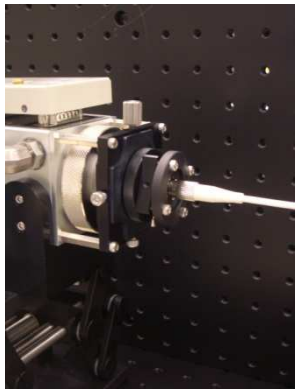
L=4.0mm → T_0=243K

→ Very weak temperature dependence of the threshold current !!

→ Suppressions of electron populations in the injector regions

(quenching of the injector-loss)

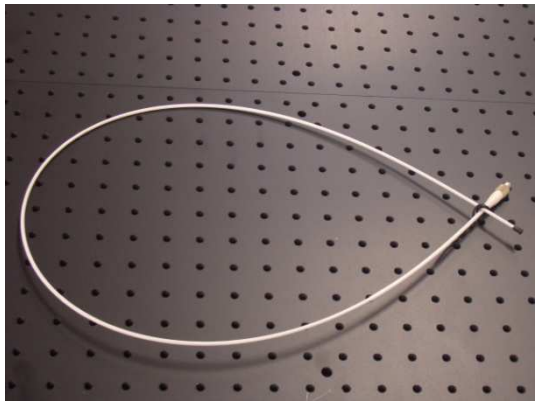
Fiber-out module (Ag-coated hollow fiber)



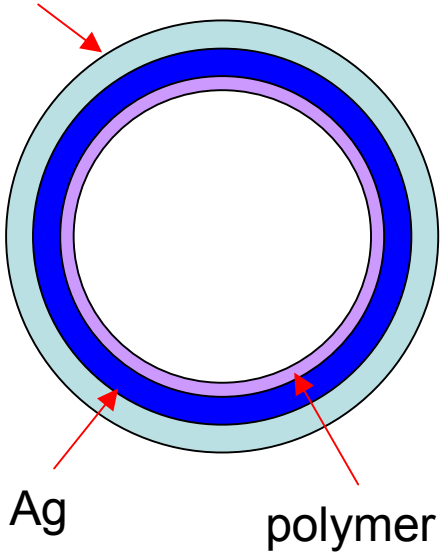
λ =9.5 μ m (TE-cooled, duty : 35%)

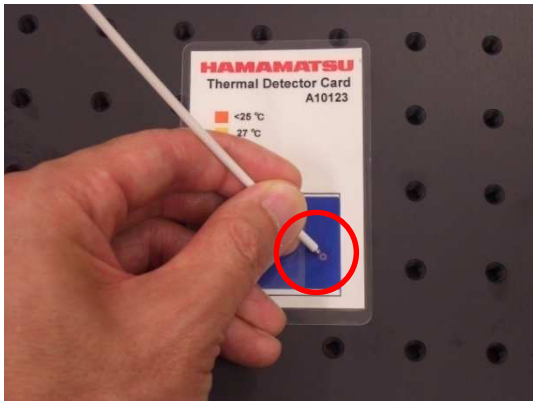
with ZnSe collimate lens and FC style connector

average output power : 10mW



L=1m, ϕ =700 μ m





"Thermal Detector Card"

Doko Engineering http://do-ko.jp/products.html

Hitachi Cable http://www.hitachi-cable.co.jp/products/optical/laser/index.html

Applications

Laser Absorption Spectroscopy (Environmental Gas Monitoring)

- Green-House Gas : CO_2, N_2O, CH_4
- Air Pollution : NOx, SOx
- Security Field : ???

→ “real time” “portable”

Bio-Medical Sensing

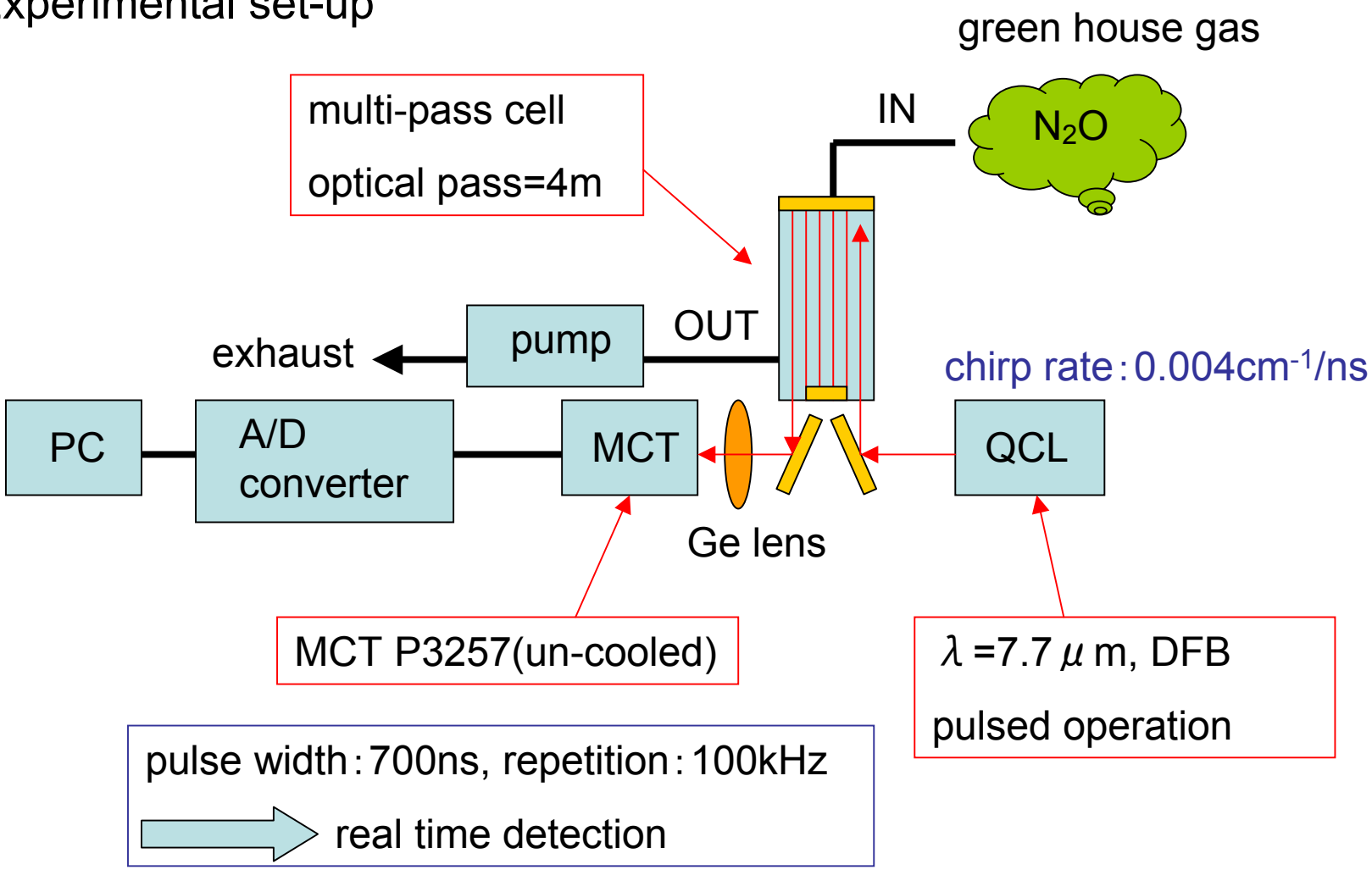
- Breath Analysis
- Glucose Monitoring

High Speed Communication

- Free-Space Communication → 2nd atmospheric window (λ =8-13 μ m)

Movie 1) sample gas : N_2O

◆Experimental set-up



Movie 2) sample gas : exhaust gas (NO)

MCT P3257

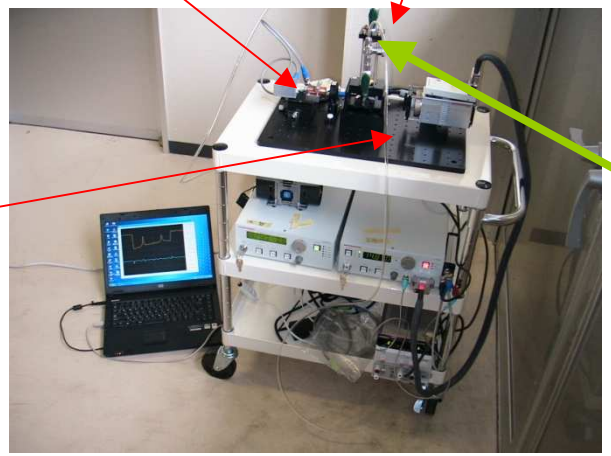
multi-pass cell

QCL

λ =5.2 μ m, DFB

pulsed operation

(500ns/100kHz)



NO

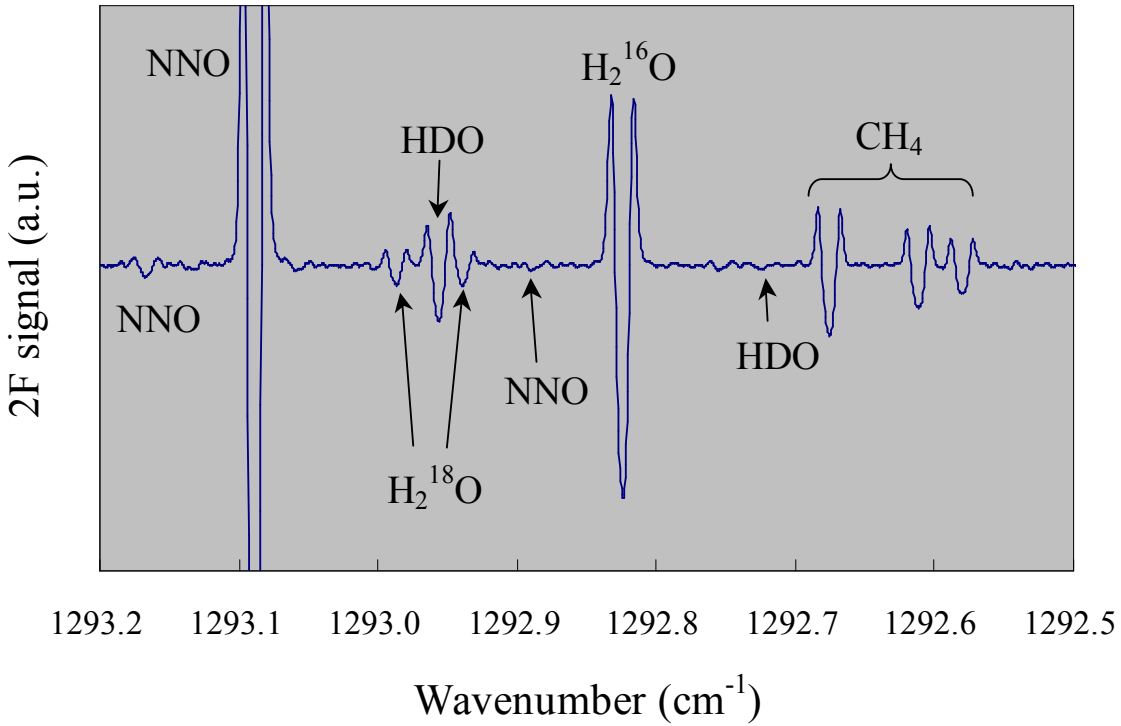
air pollutant

exhaust gas (diesel engine)

"real-time and portable" detection

Ambient air

◆CH_4, N_2O, H_2O *(collaborate with Prof.Uehara, KEIO Univ.)*



CH_4 : 1.7ppm　N_2O : 0.3ppm

QCL

λ =7.7 μ m, DFB

TE-cooled CW operation

T_{op}=0℃

Sample gas

ambient air@Hamamatsu

optical pass = 100m

Modulation

sin-wave, F＝100kHz

lock-in detection technique

- good agreement with the HITRAN data base
- isotopes (H2_16O, H2_18O, HDO) are clearly resolved

Summery

1. The MOVPE-grown QCL configuration is obviously very preferable for industrial device- production.
2. We have achieved RT-CW operation QC lasers based on SPC depopulation structure, in the wavelength range of 4.8-10.5 μ m.
3. The new pump scheme; IDP scheme may open up a new opportunity for long-wavelength, high power, high temperature operation QC lasers.
4. We demonstrate “real-time” and “portable” gas detection.

Thank you for your attention !!

Please contact our web-site or laser group sales.

http://www.hamamatsu.com E-mail:laser-g@lsr.hpk.co.jp FAX:(81)53-484-1302