Sub Group : Quantum Measurement

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Development of Low Dark-count Photodetectors

and

Mid-IR Light Sources

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2011.12.13

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Outline

Development of low dark-count photodetectors

- Near infrared PMT and hybrid photodetectors
- Collaboration with quantum measurement group
  Hokkaido Univ.

Mid-IR light sources in Molecular Finger Print Region

- Intrinsic linewidth of quantum cascade laser
- Broad-gain quantum cascade laser
- Low power consumption: short cavity QCL
- THz laser based on indirect pump scheme

Development of Low Dark-count Photodetectors

and

Low Power Consumption Mid-IR Light Source

Motivation

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For the practical application of quantum cryptography, quantum key distribution (QKD) for 200km should be achieved by using the detector under practical temperature operation.

For 200km QKD, 1550nm wavelength detector must have high sensitivity and lower dark counts.

Specifications Required for 200km QKD

- Wavelength 1.55μm (for optical fiber)
- Sensitivity ＞ ~10 %
- Dark counts ＜ ~100 cps
- Operating temp. ＞ 173 K (Thermoelectric cooler)
- High speed response＞1GHz

Summary of Last Year's Report

- Designed NIR-PMT with New Cathode Structure

  Confirmed ・Quantum efficiency: 7 % (at 1550 nm)

  ・Dark counts: 5 cps (at -75 ℃)

⇓ Promising

200 km Quantum Key Distribution

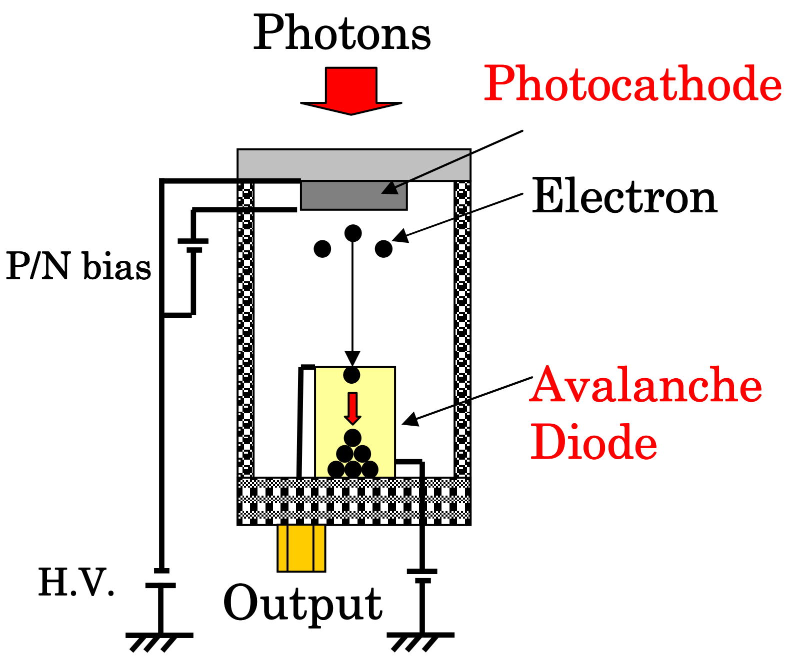
620 bps (calculation)

- Attempt to evaluate the PMT mounted on the thermo-electric cooler.

Results of The This Year

- Developed a new type PMT assembled with thermo-electric cooler and evaluated the detector characteristics.

- Designed a Near-Infrared Hybrid Photo-detector (HPD) for higher speed detection and confirmed preliminary operation.



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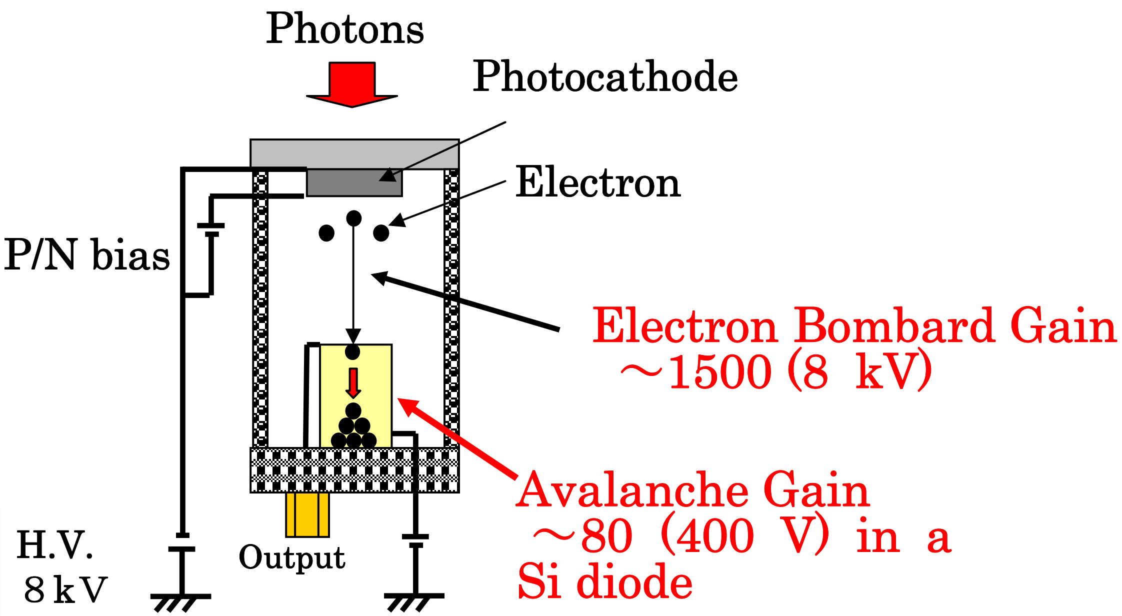
Development of NIR-PMT Module

- NIR-PMT Module Performance
  - ▪maximum cooling temperature　－87℃
  - ▪optical coupling efficiency　57%
  - ▪Q.E.　3.6 %　(@1550nm)
  - ▪dark counts　77cps

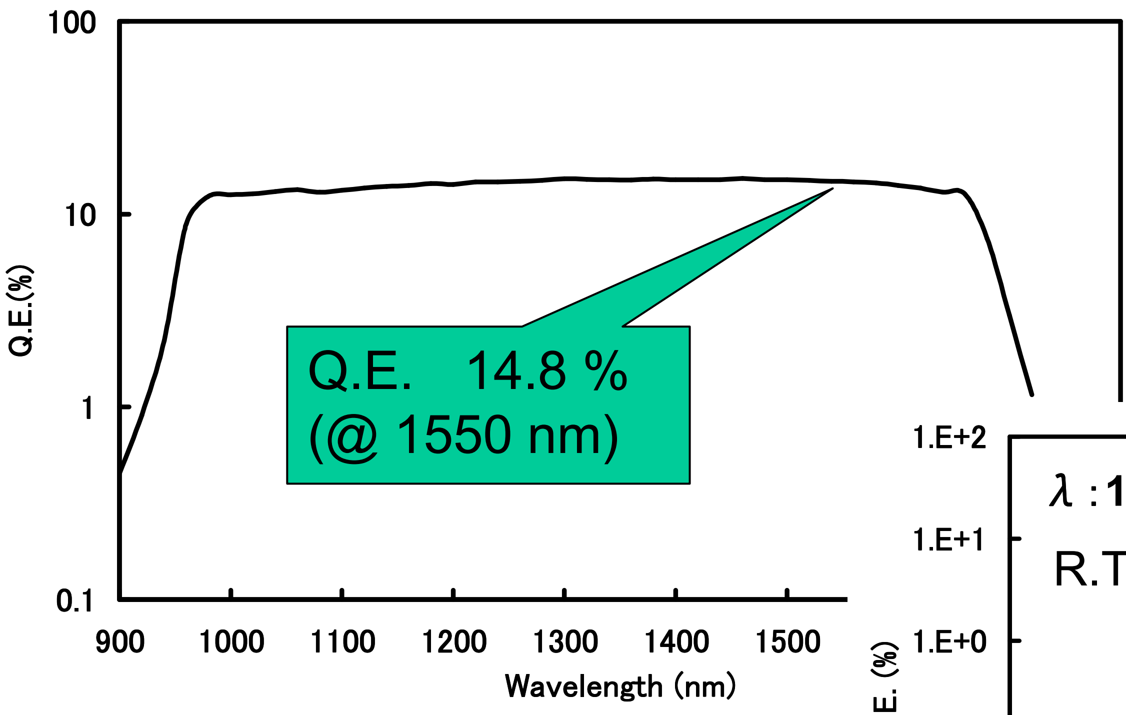
▪Q.E. of PMT must be improved.
Optimization of photocathode activation and optical coupling system

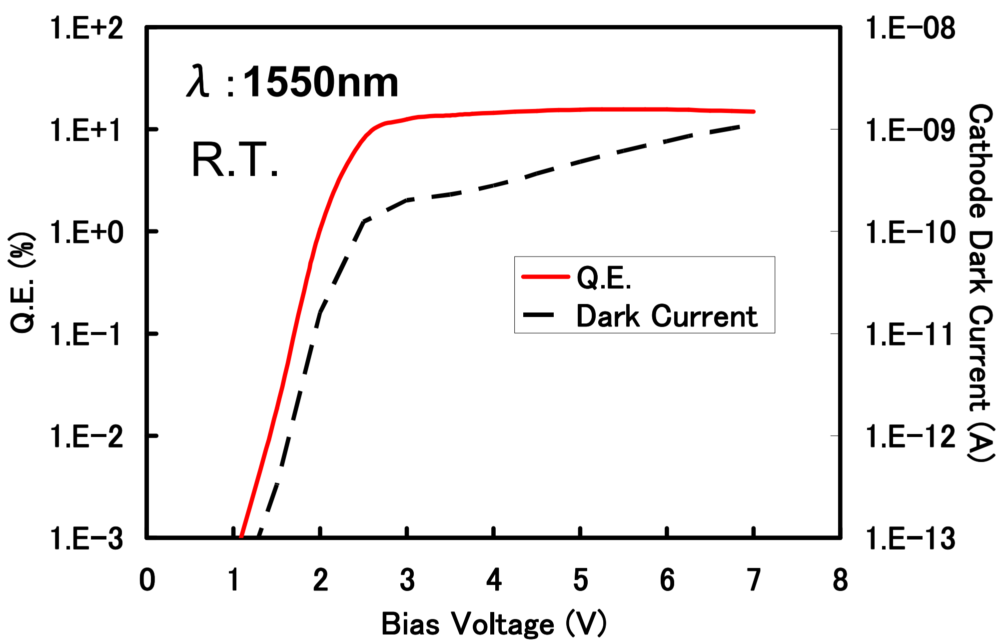
Near Infrared Hybrid Photodetector (NIR-HPD)



Design for e-beam focusing!

Confirmation of Cathode Operation

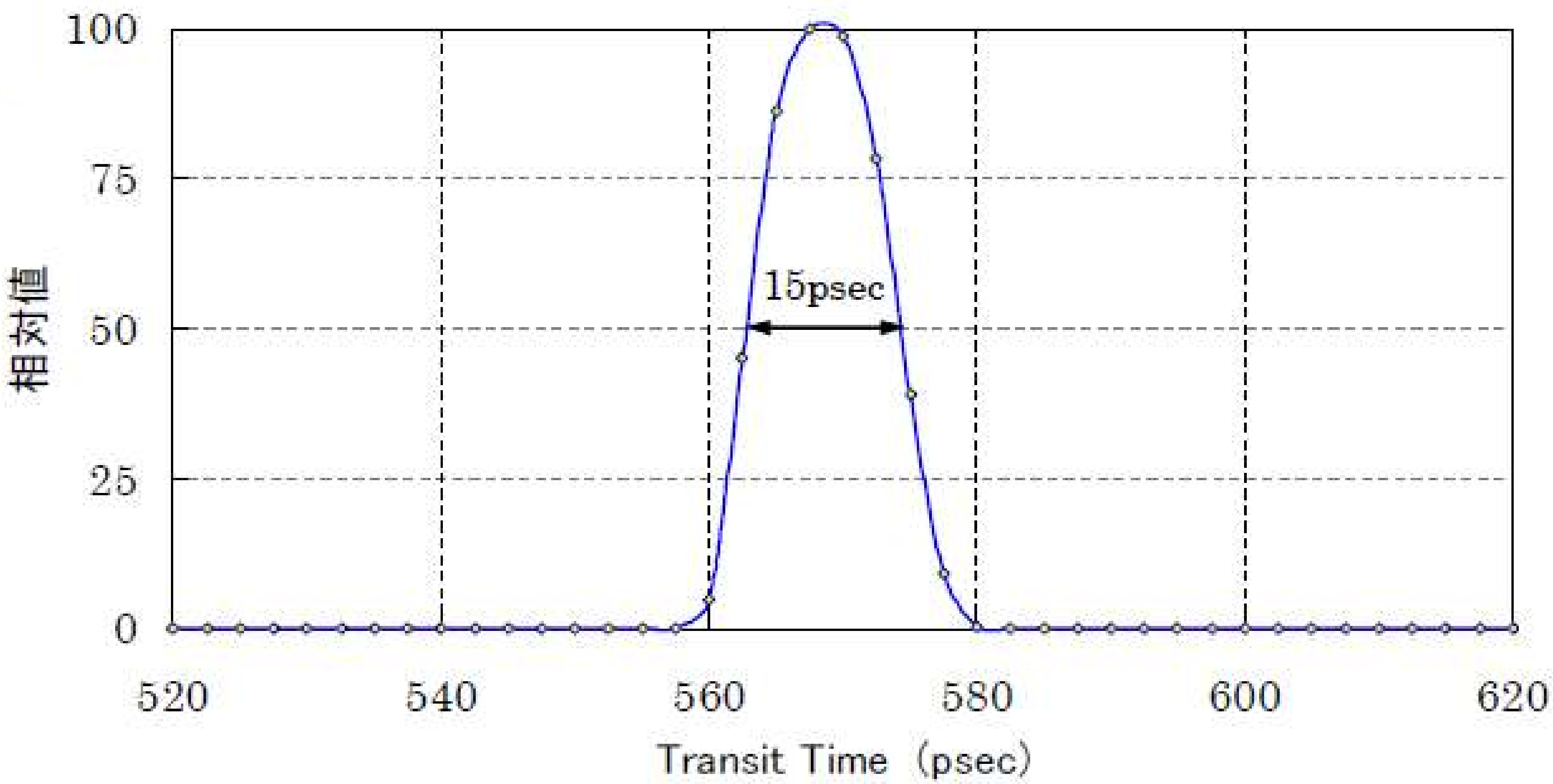




Monte-Carlo Simulation of Transit Time Spread (TTS)

Excellent TTS

HPD (15 ps) << NIR-PMT（300 ps）



Schedule

Next Year

- Evaluation of PMT module in practical measurement in quantum information research.
- Realization of high spec operation of NIR-HPD.
  - Optimization of the photocathode activation
  - Development of thermoelectric cooler for NIR-HPD

Future

- Single Photon Detection in Mid-IR region by Up-Conversion .

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Development of Low Dark-count Photodetector

and

Mid-IR Light Sources

Intrinsic Linewidth of QCL

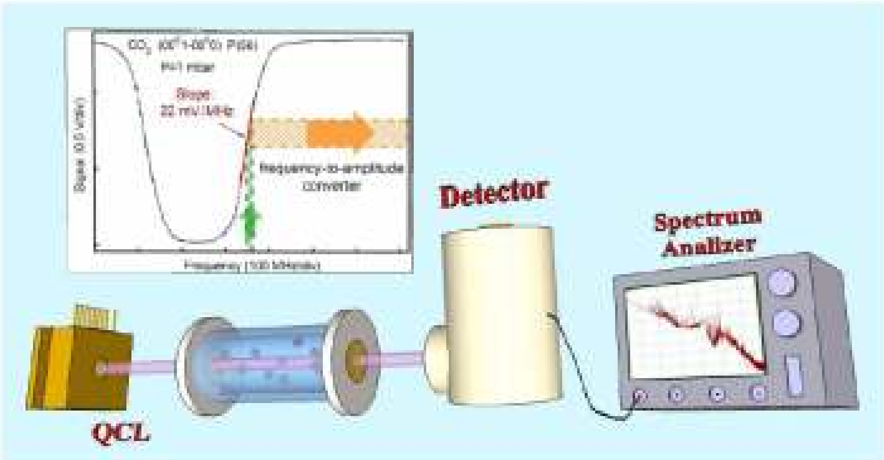
Measuring frequency noise and intrinsic linewidth of a room-temperature DFB quantum cascade laser

S. Bartalini,[1,2,*] S. Borri,[1,2] I. Galli,[1,2] G. Giusfredi,[1,2] D. Mazzotti,[1,2] T. Edamura,[3] N. Akikusa,[3] M. Yamanishi,[3] and P. De Natale[1,2]

[1] *Istituto Nazionale di Ottica (INO) - CNR, Largo Fermi 6, 50125 Firenze FI, Italy*
[2] *European Laboratory for Nonlinear Spectroscopy (LENS), Via Carrara 1, 50019 Sesto Fiorentino FI, Italy*
[3] *Central Research Laboratories, Hamamatsu Photonics KK, Shizuoka 434-8601, Japan*

Quantum
Cascade
Laser (QCL)

[Opt. Express 19 17996 (2011).]

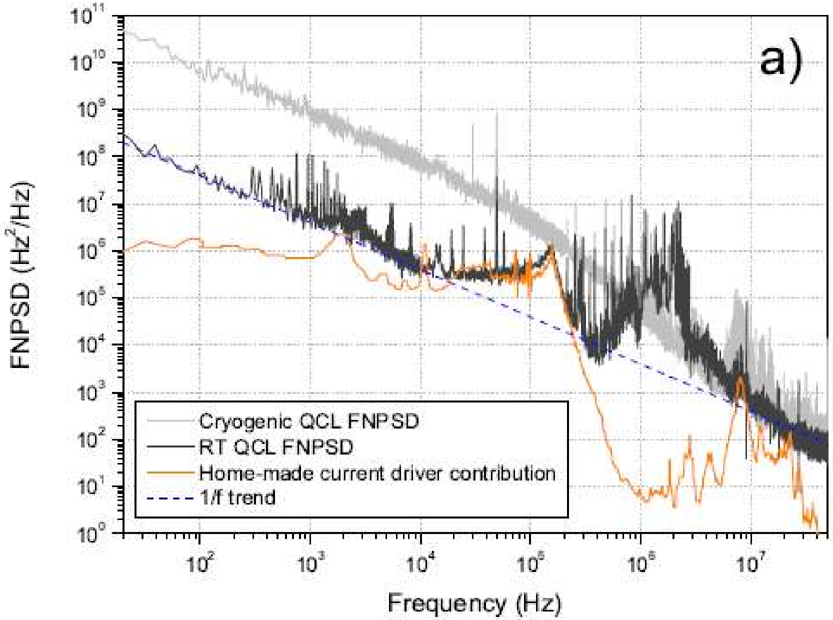


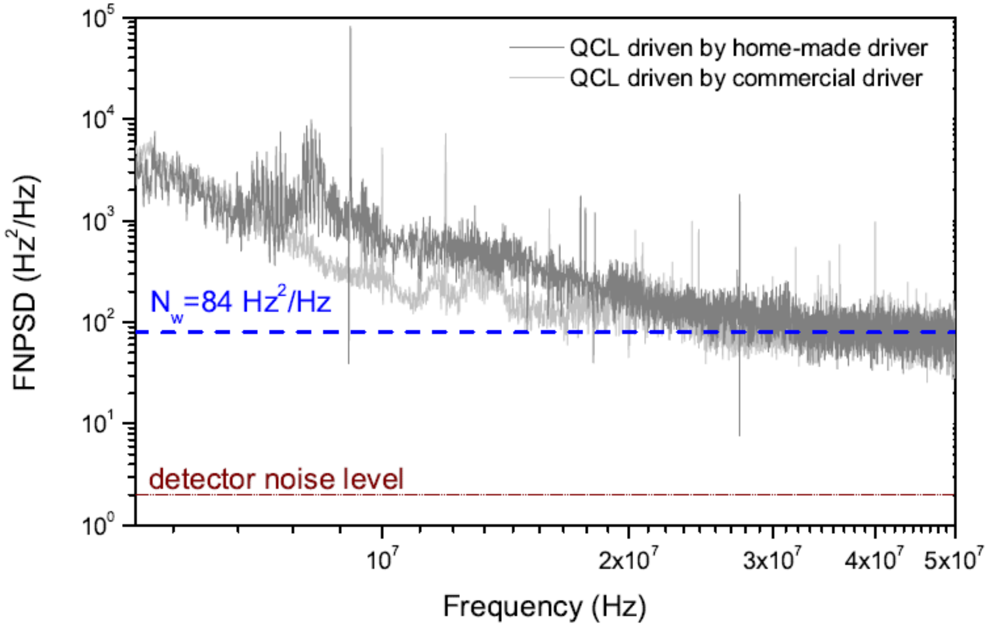
$$\delta f = \frac{1}{4\pi}\left(1+\alpha_c^{\,2}\right)\left(\frac{\tau_t}{\tau_r}\beta\right)\gamma \Big/ \left(I_0/I_{th}-1\right)$$

[M. Yamanishi et al., IEEE JQE 44 12 (2008).]

mid-IR領域：＜1 kHz

Experimental Proof





Servo control
: suppression of $^1/_f$ noise

intrinsic $\delta f \sim$ 260Hz!

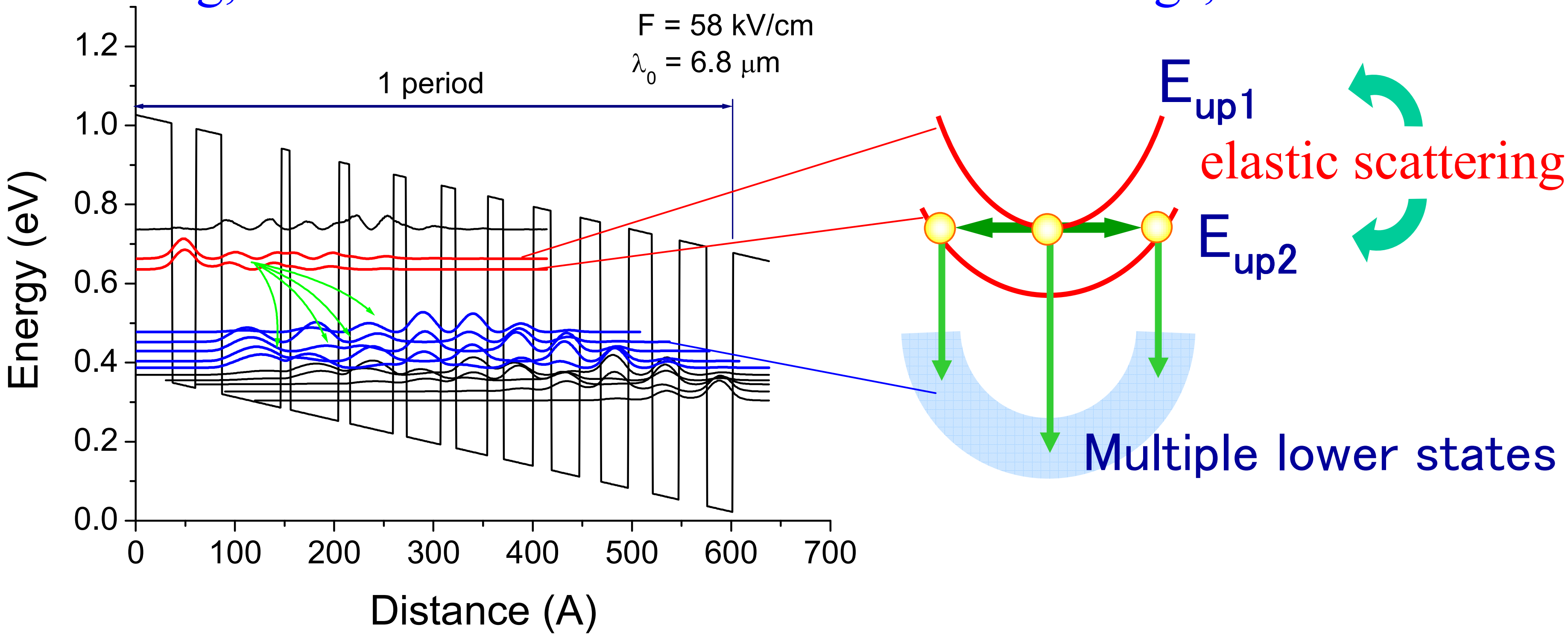
Attractive application fields

- Cooling of molecular ro-vibrations
- Mid-IR frequency comb

Supporting the Italian group

Broad-gain QCLs

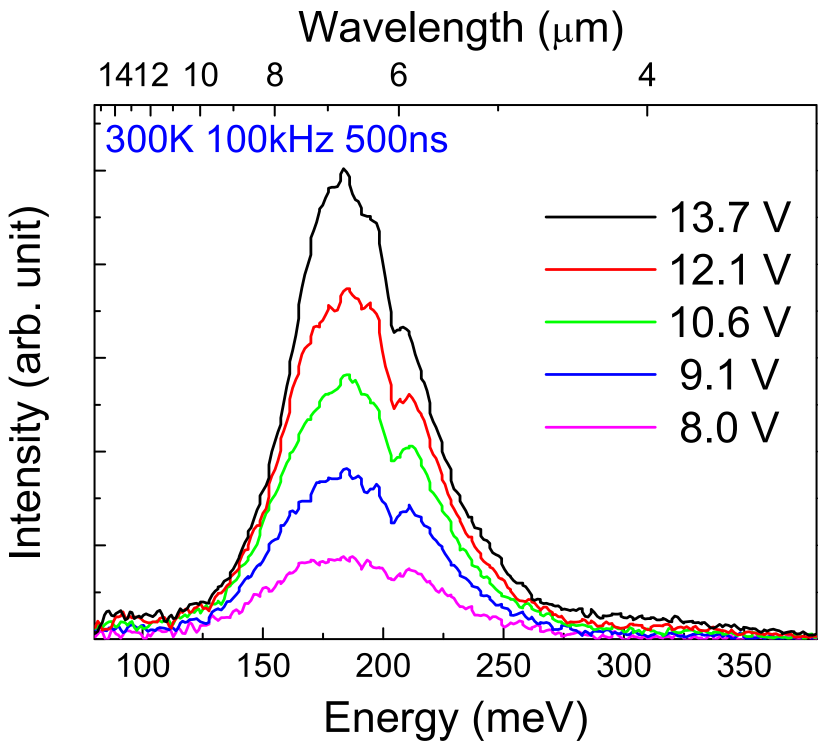
Dual-Upper to Multiple lower state Design (DAU-MS):Strong anti-crossing, ≥ 20 meV and Ultra-fast Elastic Scatterings, ~50 fs

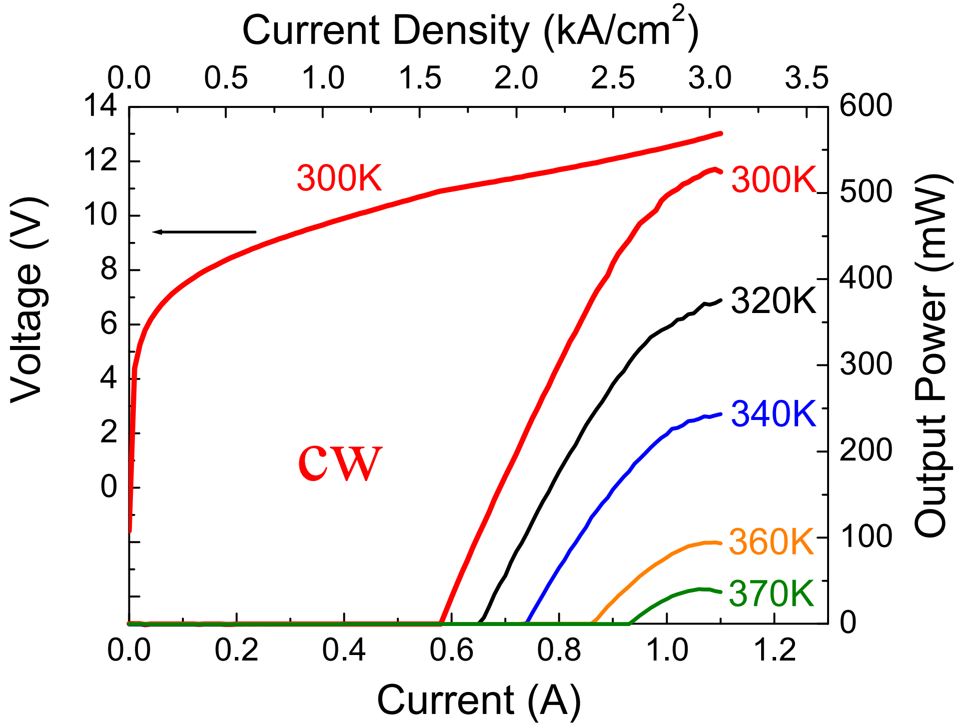


[K. Fujita et al., Appl. Phys. Lett. 98 231102 (2011).]

High performance broad-gain QCL

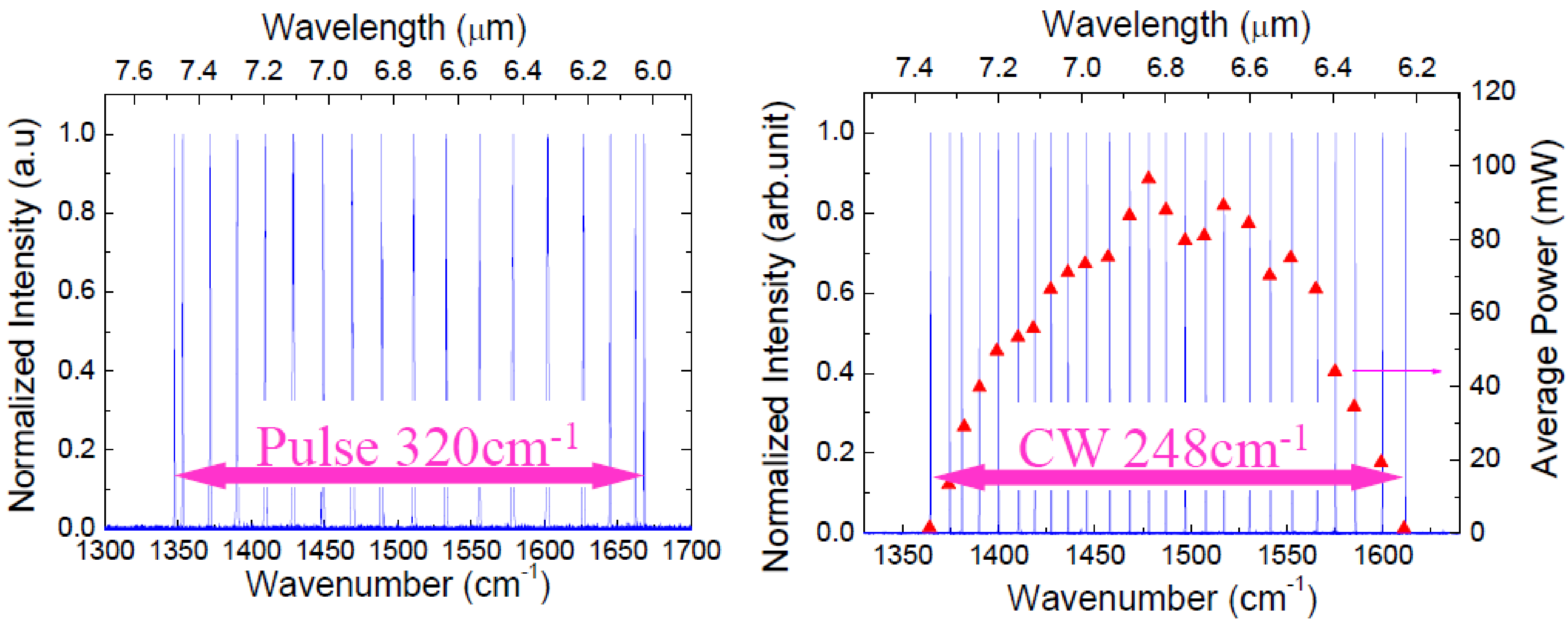
Device Performances of DAU-MS QCL





- Broad band EL (Gain) spectra → linewidth : $\Delta\lambda / \lambda_0 \sim$ 40% (300I
- High output power → over 500mW : CW / 300K

Wavelength Tuning with External Cavity



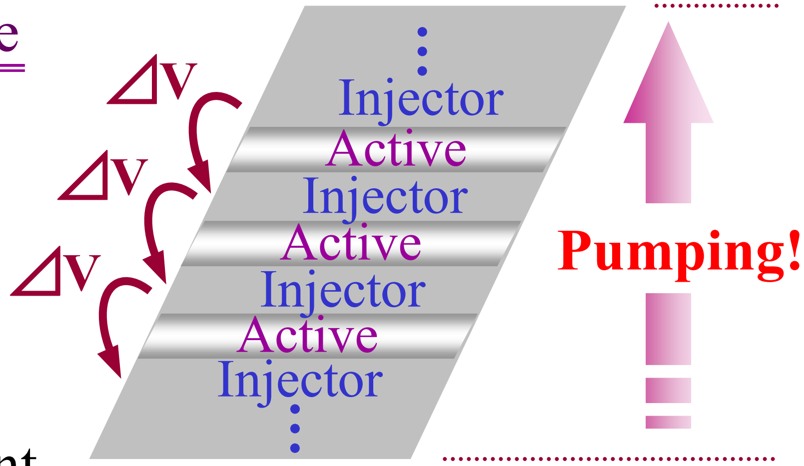
[T. Dougakiuchi et al., Appl. Phys. Express 4 102101 (2011).]

Tuned with Littrow configuration in room temperature

- Pulsed operation → $\Delta\lambda / \lambda_0$~22% (321cm^{-1})
- CW operation → $\Delta\lambda / \lambda_0$~17% (248cm^{-1})

For Low Power Consumption: Short-Cavity

Cascade structure : Inherently high voltage



Short-Cavity
(scale-down of device size)

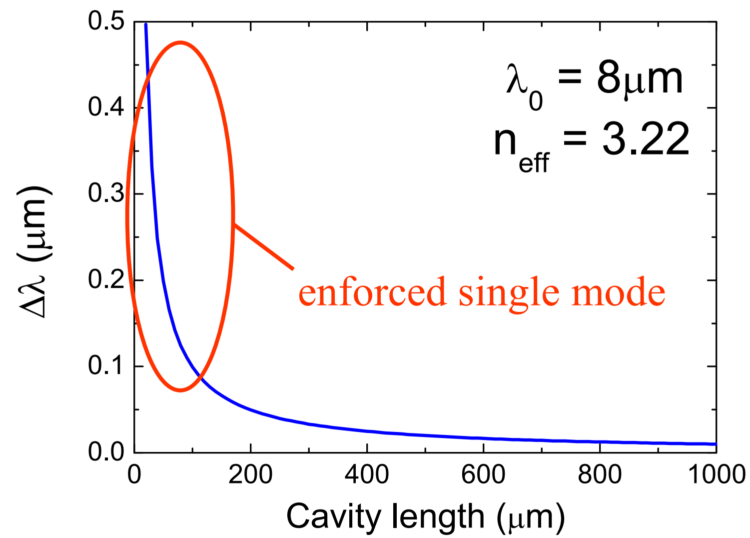
Effective low power consumption achieved by reduction of injection current

Single Mode Lasing
(restriction of cavity mode)

$$\lambda_{FSR} \approx \frac{\lambda_0^{\,2}}{2 n_{\mathrm{eff}} L}$$

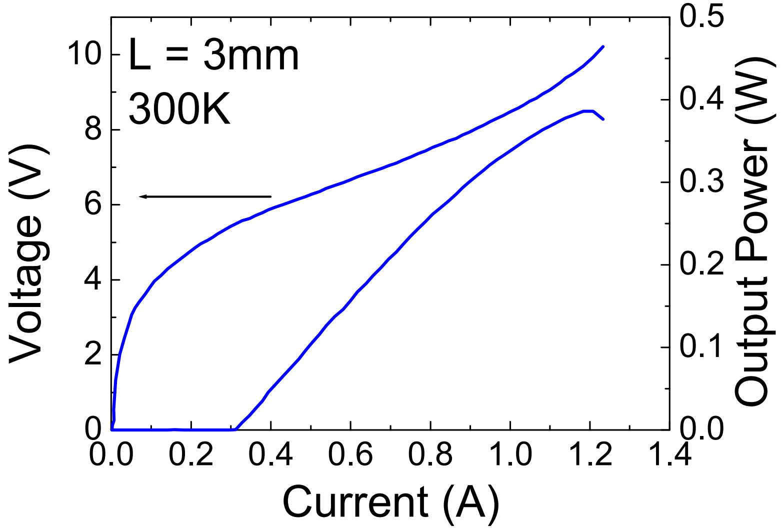
Free Spectral Range

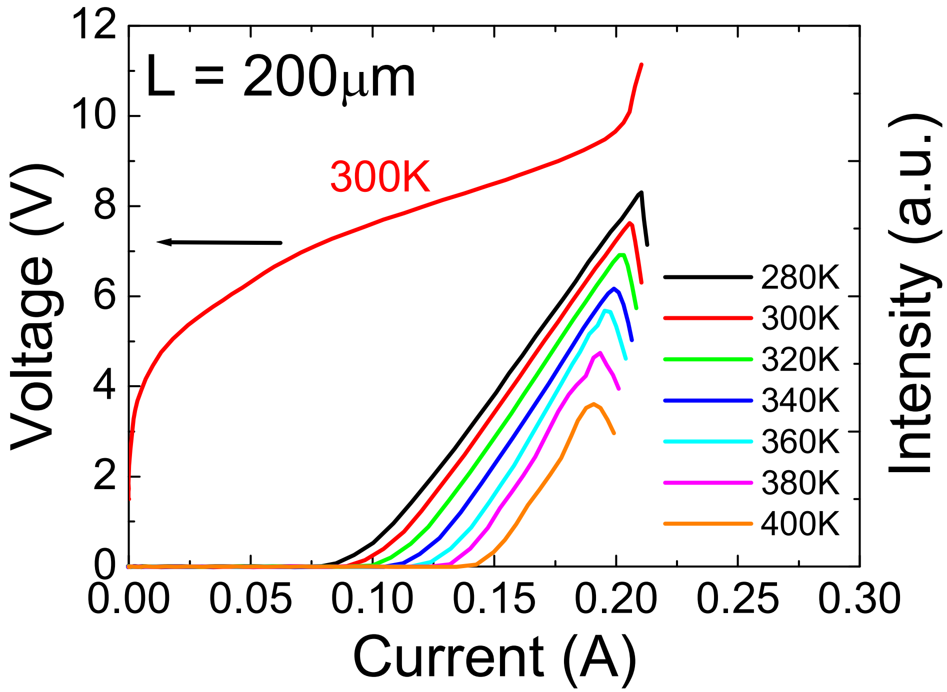
n_{eff} : effective refractivity
λ_0 : center wavelength
L : cavity length



I-L Properties : L=200 μ m

SPC CL/CL $\lambda_0 \sim 8\,\mu m$





L=200 μ m : Threshold Current : **90mA** (300K)

Typical : 300mA (L=3mm)

Single Mode Spectra : L=200 μ m $L/(\lambda_0/n) = 75$

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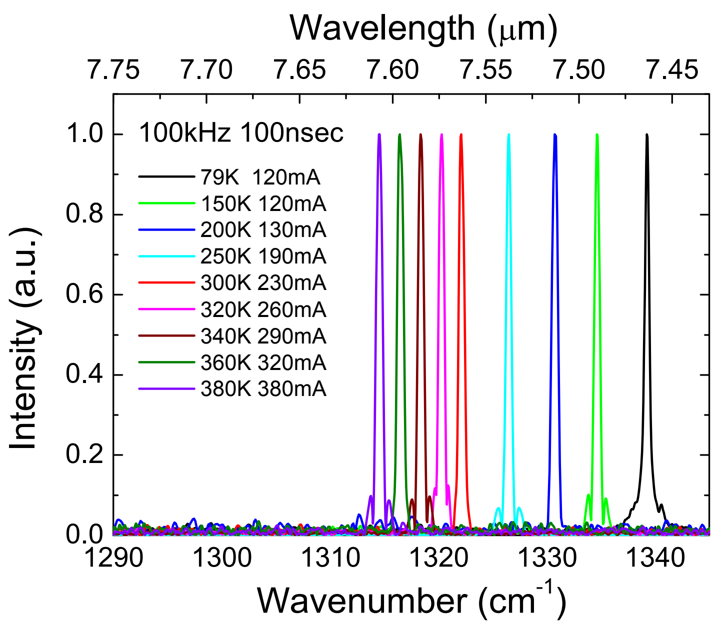
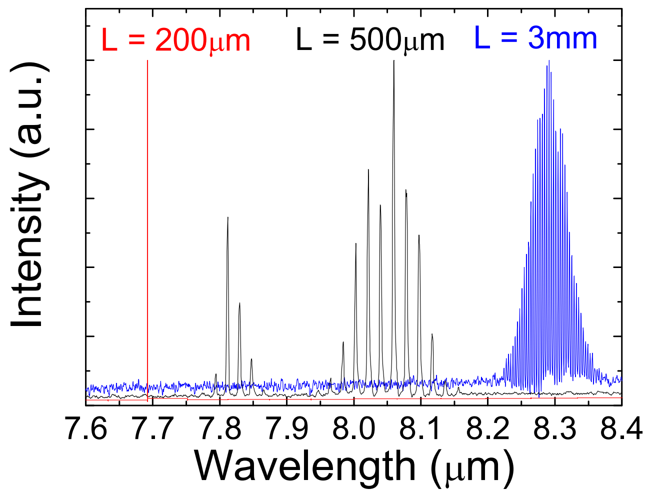
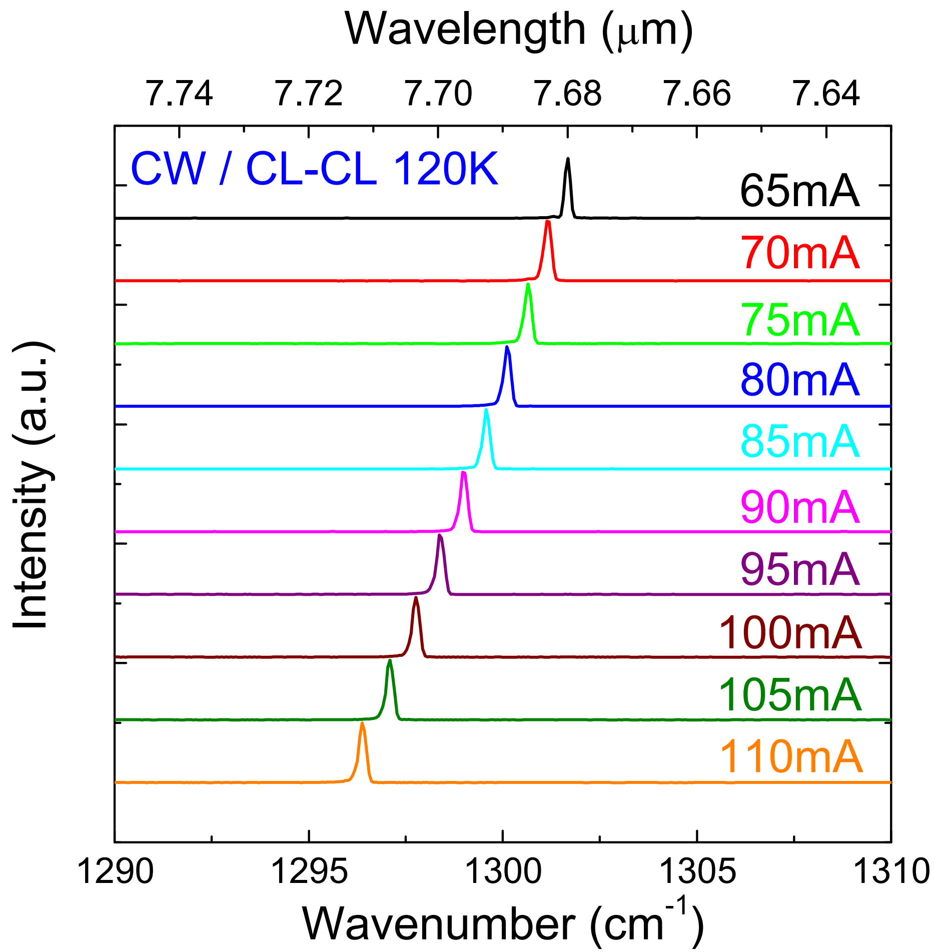
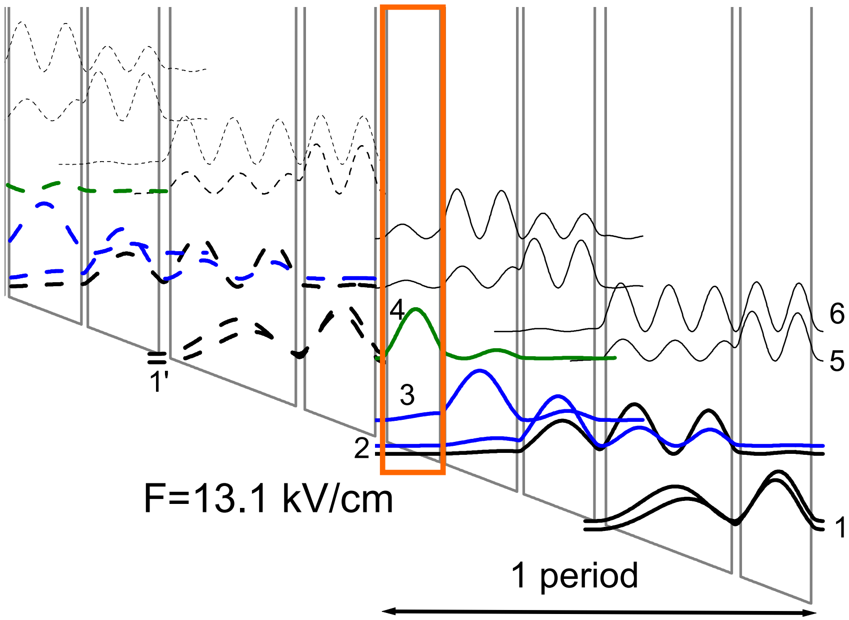




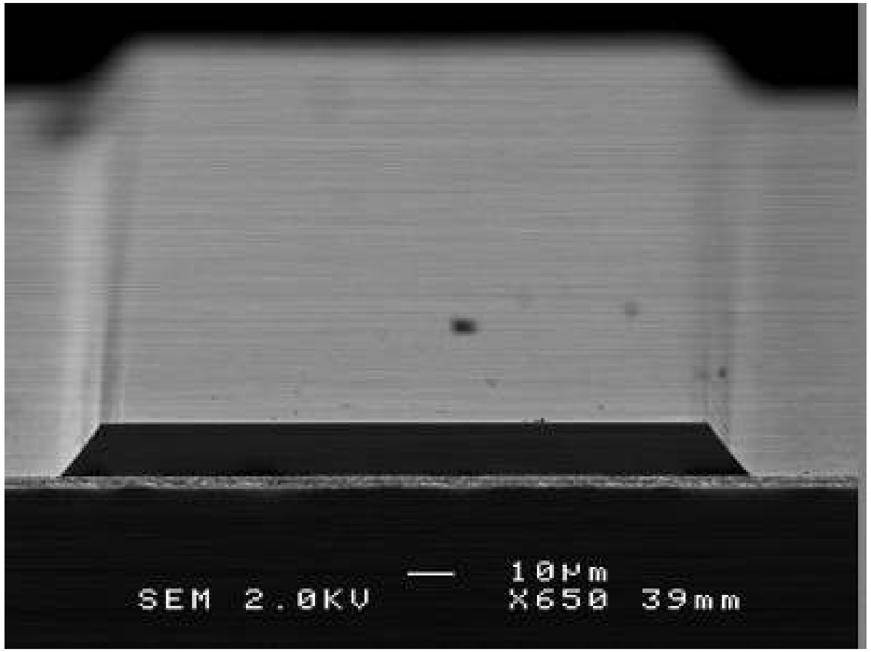


Single mode lasing
without DFB / DBR

InGaAs indirect pumping THz-laser



lattice matched InGaAs/InAlAs/InP system
140-repetition
20/89/**7**/121/**10**/119/**18**/210/**14**/118 (Angstrom)



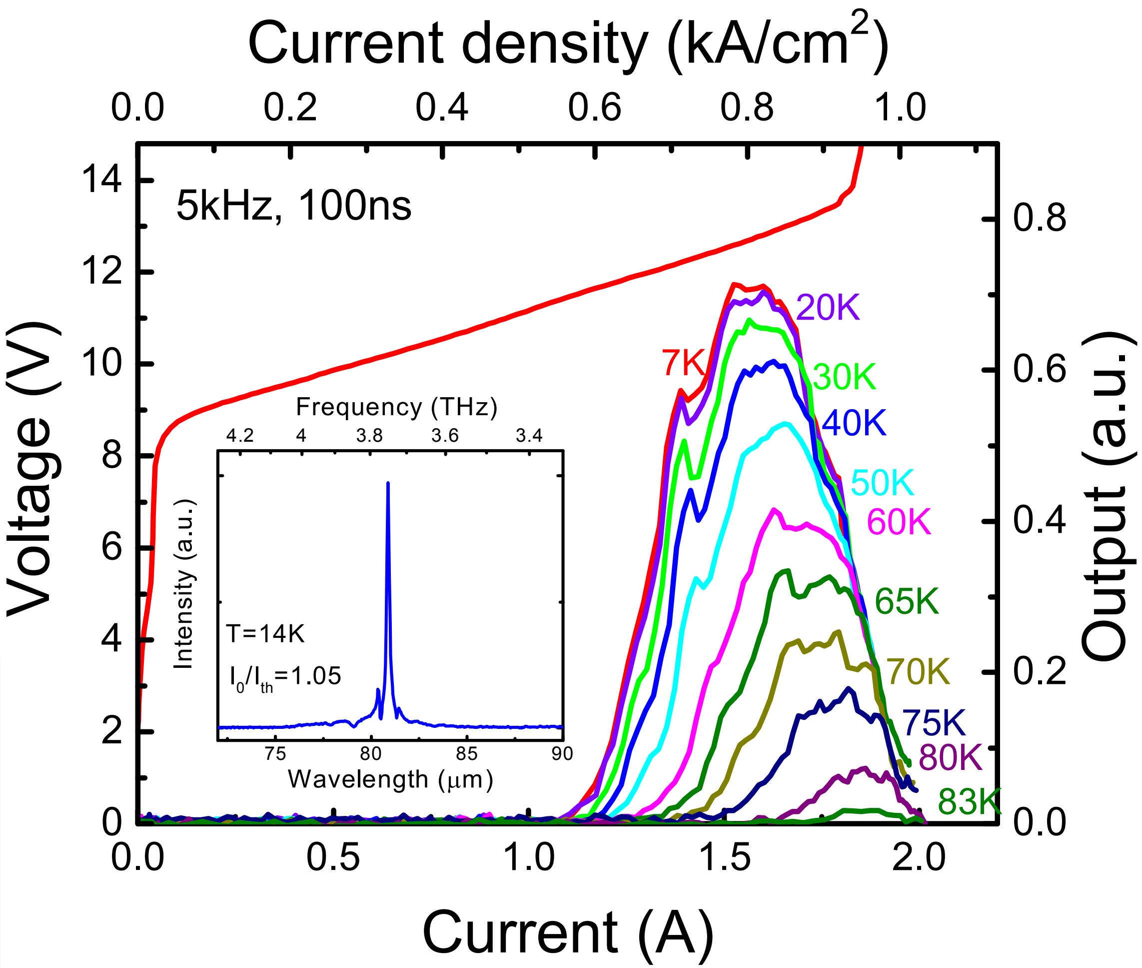
Metal-Metal waveguide
(Au/Ti-Au/Ti)

E_{43}~35 meV
E_{32}~15 meV
Z_{32}~4.3 nm
N_{inj}~6x10^{16} (cm^{-3})

τ_{43}=0.56 ps
τ_{42}=7.5 ps
$\tau_{42'}$=21 ps
η_{pump}~0.9

diagonal transition
LO-phonon depopulation
with two well injector

I-L and I-V characteristics of IDP THz laser



j_{th}~ 550 A/cm^2 at 6 K,

despite the smaller number of cascade stages, *N*~140

DP-QCL with N=222

j_{th}~410 A/cm^2 at 9 K

T_{max}=186 K

S. Kumar et al., APL **94**, 131105 (2009)

Summary and Future Work

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Summary

- ○Intrinsic narrow linewidth : ~260Hz
- ○Realization of High-performance broad-gain QCL
  based on DAU design : ⊿λ/λ 0~40% (tuning of 17% in cw)
- ○Single mode lasing in short cavity (L=200μm) QCL
  low power consumption : threshold current of 90mA at 300K
- ○THz-QCL based on IDP design
  observation of lasing up to 83K

Future Work

- ○Research of the limit of linewidth: a few HZ
  QCL with External Cavity
- ○Very low power consumption Mid-IR light sources
  Polariton Device with Short Cavity
- ○TEC (~250 K) operation of THz QCLs
  Optimization of Active Region based on IDP design

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