Game Changing by Phonon Control

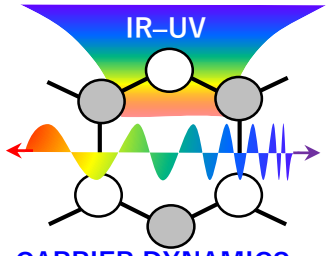
(Ishitani・Ma・Oki)

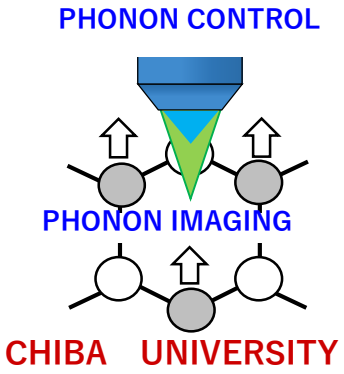
国立大学法人 千葉大学
National University Corporation
Chiba University

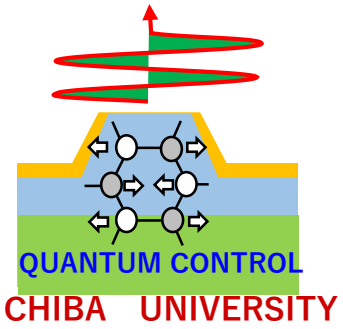
UV-IR emission
Device material properties
Solar Cell material properties
Photonic physics

Optical characterization of Phonon transport
Novel devices by phonon transport control

Innovation toward IR – THz emission devices by phonon and quantum interference





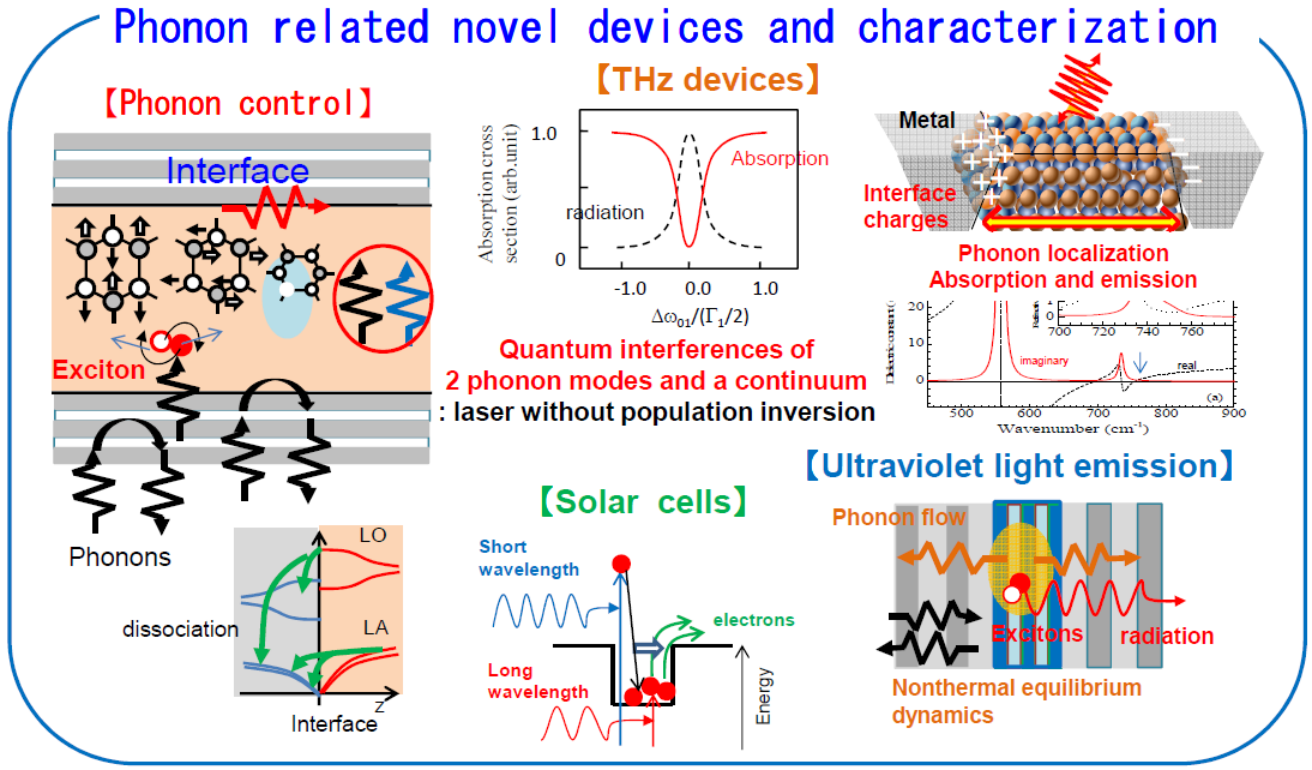


国立大学法人 千葉大学
National University Corporation
Chiba University

Novel device design concept

Control of total energy including thermal energy and electronic energy

Further, Phonon as the protagonist ＋Quantum interference



Instruments

- Fs laser+ ps time resolved luminescence measurement
  Extremely low temperature ～RT
- Raman scattering using multiple lasers
  Nano-micrometer imaging
- FTIR：reflection, radiation, transmission up to 650 K
- Device processing： 1 μm structure
- SEM Cathode Luminescence

Laser：266nm, 325nm, 336nm, 400nm, 532nm, 980nm, 1064nm, 1500nm, nitrogen laser

国立大学法人 千葉大学
National University Corporation
Chiba University

Essence is LO phonon

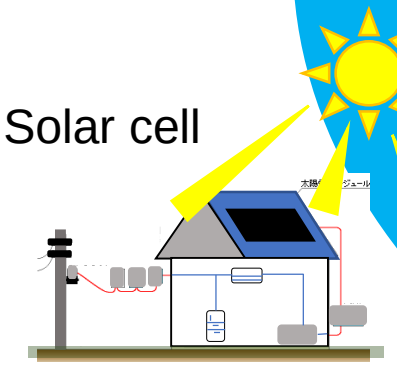
Power devices

Limit of current by phonon scattering

Can we increase the current limit?

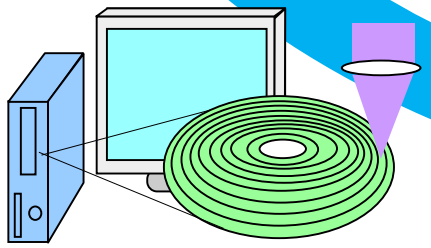
Mobile communication

Solar cell



$h\nu - E_g$: Can we reduce the loss?

Can we increase the radiation rate?



Information storage
UV laser

Activation of nonradiative recombination

Absorption by DNA

Iwasaki Electric web
https://www.iwasaki.co.jp/optics/chishiki/uv/02.html

Deep UVLED

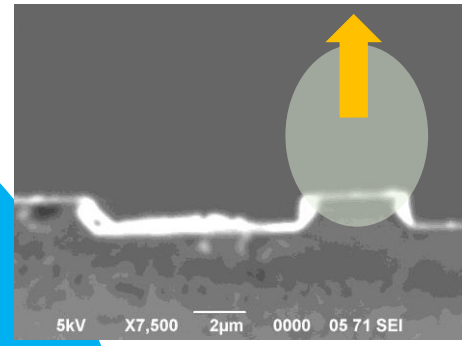
Dismantle of pollution molecules

At present, impossible THz emission at T>RT

Quantum Efficiency a few %

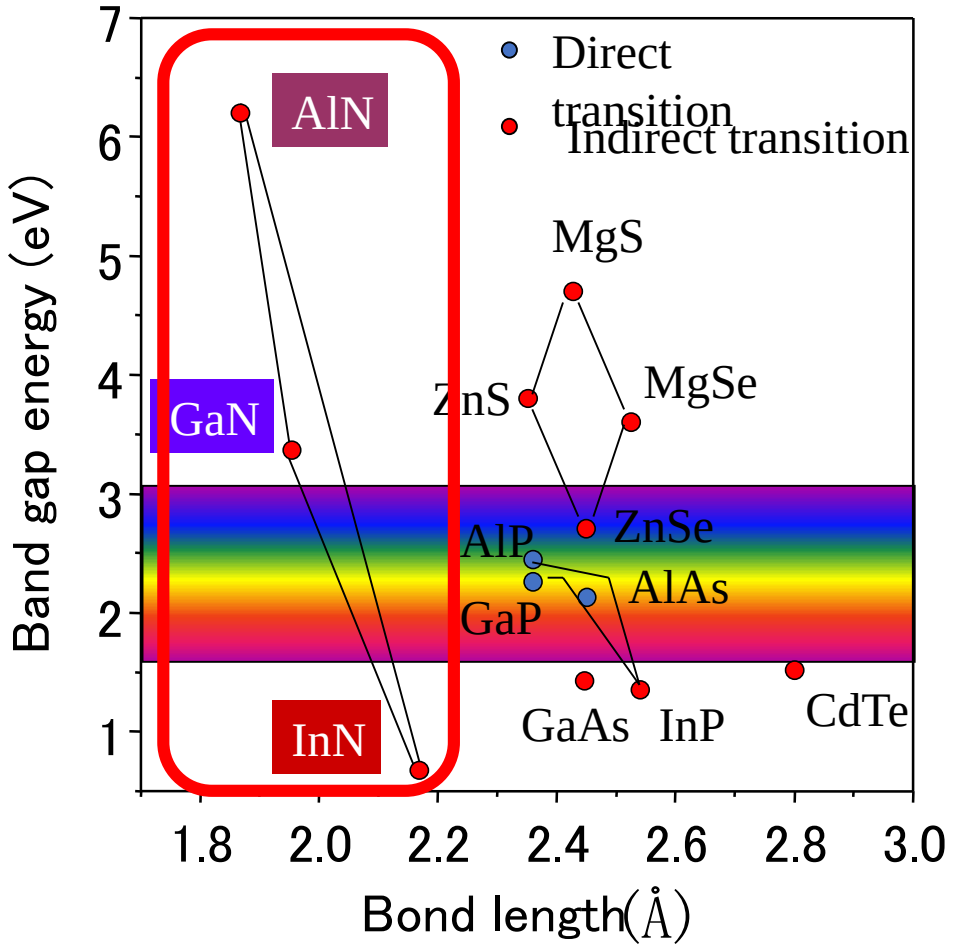
LO phonon resonant THz emission

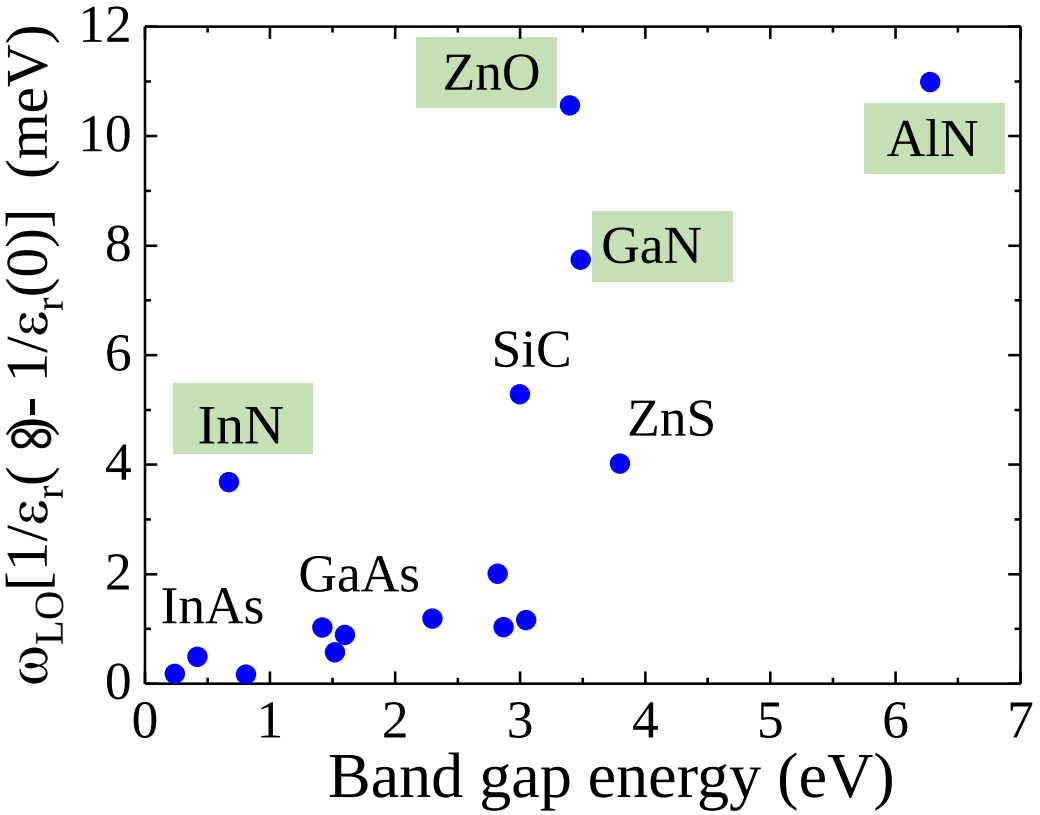
Wireless LAN in near field



Novel concept of phonon based and phonon-control devices

Strong electron-LO phonon interaction of widegap materials





The term in the interaction matrix element

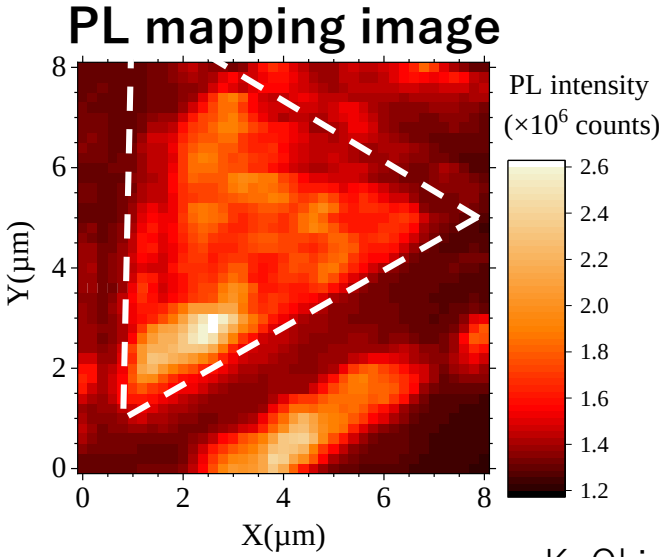
IR–UV

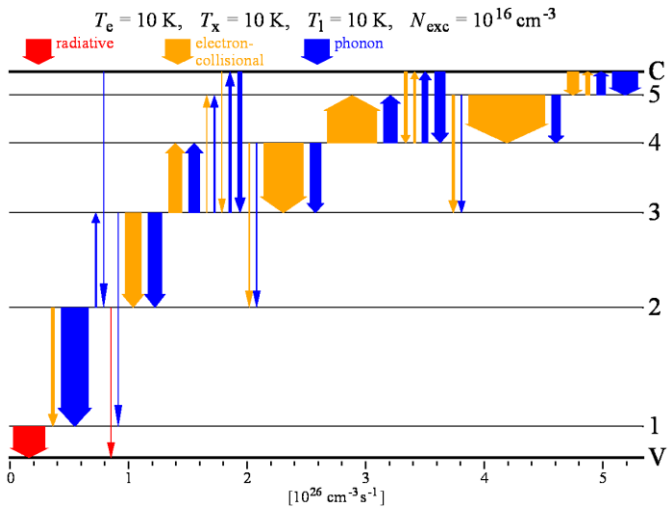
CARRIER DYNAMICS

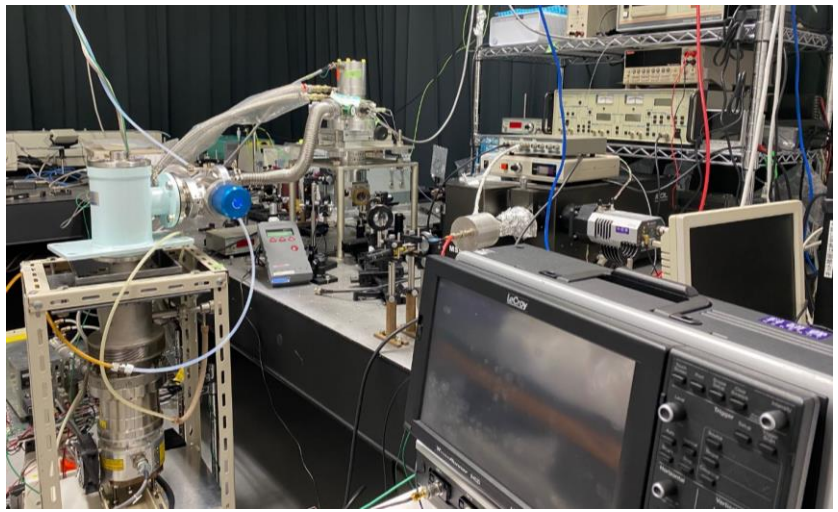
CHIBA UNIVERSITY

IUV LED and LD by phonon exclusion control and high efficiency solar cell by phonon control

- Proposal of phononic-excitonic-radiative model and theoretical analysis of exciton and biexciton dynamics
  The dynamics of electron-hole pairs (excitons), like hydrogen atoms, is analyzed by the integration of whole energy species of electron and phonon systems.
  This methodology is applied to UV emission system.
- Experimental analysis using time resolved photoluminescence.
- Spectroscopy in wide photon energy region from UV to infrared region: excitonic emission and emission related to deep levels. Emission in mid infrared and THz region is detected by an FTIR system.







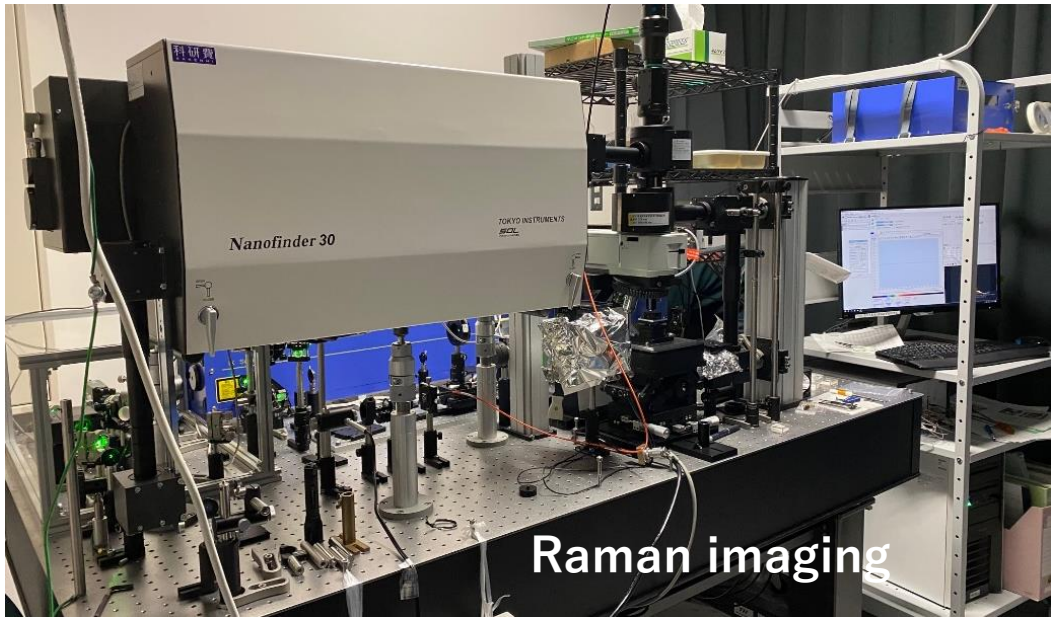
K. Oki *et al.* Phys. Rev. B **96**, 205204 (2017), Y. Ishitani *et al.* Jpn. J. Appl. Phys. **58**, SCCB34 (2019), D. Uehara *et al.* Appl. Phys. Exp. **13**, 061003 (2020)

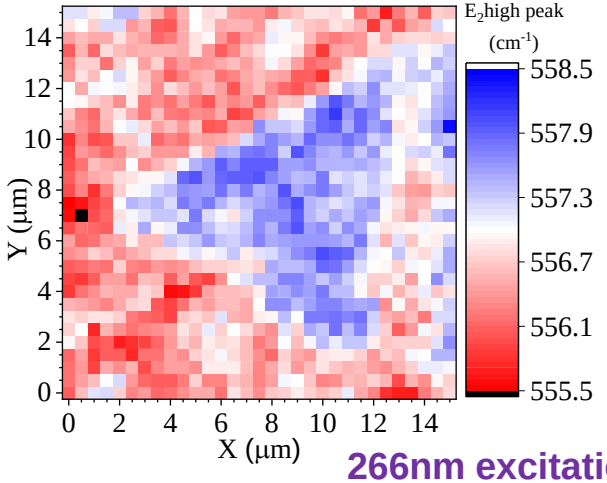
PHONON CONTROL

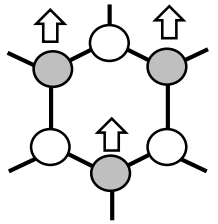
PHONON IMAGING

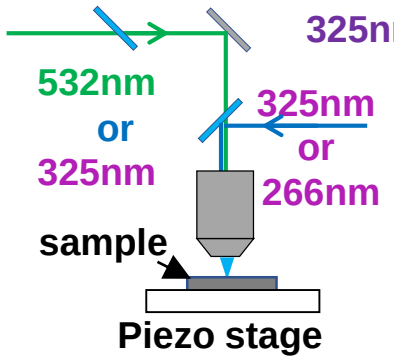
CHIBA UNIVERSITY

Control of energy in nano space : control of phonon transport
Application to LED, LD, HEMT, Solar Cells



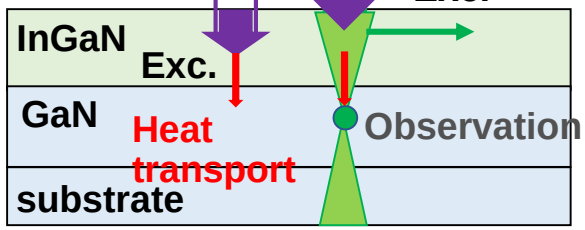




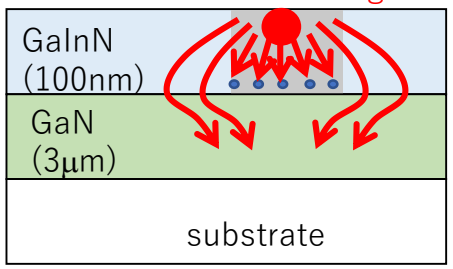


266nm excitation
325nm probe

532nm probe
325nm excitation



Phonon generation



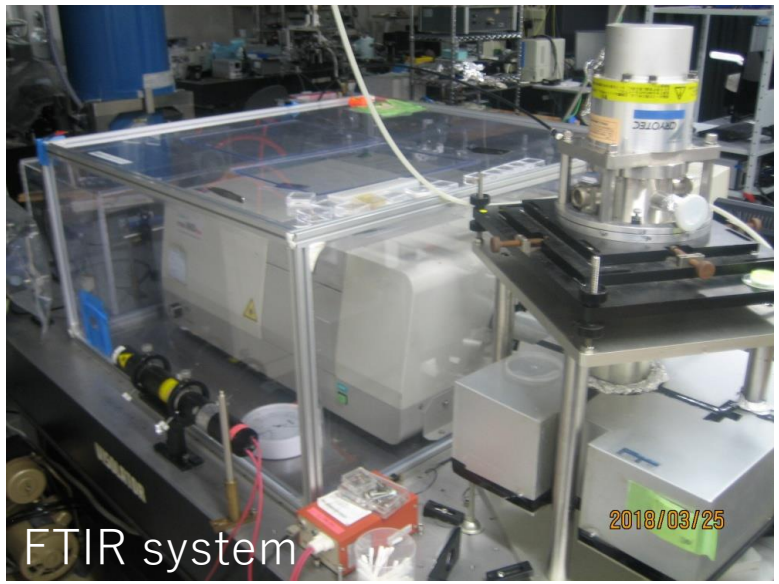
Using double laser beams on to the sample surface:
One for phonon generation and the other for Raman probing

S. Okamoto *et al*. Appl. Phys. Lett. **116**, 142107 (2020)

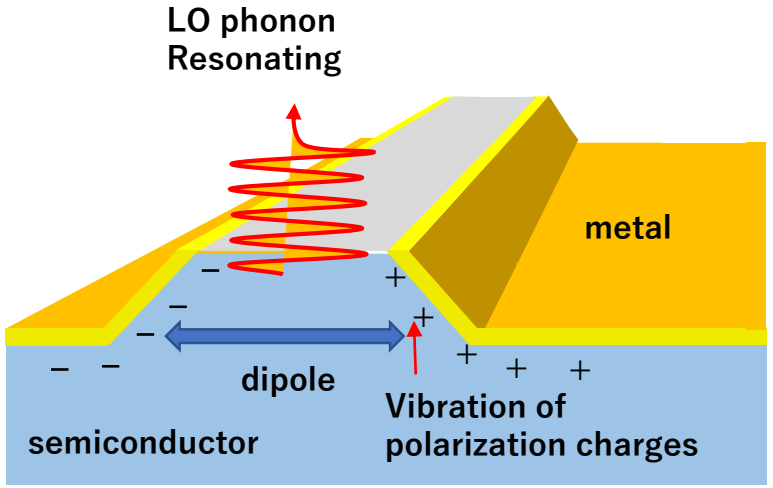
QUANTUM CONTROL
CHIBA UNIVERSITY

THz-mid IR emission by LO phonon and the underlaying physics – quantum interference etc.

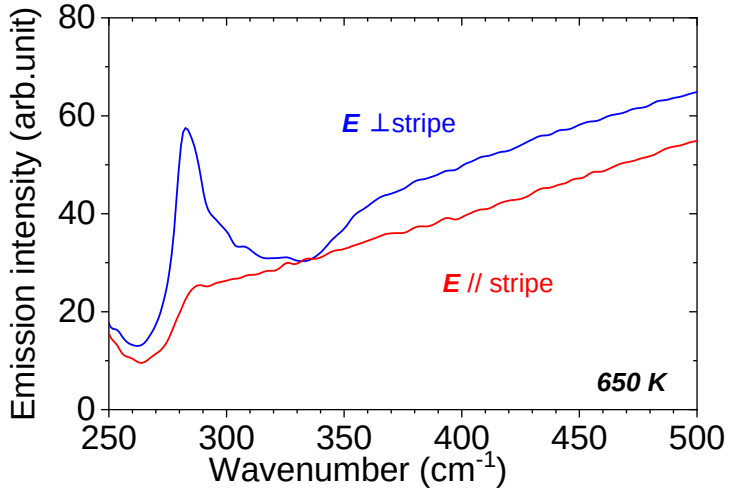
- Electric dipole emission of LO phonon resonant THz-IR light
- Fundamentals of quantum interference in phonon system
- THz-IR optical analysis



FTIR system



Y. Ishitani *et al.* Appl. Phys. Lett. **113**, 192105 (2018)



Microstructures of GaAs-Au
8.5THz emission peak

Research topics for game changing by phonon transport control

UV and visible light emission

- Emission augmentation by controlling phonon processes
- Application of PXR-model to 2D and 1D system
- 2D crystal by controlling 1ML and its application to UV emitter

TCSPC software, fs laser and TCSPC , effective meas. by CCD camera

- Advantage of III-nitrides in visible light emission

Phonon transport analysis

- Space-time resolved Raman imaging using two laser beams
- Thermal analysis of multilayers
- Control of thermal capacity and phonon velocity

THz emission

- THz – mid IR emission by metal-semiconductor microstructures
- Augmentation of THz emission：stimulated emission of phonon
- Fano effect and THz emission by optical excitation of indirect transition materials

Quantum interference THz laser

- Radiation from indirect transition type material by optical excitation
- Quantum interference of 2 LO-valence band transition using alloys