遠赤外線検出器の開発
Development of the Far-Infrared Detectors for Astronomical observation (n-GaAs based extrinsic semiconductor)

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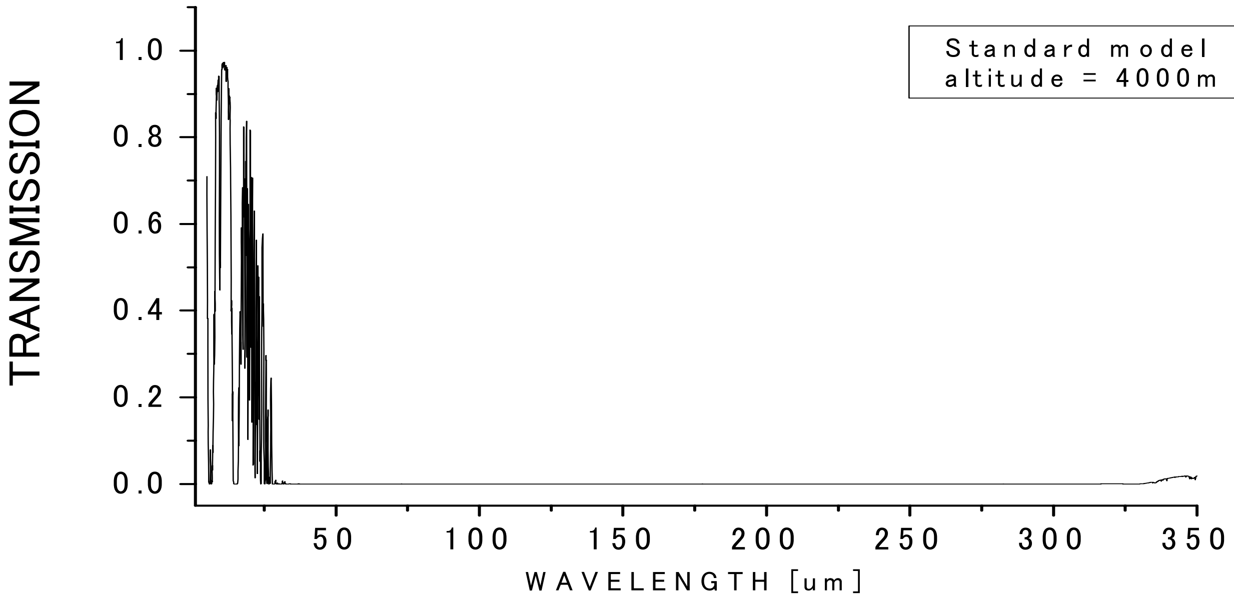
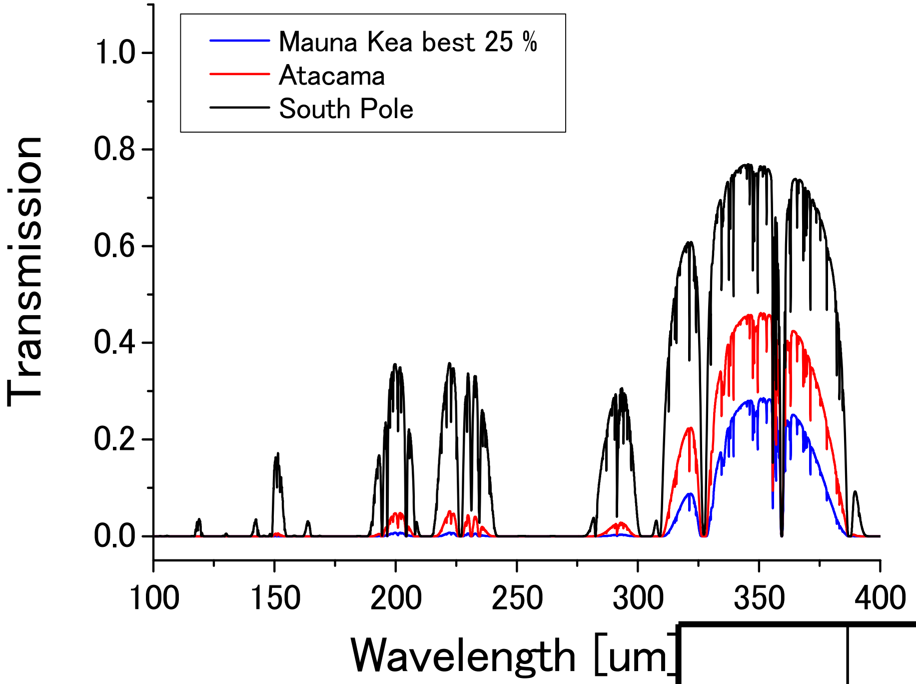
Background

- Far-Infrared Astronomy (50-200 μ m)
  - Strong telluric absorption - Space Astronomy
    - Balloon-borne, Airborne,
    - Satellite (IRAS, ISO, SST, AKARI, …)
  - Significant astronomical information – Low temperature Dust / Gas emission
    - Star formation, Galactic evolution, Cosmology



Antarctic is Attractive IR / submm (THz region)

- Very low perpendicular water vapor ⇒ Open new windows
- Low ambient temperature ⇒ Low background emission



- 200, 230, 280, 320 micron band
- CII (158 micron)
- NII (205 micron)

Lane, (1998)

- There are little scientific results in 200-300 micron region even in space telescope

	PWV [mm]					
	South Pole		Mauna Kea		Atacama	
	winter	summer	winter	summer	winter	summer
25%	0.19	0.34	1.05	1.73	0.68	1.1
50%	0.25	0.47	1.65	2.98	1.0	2.0
75%	0.32	0.67	3.15	5.88	1.6	3.7

FIR/Submm observation method

- Heterodyne detection
  - Very high sensitivity for line emission
  - Very high spectral resolution
  - Difficult for high frequency (shorter wavelength)
- Broadband photometric detection
  - High sensitivity continuum radiation
  - Low-Middle resolution spectrometer

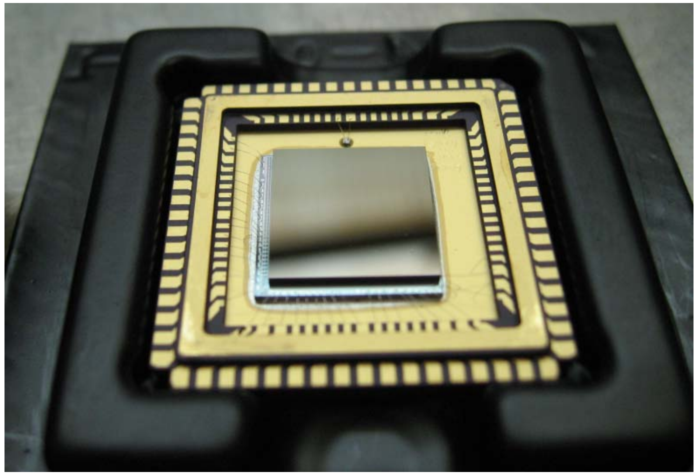
  - Detectors
    - Resistance based Bolometer
    - Semiconductor based Photoconductor
    - STJ, KIDs
    - Quantum dots, Quantum Well based detector

Extrinsic Photoconductor

- Each material covers different wideband wavelength region
  - Si:As(5-28um), Si:Sb(10-38um),
  - Ge:Ga(50-100um), Stressed Ge:Ga(100-200um)
  - GaAs:XX(150-300um) (our development)
- Operating at cryogenic temperature
  - Si based-4K, Ge based-2K, GaAs:XX-1.5K
  - Background limited NEP~10^{-18} – 10^{-16} W/$\sqrt{\text{Hz}}$
- Application of the CCD/CMOS based technology
  - Array
  - Readout circuit

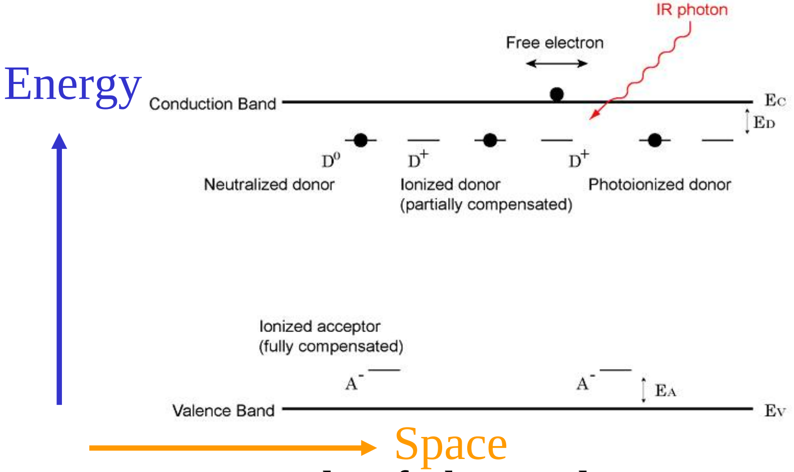
MAX38 Si:Sb array

(128 × 128)



Development of the n-GaAs photoconductor for 300 micron astronomy

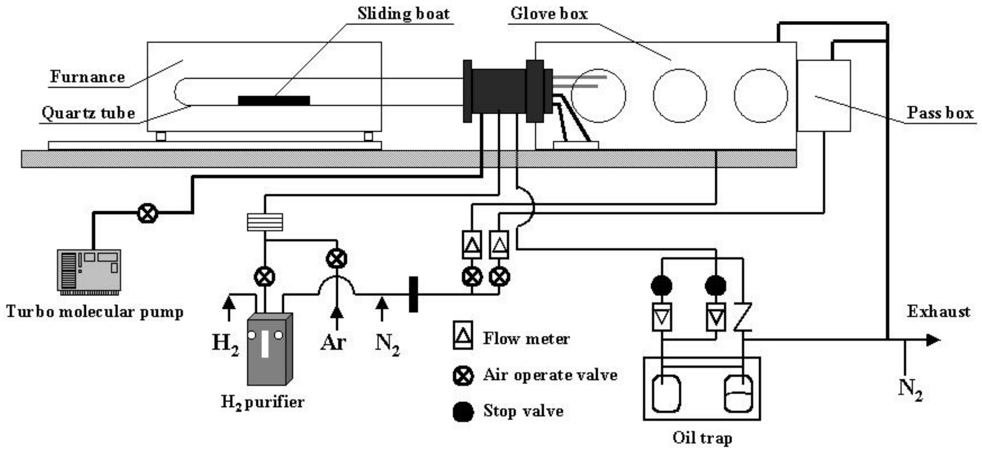
- Wavelength coverage ~ longer than Ge:Ga
  - Shallow donor level~6meV(200um)
- Requirement of the very high-purity GaAs material
  - Low dark current
  - High mobility and photoconductive gain
- Requirement of the large thickness with high-purity
  - Sufficient quantum efficiency with low dark current



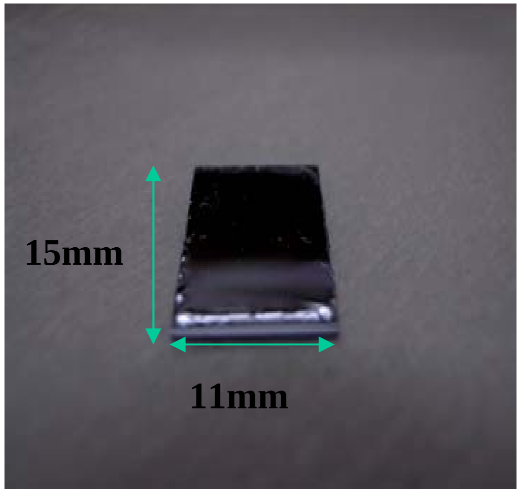
Principle of photon detection

GaAs crystal gwowth by Liquid Phase Epitaxiy

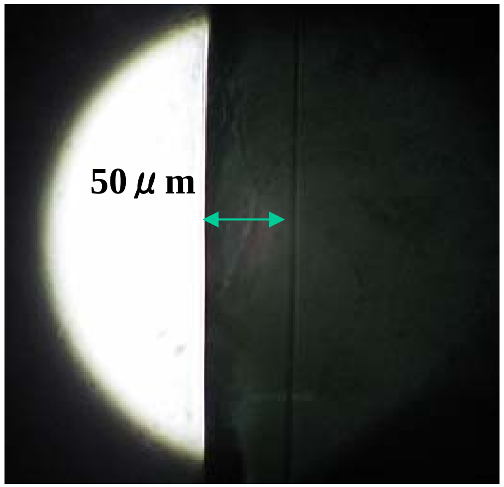
- Low impurity
  - ~10^{13}cm^{-3}
  - C,Si 4series residual impurity
- Sufficient thickness
  - >100 micron can available



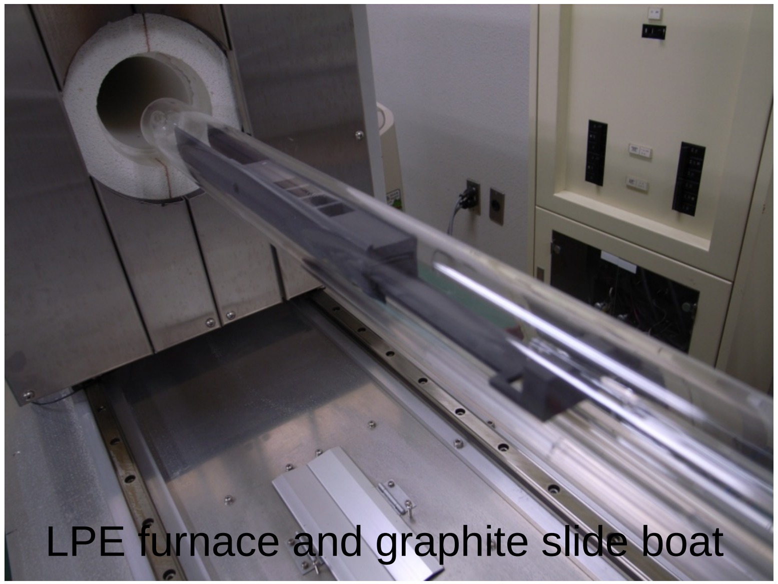
Schematic diagram of the LPE system



LPE grown GaAs/GaAs substrate (semi-insulate)

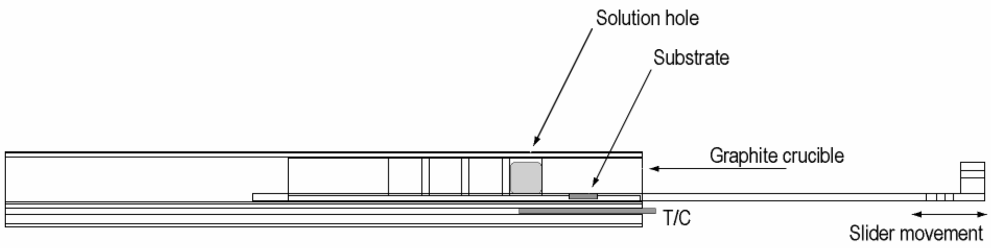


Cross section of epitaxial layer



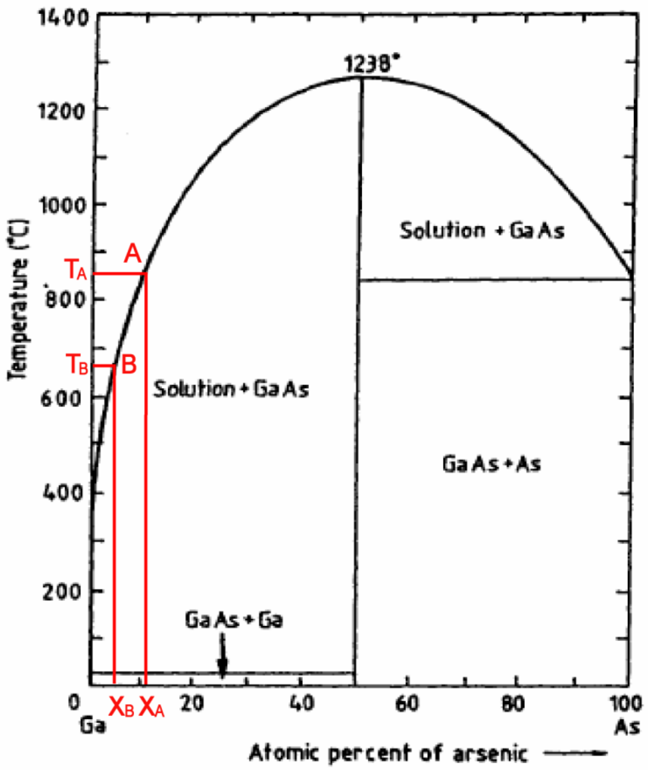
LPE furnace and graphite slide boat

LPE Process and principle of crystal growth



Schematic diagram of graphite sliding boat

Liquid – Solid phase diagram of Ga/As system



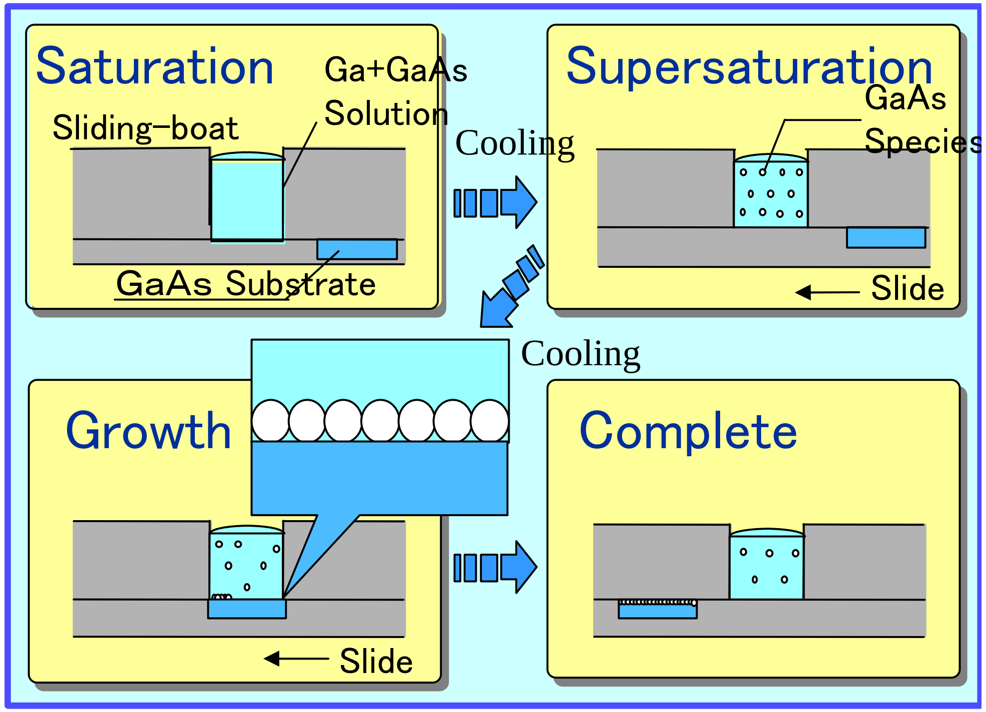
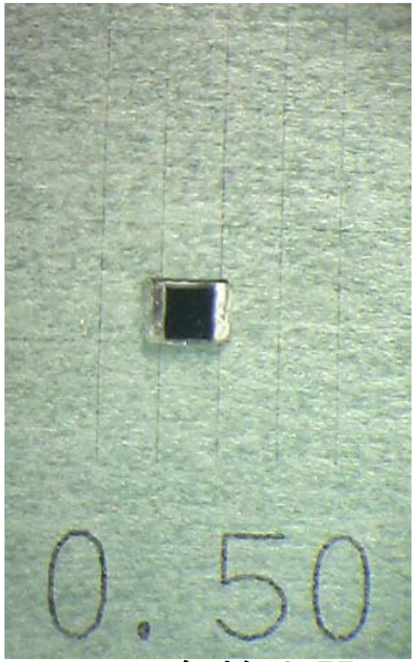


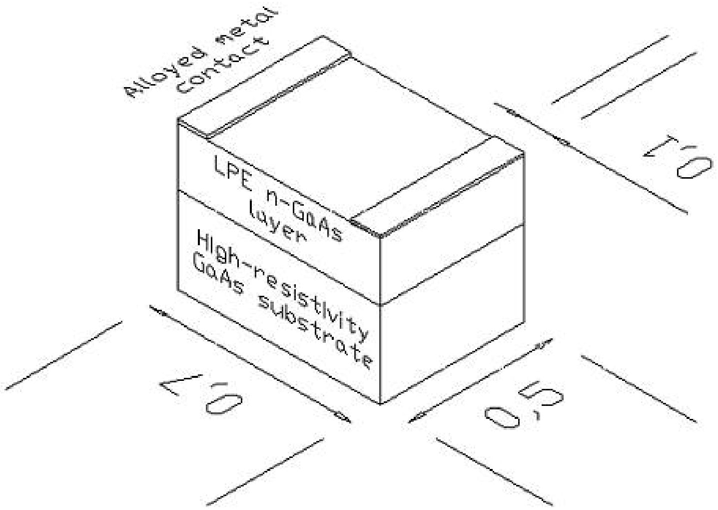
Diagram of the LPE process steps

Fabrication of the test detector chip

- Dicing/Lapping a LPE grown GaAs sample
- Transverse metal ohmic contact (Au-Ge-Ni alloy)



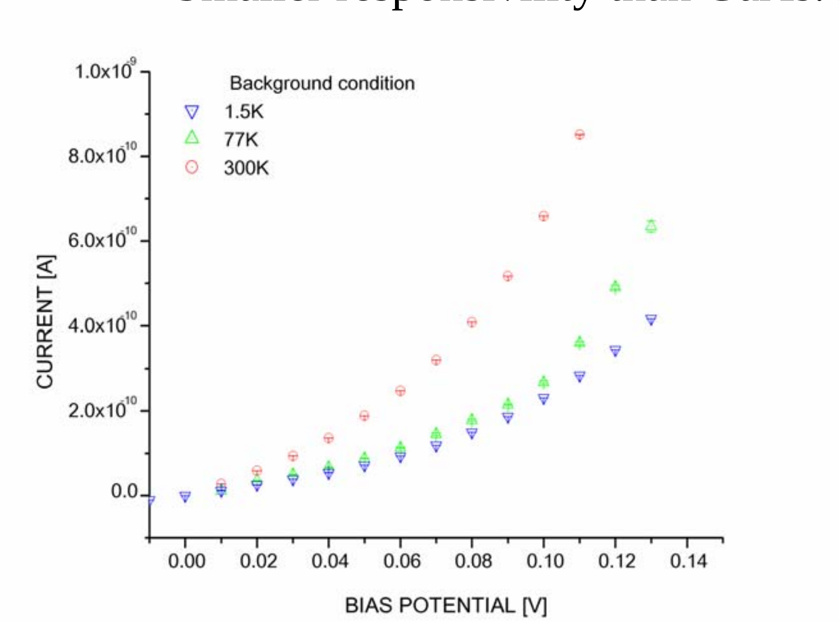
0.5 mm角検出器チップ



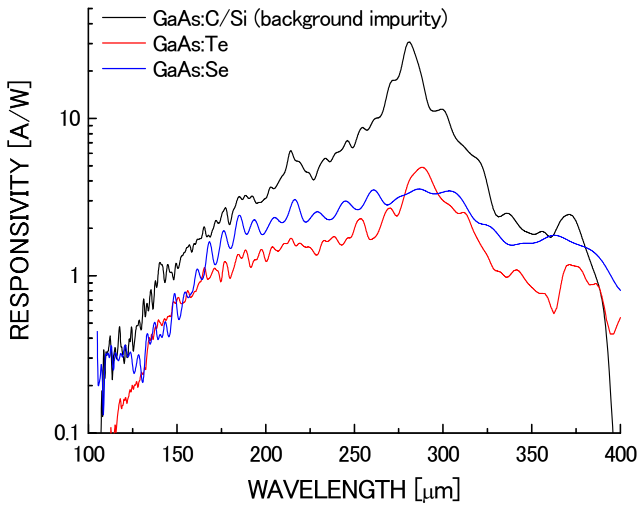
Transverse型電極/検出器構造

Performance of the n-GaAs photoconductor

- GaAs:C/Si (Background doping)
  - Donor impurity : 5 × 10^{13} atoms/cm^3
  - Wavelength coverage : 150-320 micron
  - NEP : 3 × 10^-16W/√Hz at T=1.5K, λ =300um (with low background radiation)
- GaAs:Te, GaAs:Se
  - Donor impurity : 1 × 10^{14} atoms/cm^3
  - Smaller responsivility than GaAs:C/Si due to low mobility



I-V characteristics with different background



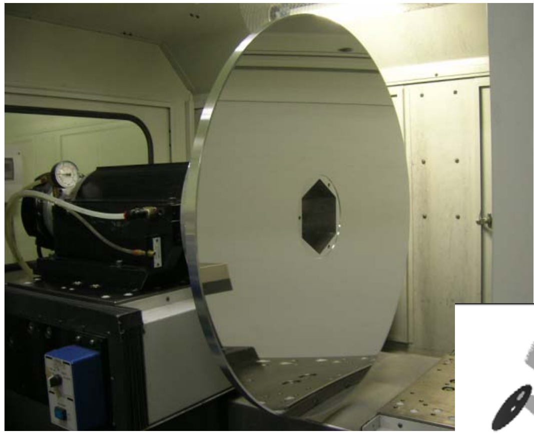
Spectral response of the n-GaAs photoconductors

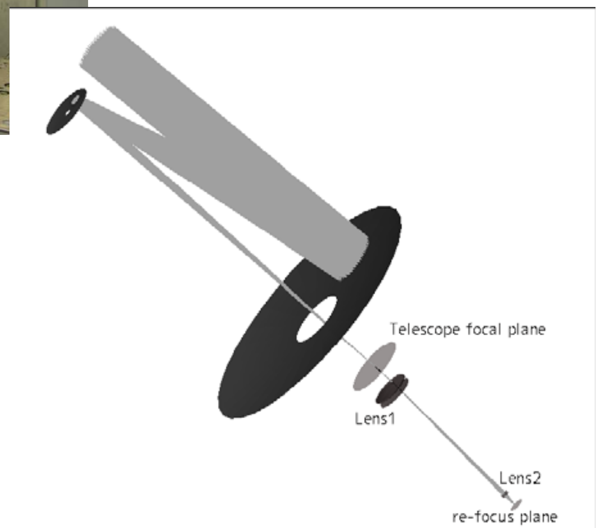
Balloon-borne project 'Tera-GATE'

- THz Observation with GaAs Photoconductors and a balloon-borne TElescope
  - Image stabilizer for compensating a balloon fluctuation
  - GaAs photoconductor array / Low resolution Spectrometer

Optics (Kataza and Kamizuka)

- Primary mirror
  - 70cm spherical shaved Aluminum
- Movable secondary mirror
  - Image stabilizer
  - 5 axis control（parallel move＋tip tilt）
  - RMS0.1deg (6 arcmin) to <30 arcsec

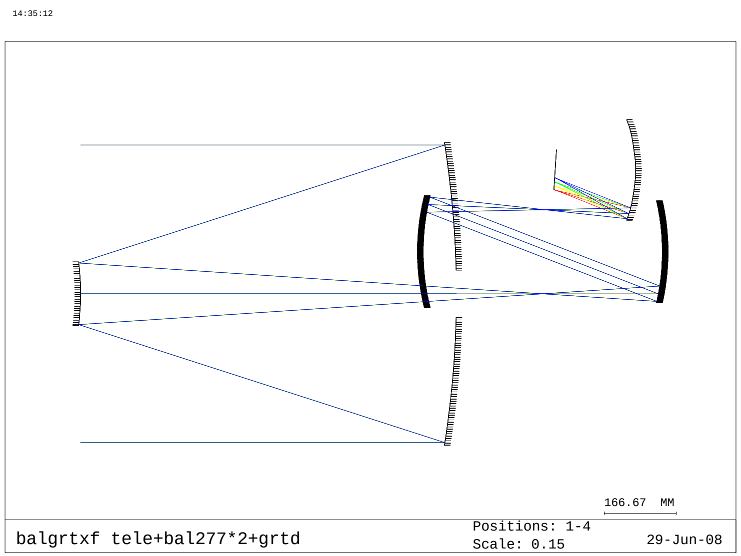


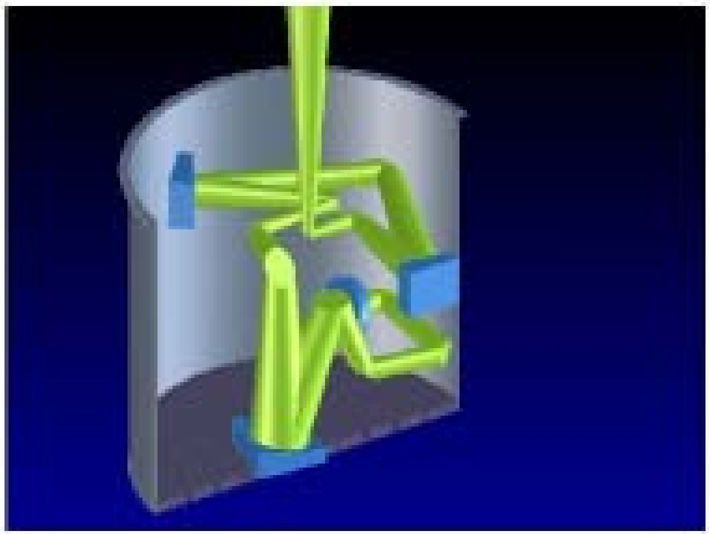


THz Low resolution spectrometer Multi-band photometry

- Spectrometer
  - Diffraction grating
  - Arrayed GaAs photoconductor

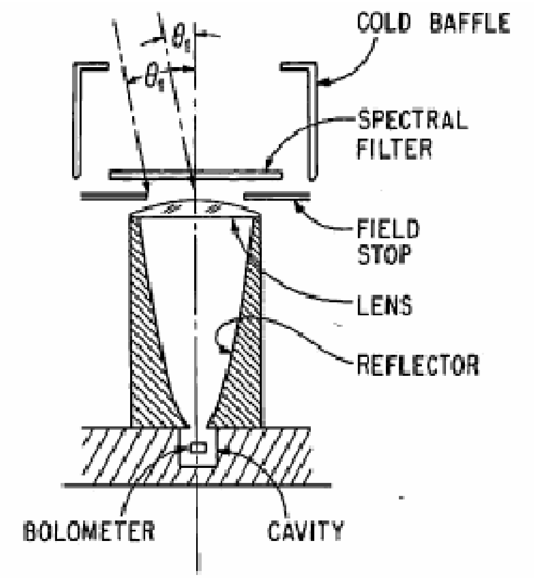
Optical and mechanical rough design





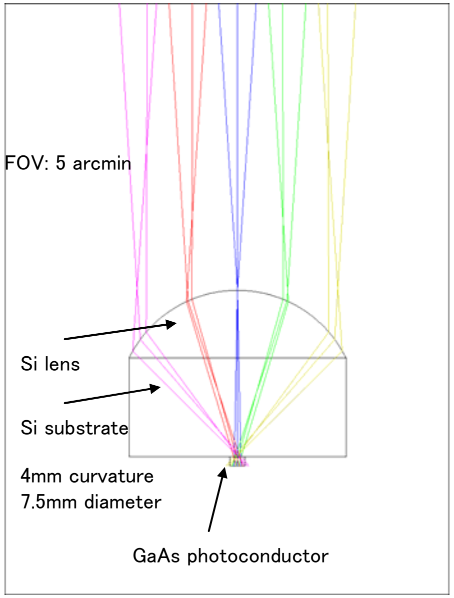
Si lens coupling for arrayed detector

- Problem : Size mismatch between the detector chip and PSF
  - Smaller detector chip is ideal for photoconductor(~0.5mm)
  - F/5, λ =300micron →2.44F λ = 3.66 mm
- Si lens direct coupled Field optics for Focal Plane Array
  - Compact, high throughput, wideband field optics



Reflecting cone + Optical cavity

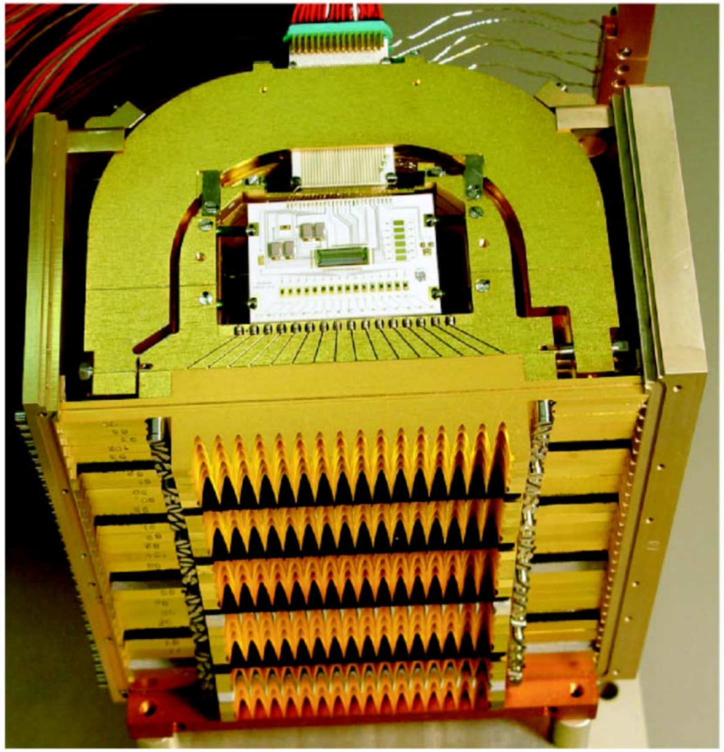
(Hildebrand, Appl. Opt, 1986)



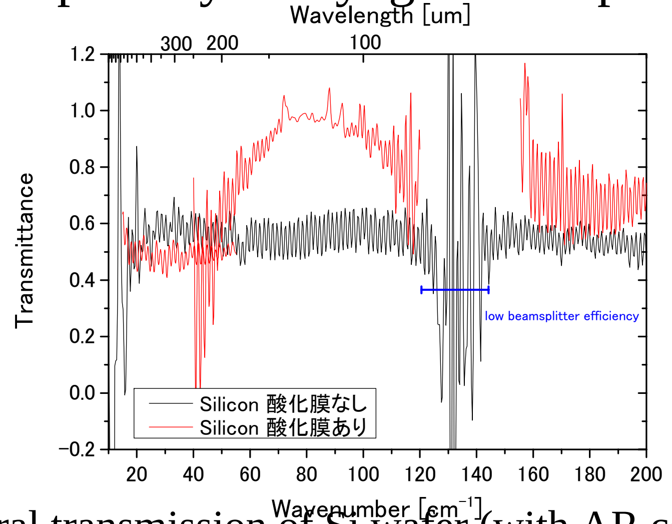
Refracting collimator + Self cavity

Large format Focal Plane Array with Si micro lens

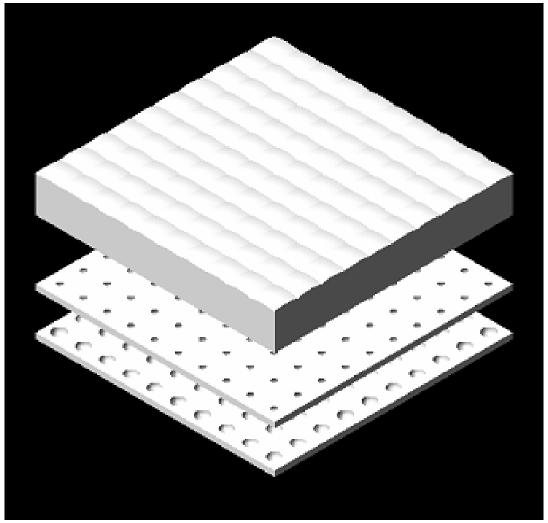
- Si : high refractive index → compact device size and small PSF
- Si : there is no transition band → high transparency in cryogenic temperature



cf. Herschel / PACS 25 x 16 stressed Ge:Ga array



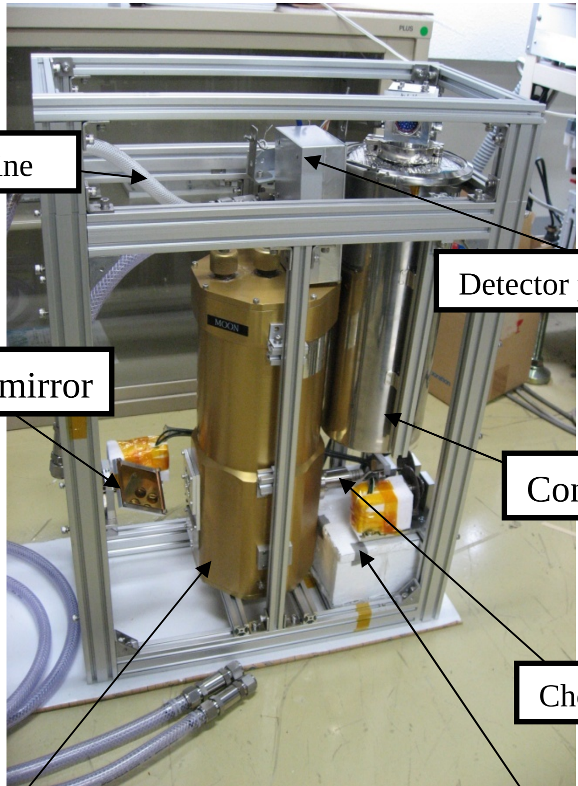
Spectral transmission of Si wafer (with AR coating)



Si lens array design with metal cavity array

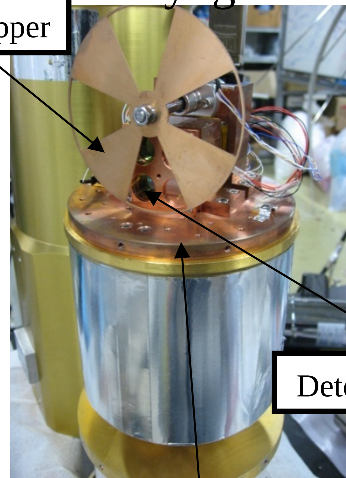
TG-ZERO (balloon-borne THz photometer module)

- 4ch THz photometer
- Balloon-borne air background radiation monitor



Picture of the TG-ZERO

Cryogenic detector part

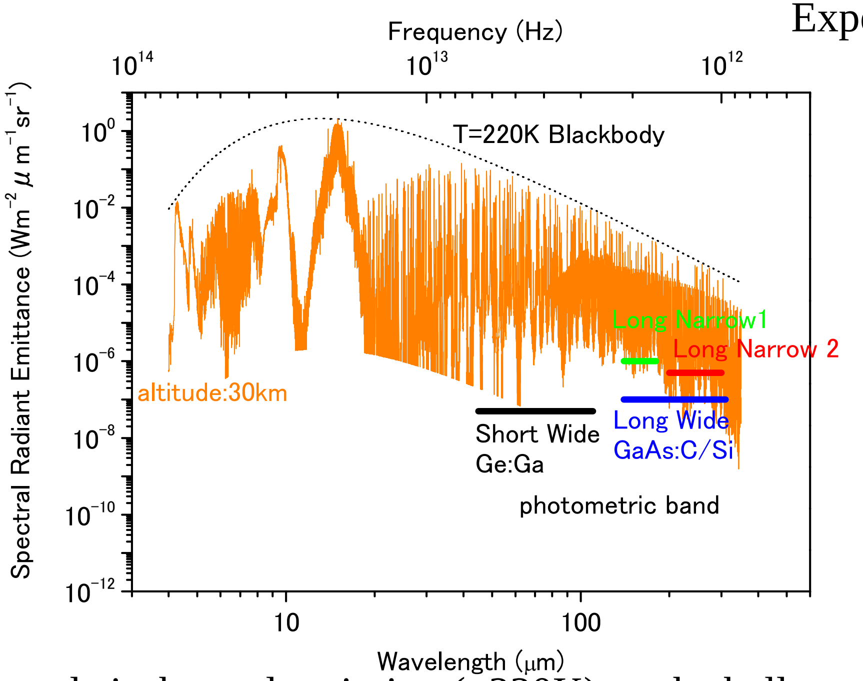


Total Size : 250 x 500 x 700 mm3
Total Weight : <30 kg
Detector : Ge:Ga (Short Wide)
GaAs:C/Si (Long Wide,
Long Narrow1, Long Narrow2)
Detector Temperature : ~2K

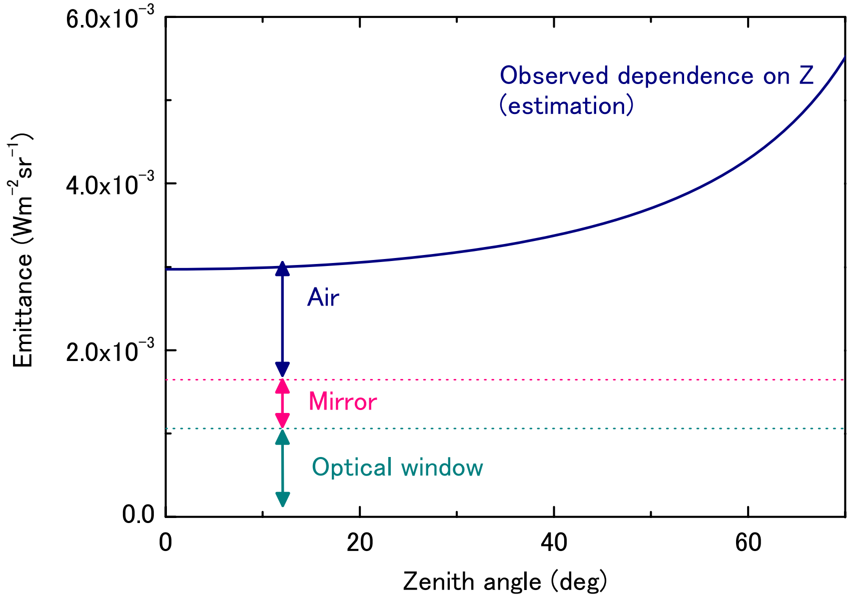
FOV : ±1° / channel

TG-ZERO target

- Monitor the fluctuation of air background radiation at balloon altitude (~25km)
- For optimization of the chopping frequency of the Tera-GATE



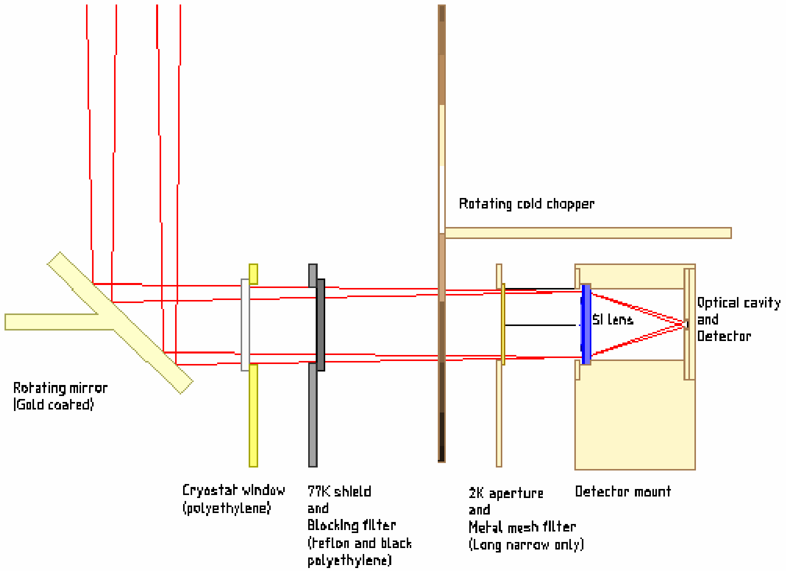
Expected dependence of air thermal emission on zenith angl



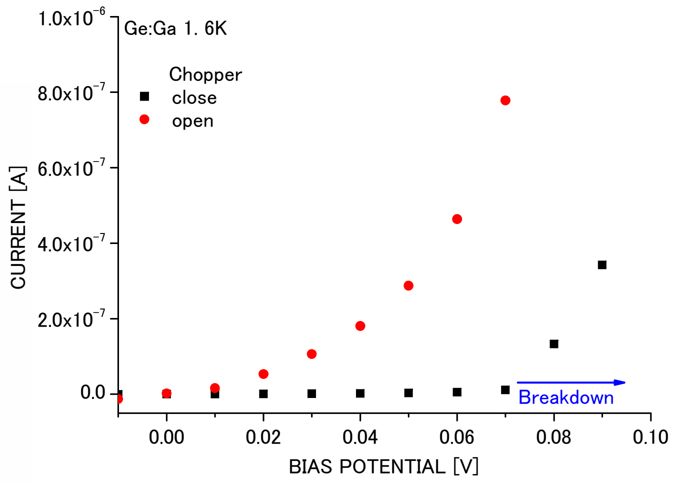
Expected air thermal emission (~220K) at the balloon altitude (~30 km)

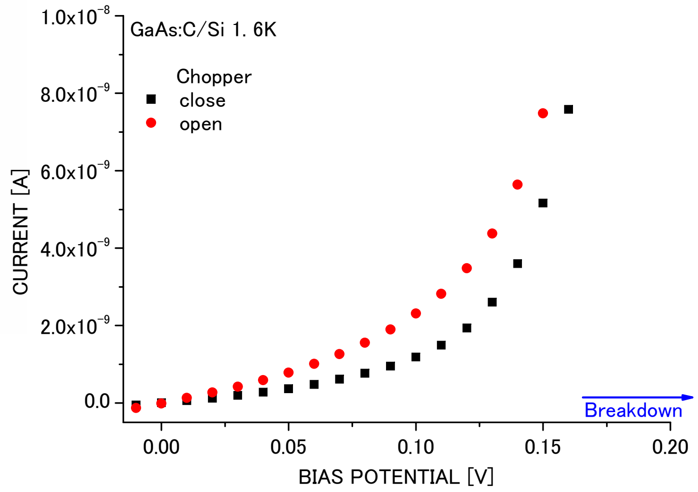
and photometric band (SW, LW, LN1, LN2)

TG-ZERO Optics and I-V characteristics



Schematic diagram of the optics





I-V characteristics of wide band channels (SW and LW)

Each channel see ~300K air when chopper is open

Summary

- New transmission window in Antarctic is attractive for THz observation
  - 200-300 region is very unique
  - Large diameter telescope is available?
  - Accessibility is good
- Development of N-type GaAs based extrinsic photoconductor is progressing
  - High quality GaAs material preparation by LPE growth
  - Detector chip fabrication and test is done
- Balloon-borne telescope project is progressing
  - ‘Tera-GATE’ and TG-ZERO
  - Arrayed detector in THz region
  - Technical and device sharing is available for space-borne and ground based telescope ?