תחום התקני מצב מוצק (המ"מ)
ואשכול גידול השכבות (אשכול התקנים)
במרכז הפוטוניקה

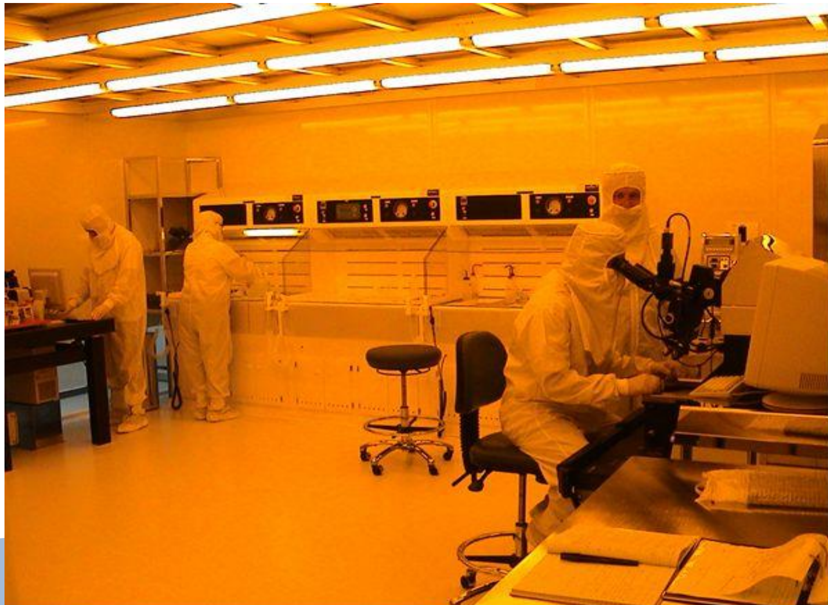
Solid State Devices group
and
The Photonic Devices branch at
the Israeli Center for Advance Photonics (ICAP)

Solid State Devices Group

(8-Ph.D, 2-M.Sc, 1-Stud., 1-Tec, 2- consultants)

Main Facilities

- Clean room (70-m^2, Class-100)
- MOCVD (As/Sb/P)
- Metal deposition (E-Beam, Sputter)
- RIE, PECVD, RTP
- Characterization equipment:
  - HR-XRD (ICAP)
  - Photoluminescence (0.3-14μm, 10-350^{0}k)
  - Life-Time (10-350^{0}k)
  - Hall Effect
  - FTIR
  - Ellipsometer
  - Probe station, Black body, I-V, C-V

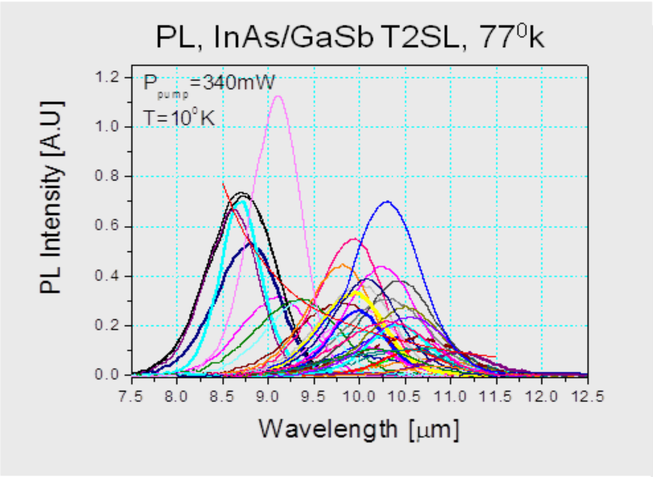


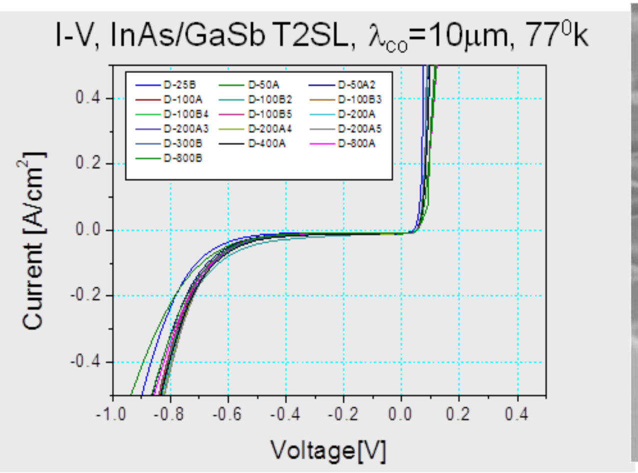
Main activities:

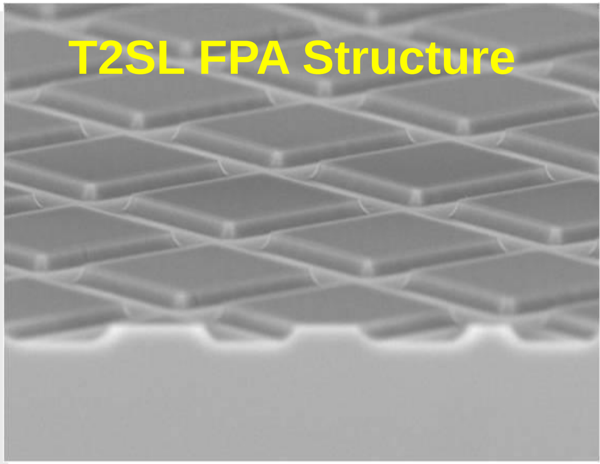
- IR Semiconductors (Detectors, DL, QD)
- Frequency conversion devices
- GaN (Detectors and Photonic devices)
- UWB Silicon devices

IR Semiconductors (Detectors)

- InSb Epi layers for MWIR detectors (MOCVD)
- InAsSb MWIR detectors (MOCVD)
- InAs/GaSb Type-2 Super-Lattice LWIR detectors by MBE (SCD and commercial vendor)



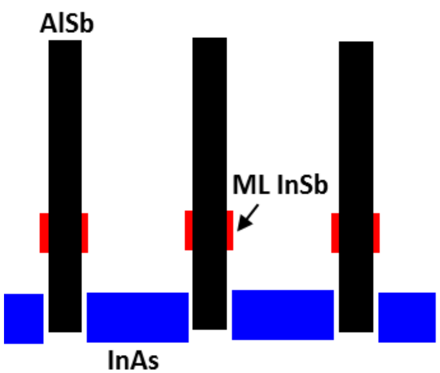




- Currently - extended SWIR (1-2.6µm MBE and MOCVD)

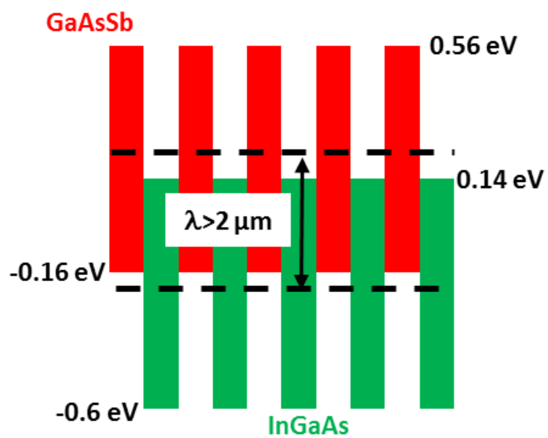
E-SWIR – 3 types of detectors

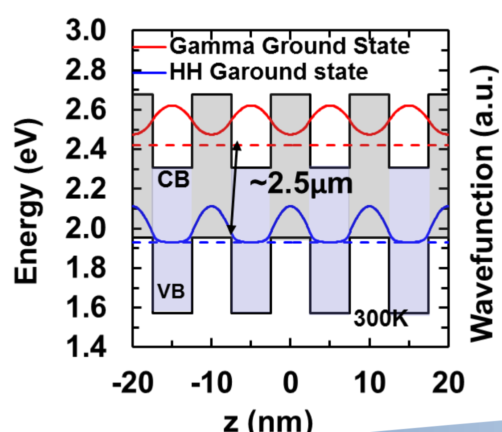
InAs/AlSb
pn Junction, T2SL
Epi layers - SCD



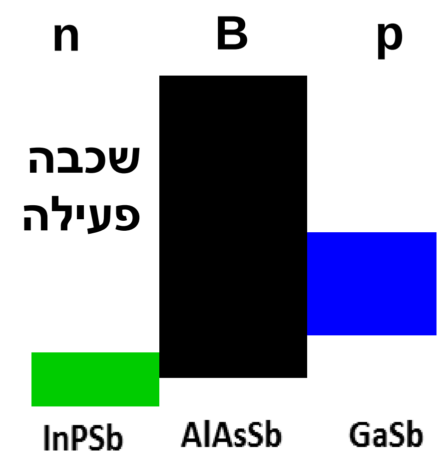
T2SL: Type-2 Super-Lattice

InGaAs/GaAsSb
pn Junction, T2SL
Epi layers - IQE



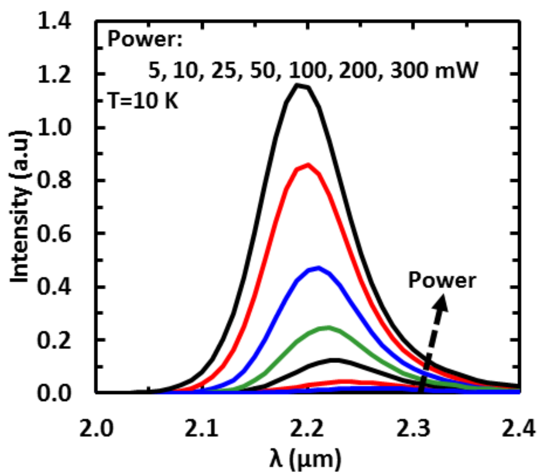


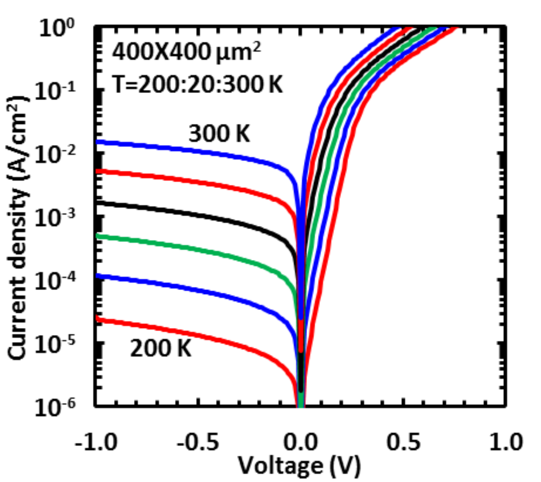
GaSb/AlAsSB/InPSb
pBn barrier structure
Epi layers - IQE



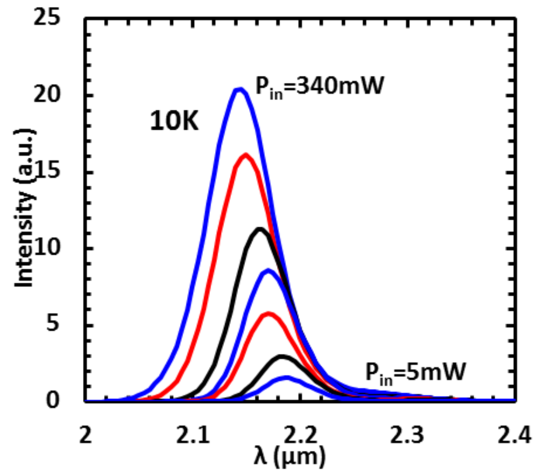
PL and Dark current Characterization

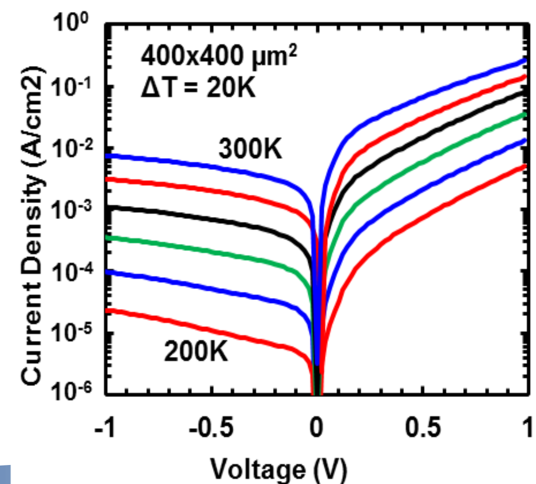
InAs/AlSb
Epi layers - SCD
λ_{PL}~2.2 µm : 10 K ב
λ_{PL}~2.35 µm : 300 K ב



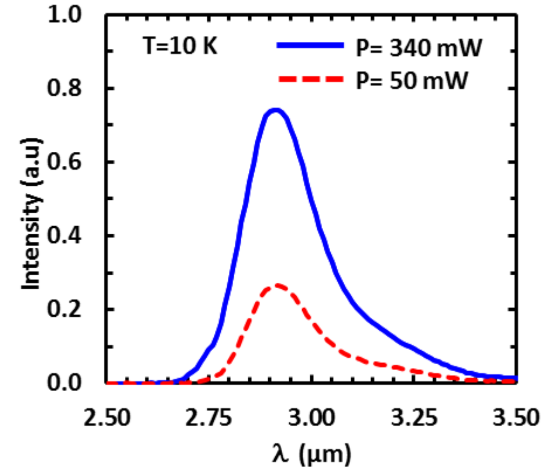


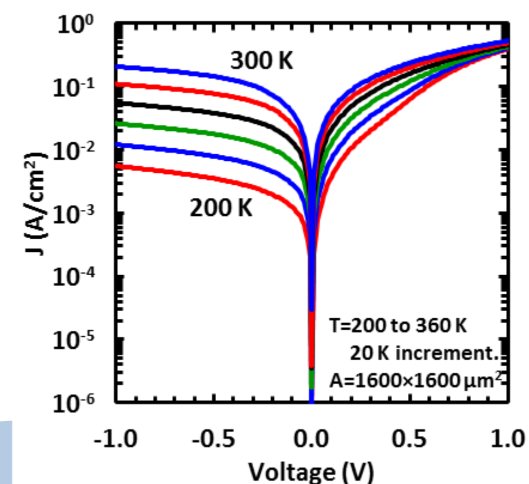
GaAsSb/InGaAs
Epi layers - IQE
λ_{PL}~2.2 µm : 10 K ב
λ_{PL}~2.35 µm : 300 K ב





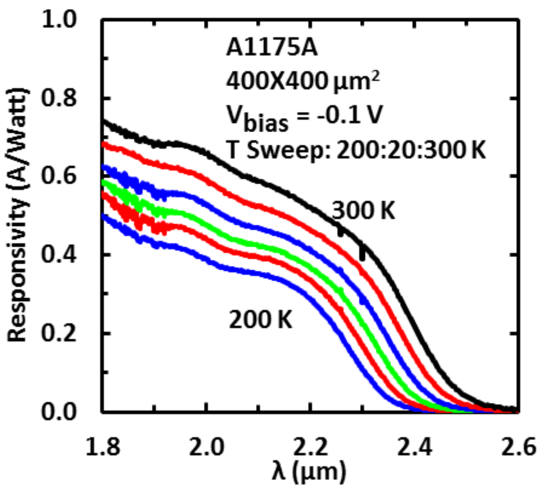
InPSb
Epi layers - IQE
λ_{PL}~2.9 µm : 10 K ב
λ_{PL}~3 µm : 300 K ב

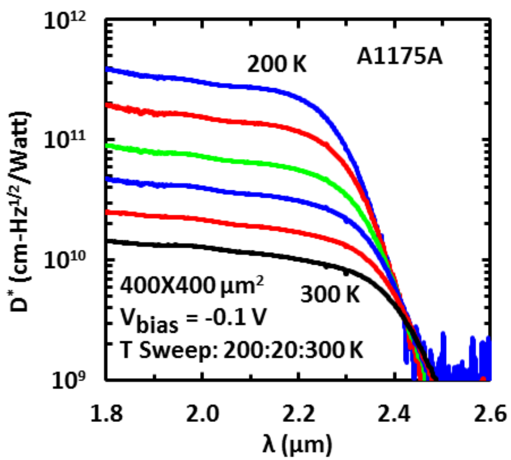




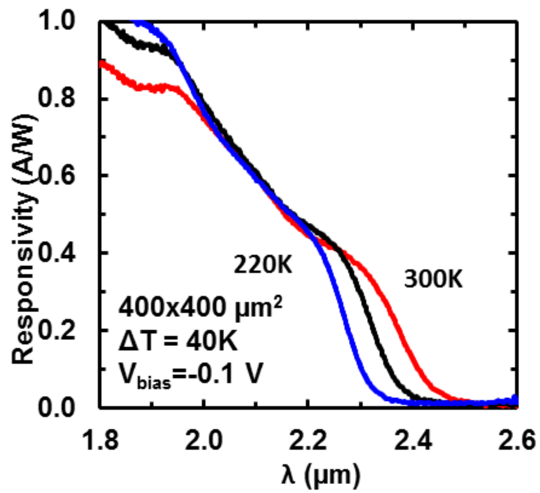
Spectral response and D* Measurements

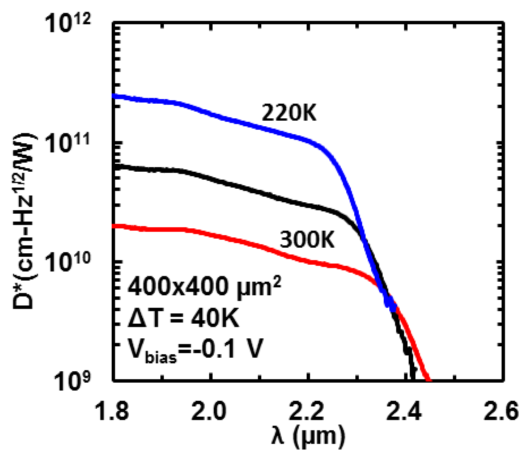
InAs/AlSb



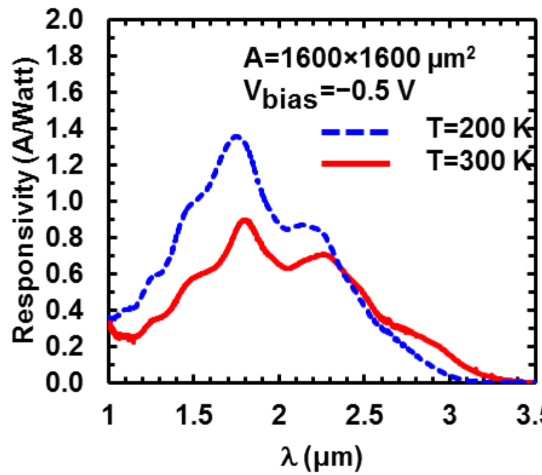


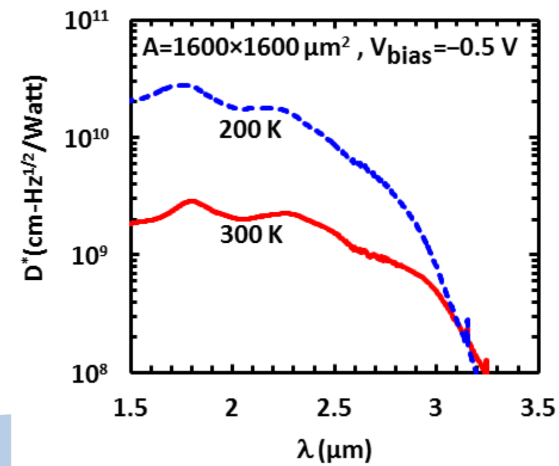
GaAsSb/InGaAs (Mesa)





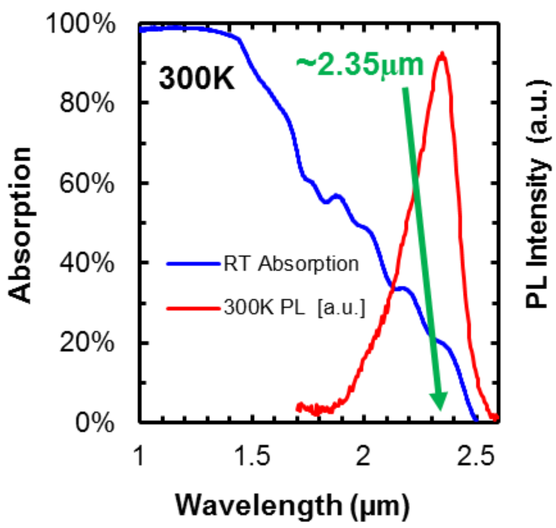
InPSb

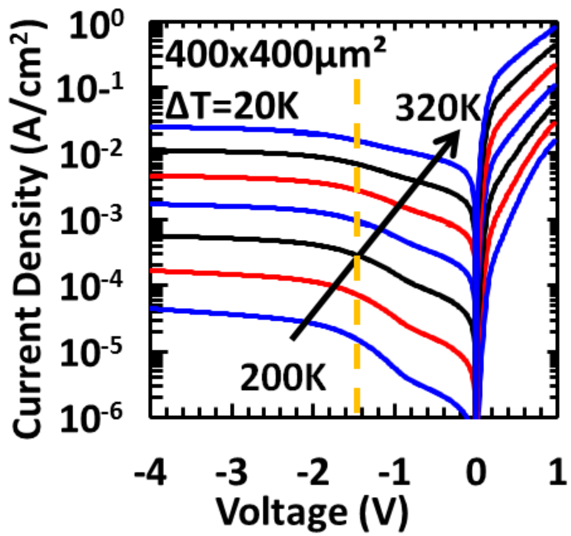




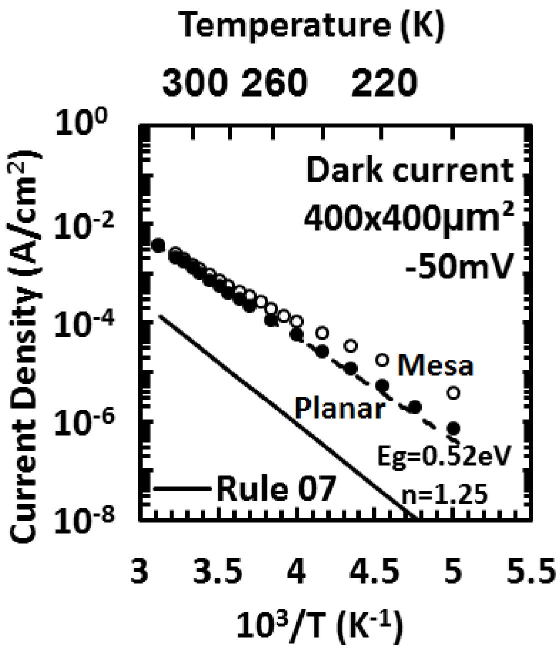
E-SWIR Detector, GaAsSb/InGaAs Type II Superlattice (T2SL) pn Junction, Planar device Absorption and I-V Measurements

- Dark current 1.2mA/cm ^{2} at 300K (11µA/cm ^{2} at 230K) at V= -50mV
- About 1.5 orders of magnitude above Rule 07 (300K)
- R_0A Product 28Ω·cm² at 300K (1220Ω·cm² at 230K)
- Ideality factor ~1.25 at high temperatures





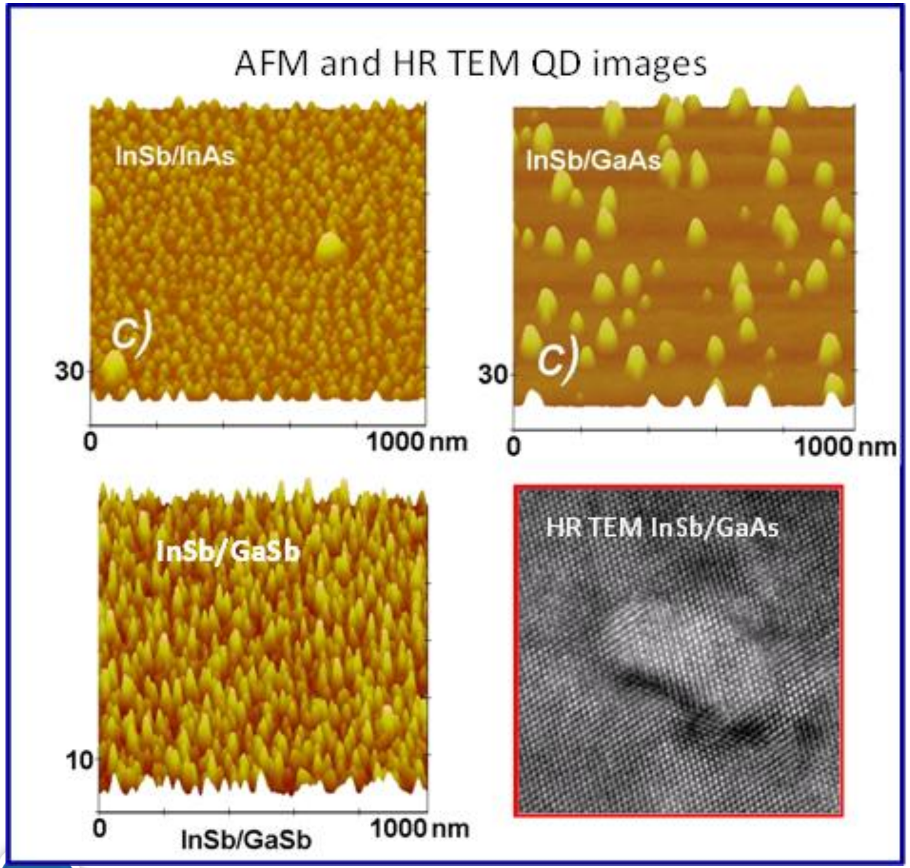
(a)



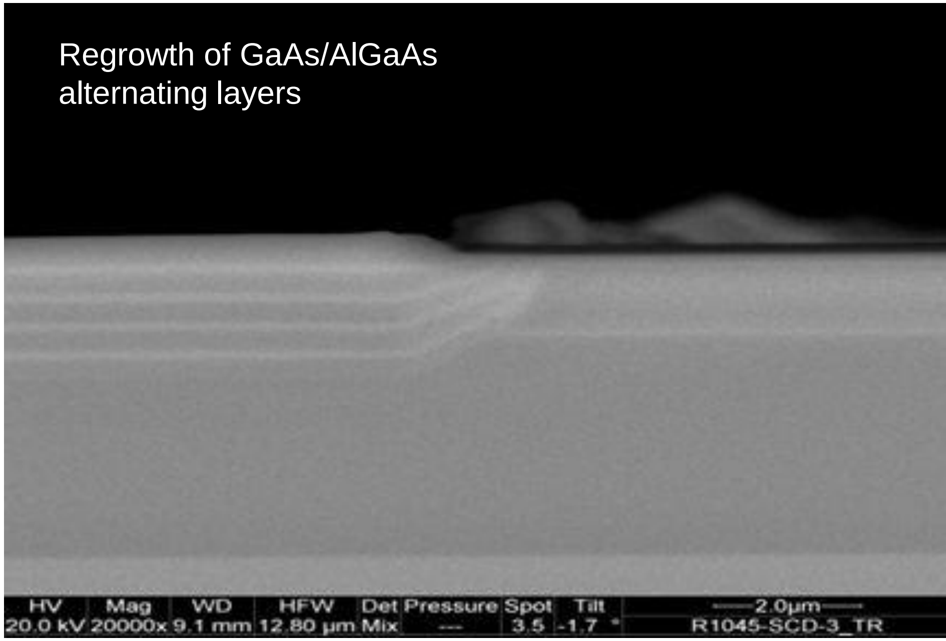
(b)

MOCVD growth research

Droplet epitaxy QD

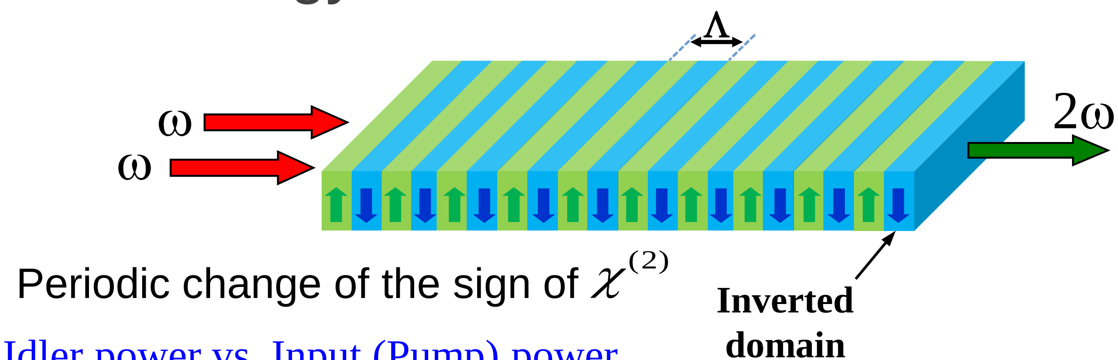


AlGaAs regrowth for high power diode lasers

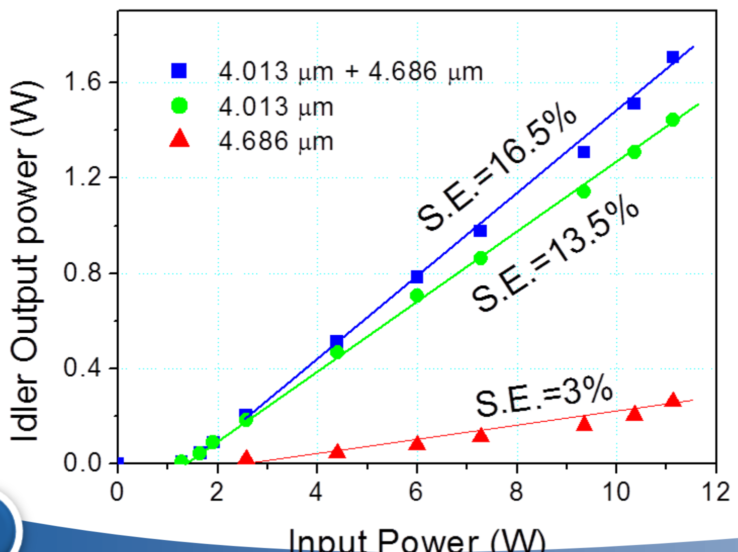


Frequency conversion devices

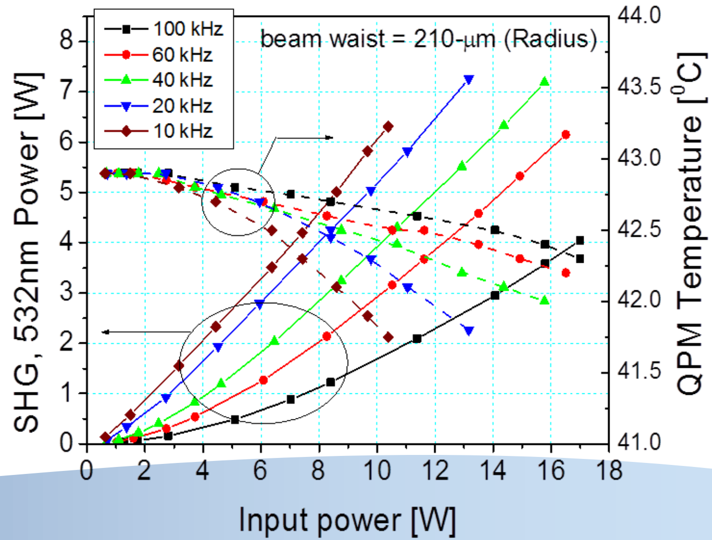
- Ferro-electric crystals (PPKTP and PPSLT)
- The technology was commercialized at “Raicol Crystals”



OPO: Idler power vs. Input (Pump) power

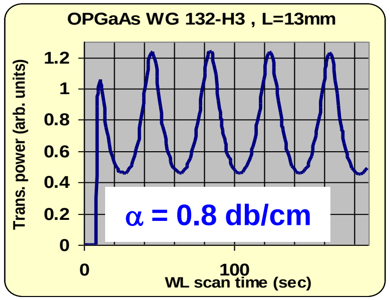


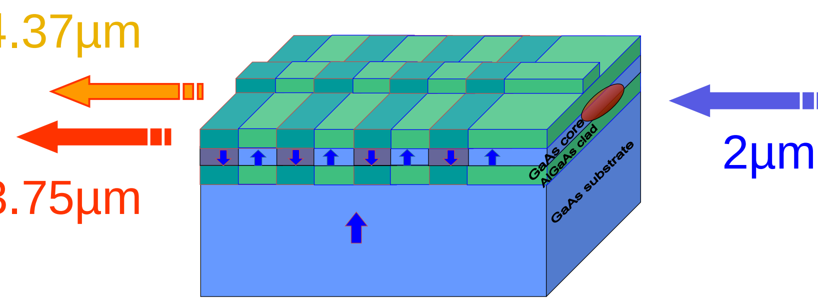
SHG: Multi-Watt green generation by SLT



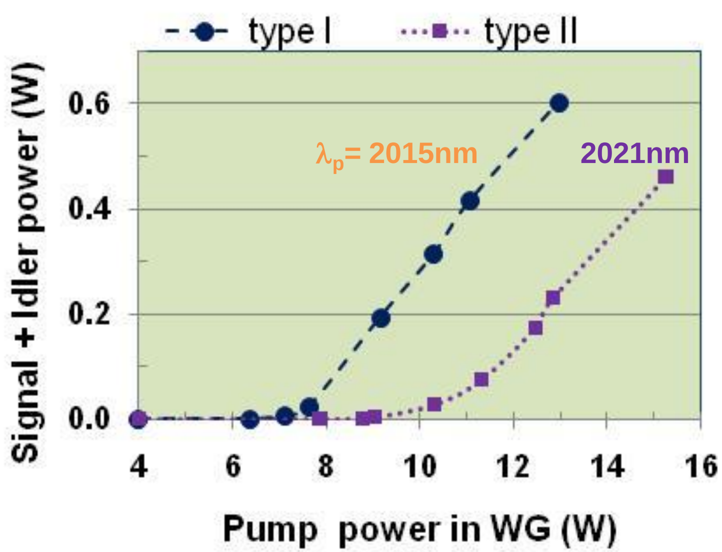
Frequency conversion devices

Orientation Patterned GaAs (OPGaAs) Waveguides (MOCVD)



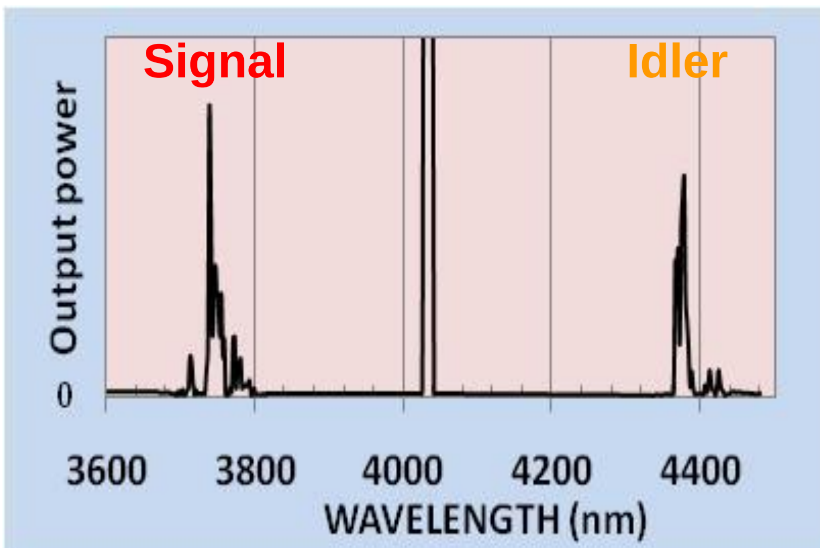


First reported OPGaAs WG – OPO by pulse laser



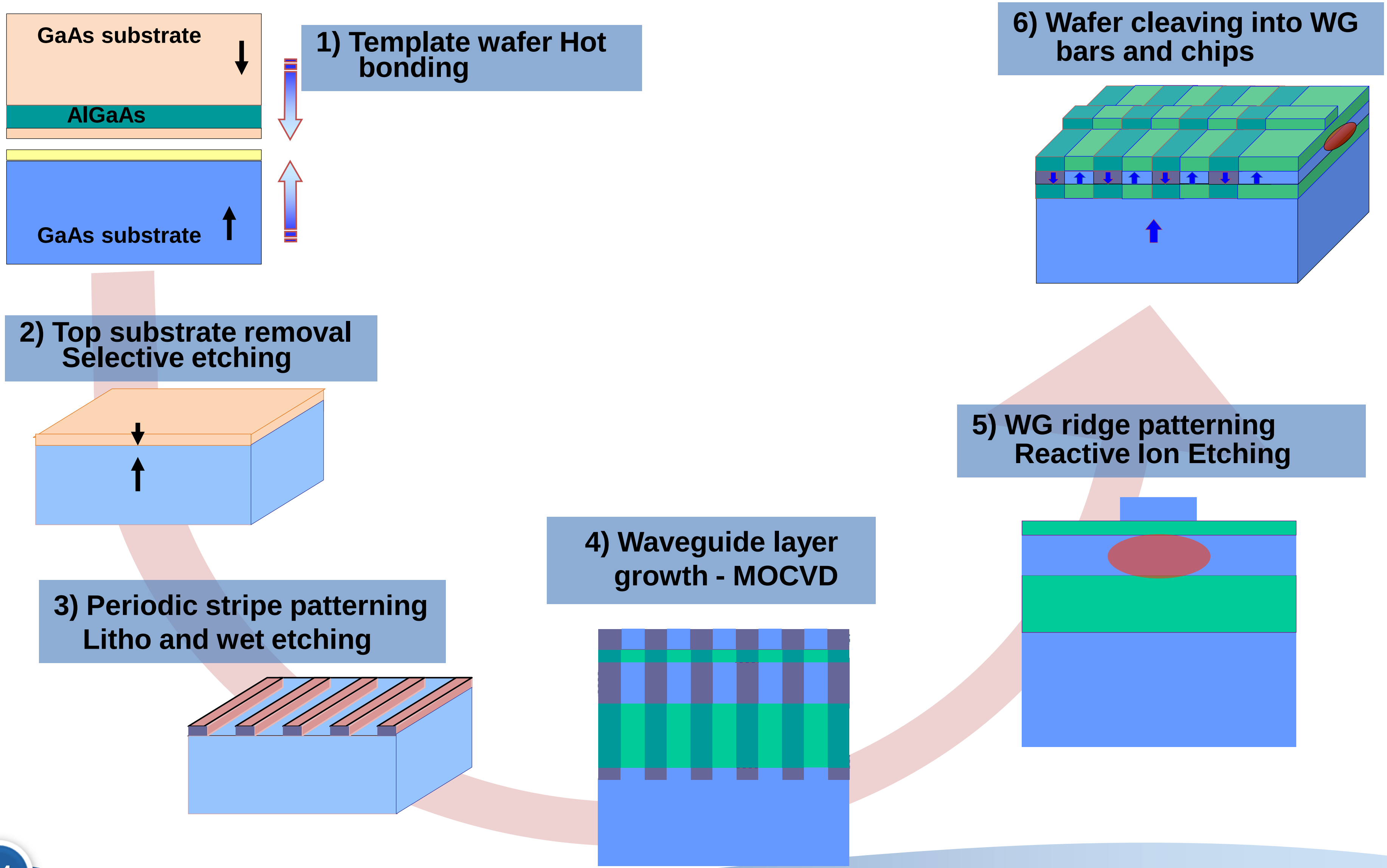
OPO threshold (peak) power

P_{th} (Type-I) = 7W P_{th} (Type-II) = 9W



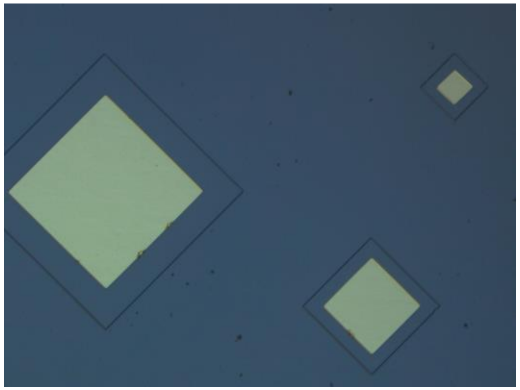
Parametric power spectral scan
Pump : 12W , 2017nm-TM
WG: 3mx12mx13mm

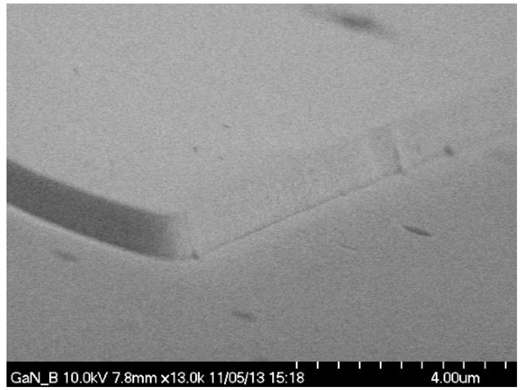
OPGaAs Wafer fabrication - process flow

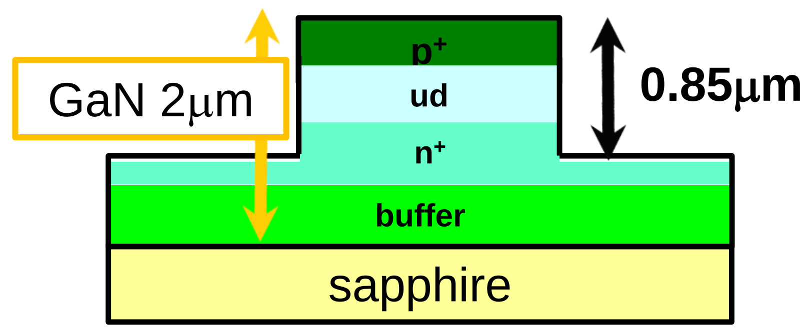


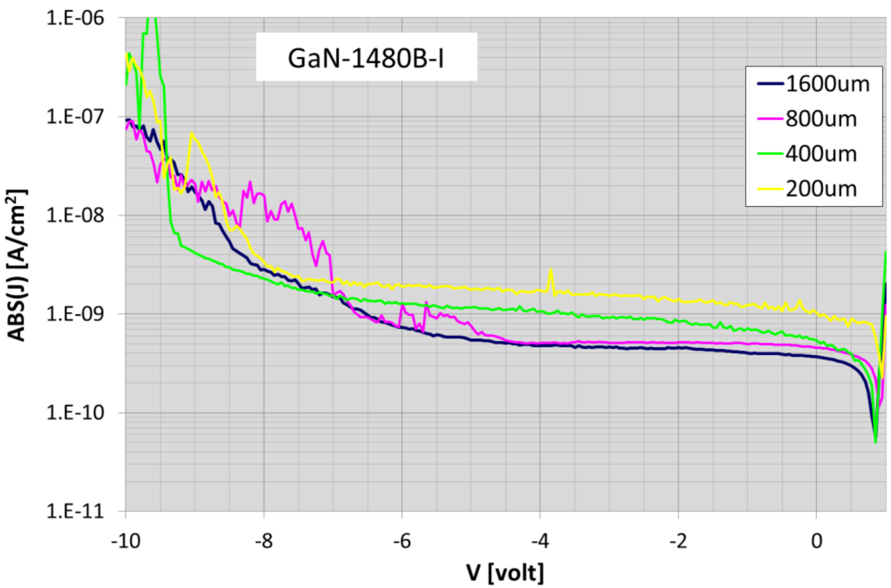
GaN photo-diodes (MOCVD – commercial vendors)

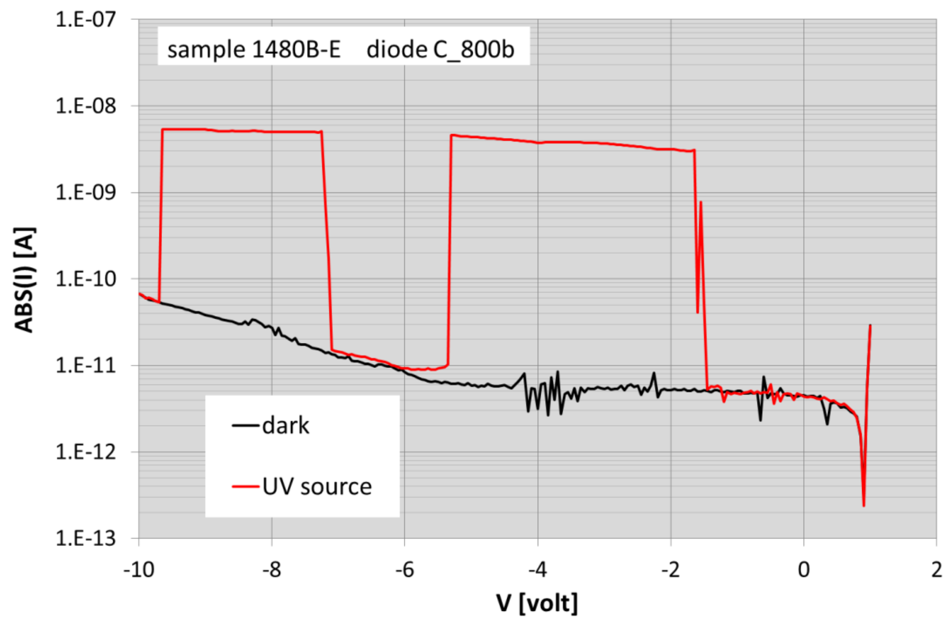
Low p-contact resistance $\rho_c = 6x10^{-4}\Omega cm^2$



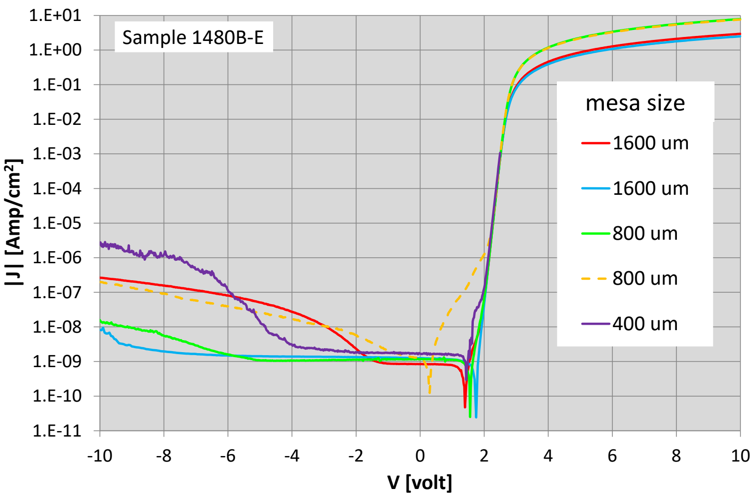






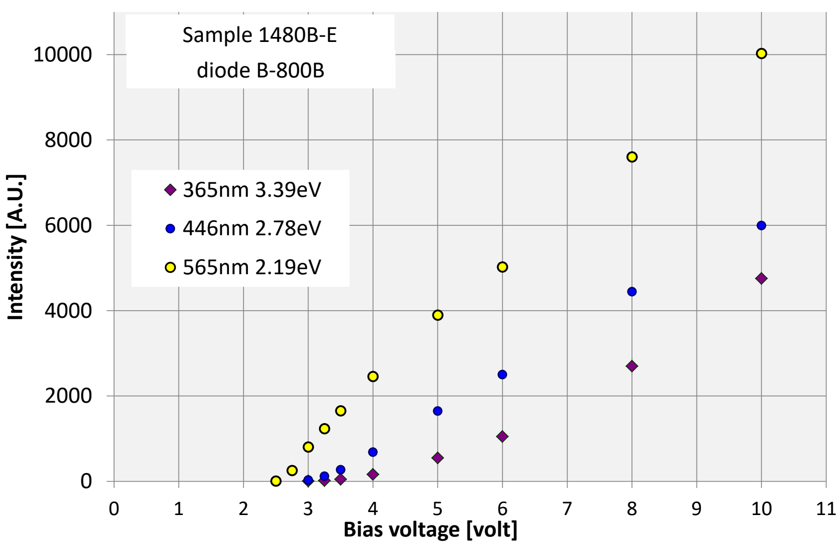


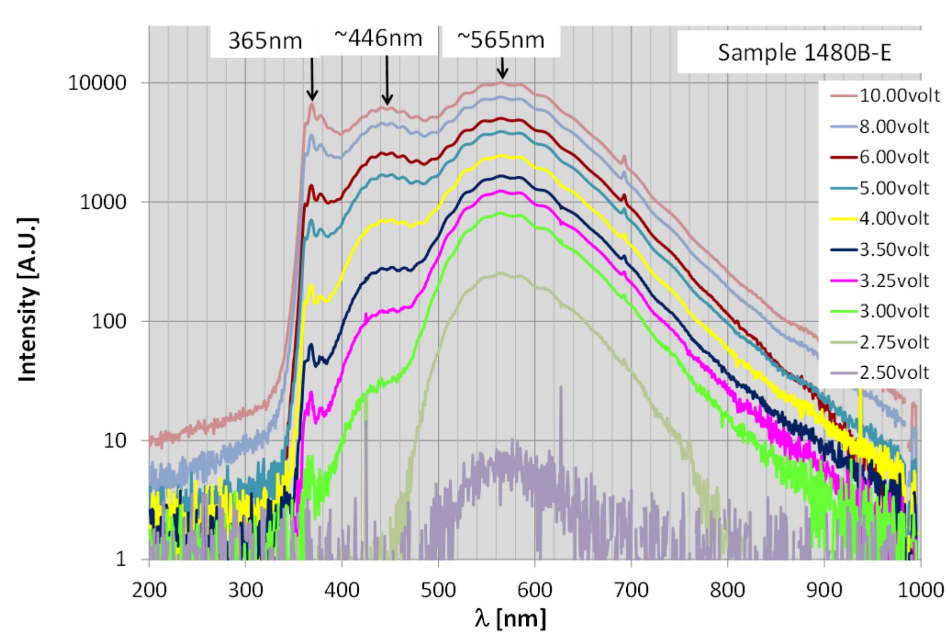
GaN diodes under positive bias



Electro-luminescence (EL) under positive bias

- EL emitted only under p contact
- Fabry-perot oscillations
- Yellow, Blue and UV lines



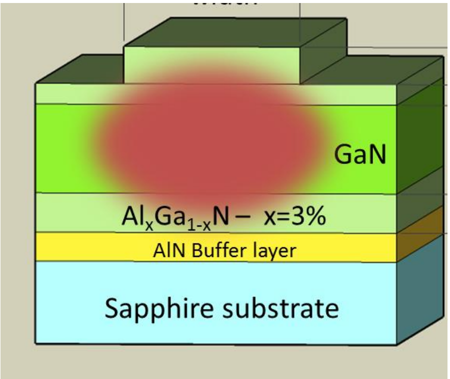


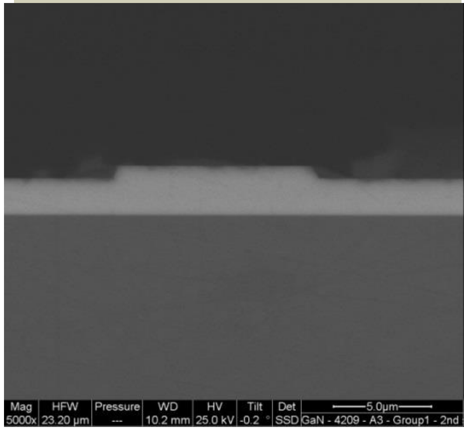
GaN photonics

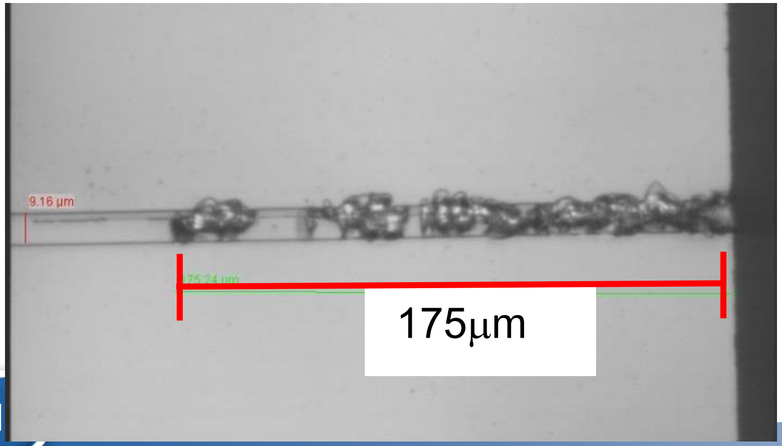
GaN:

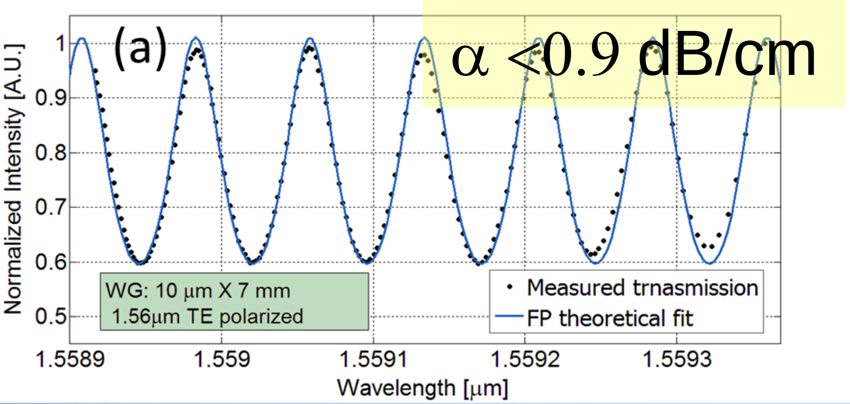
- Wide, direct band-gap (3.4eV)
- Transparent for λ>365nm
- Suitable for high power photonics

- Low loss waveguides demonstrated
- High damage threshold (~4GW/cm^2)

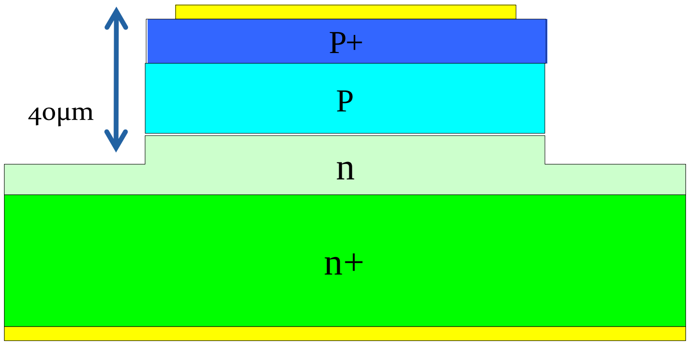




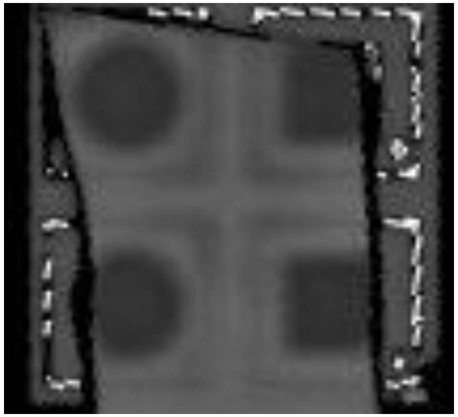




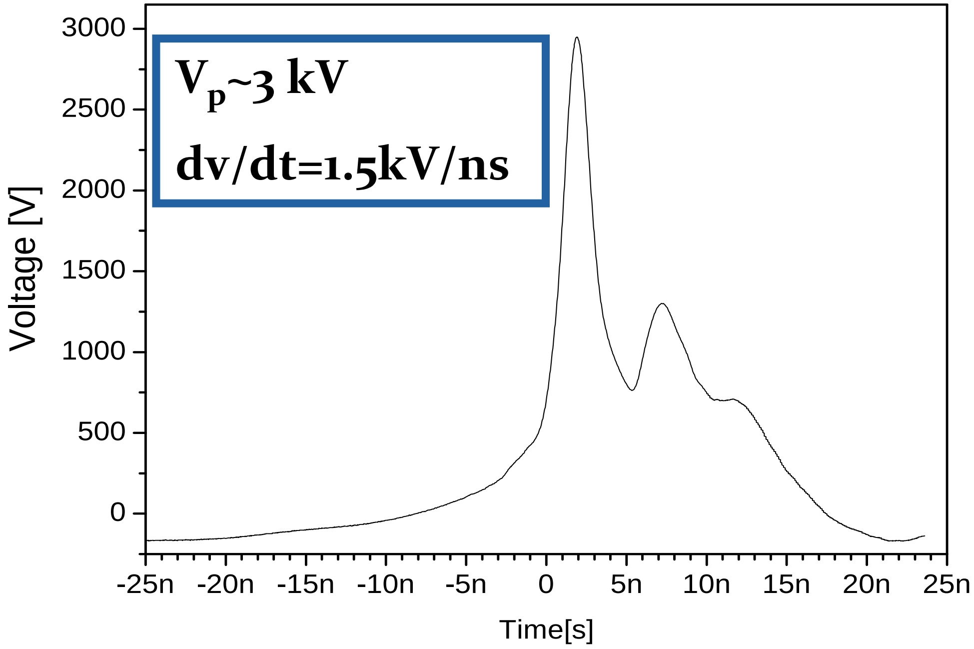
DSRD - Drift Step Recovery Diode
Epi-CVD (commercial vendors)



Silicon step recover diode for high voltage pulse with a rise rate of the order of 1kV/ns



Acoustic Microscope image is using to analyze the wafer bonding



The Photonic Devices branch at ICAP

The photonic devices branch is obliged to have the capabilities of design, growth and characterization of epitaxial structures of:

- **Nitride compounds (III-N)**
- **Arsenide/phosphide/antimonide compounds (III-V)**

The epi-structures will serve as the base to a variety of photonic (and electronic) devices

The center will also be able to supply small series of grown wafers to the industry

Epitaxial growth infrastructure

(Epitaxy growth = deposition in ordered manner)

- MBE and MOCVD of As/P/Sb compounds
- MBE and MOCVD of nitride compounds
- Dedicated characterization tools

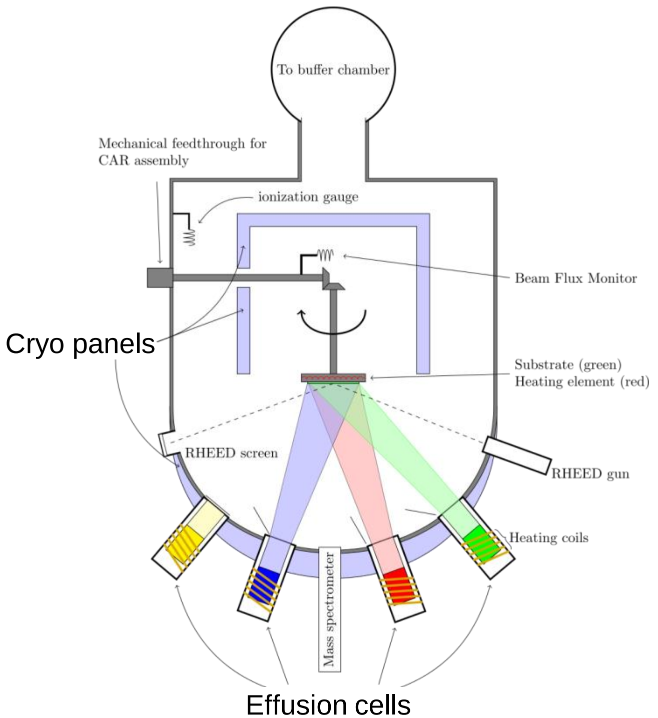
MOCVD - Metal-Organic Chemical Vapor Deposition

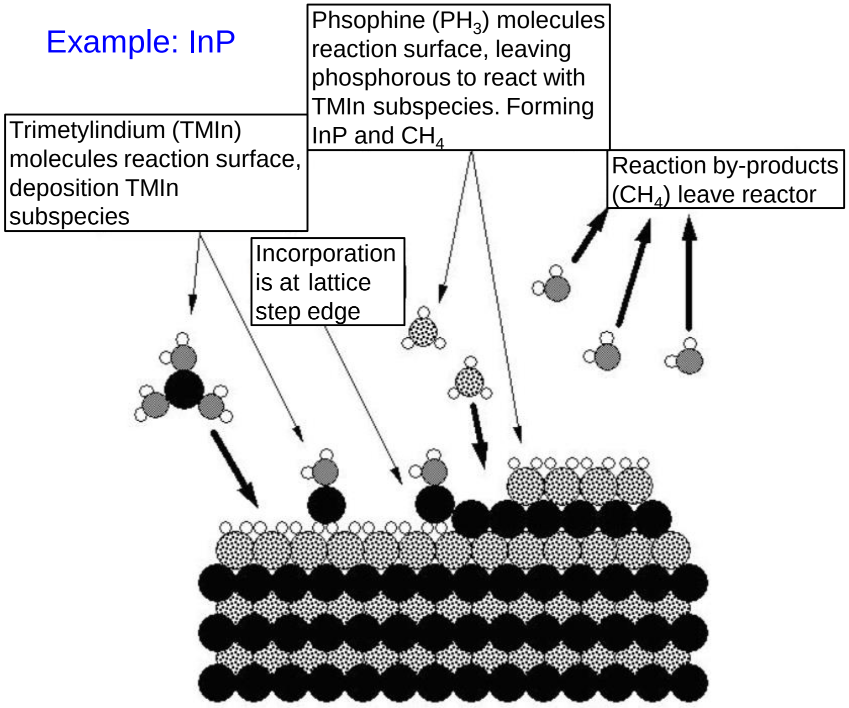
MBE - Molecular Beam Epitaxy

Infrastructure requirements:

- State of the art technologies
- Maximum flexibility
- Small scale manufacturing capabilities

MBE and MOCVD basic principles





- Ultrahigh vacuum (~10^{-11} Torr) evaporation of pure elements.
- Thermal evaporation or E-Beam evaporation (Thermal evaporation in our system)
- Growth of crystals is by physical deposition

- Gas phase transfer of the materials to be deposited on the substrate.
- Moderate pressures (10 to 760 Torr)
- Pyrolysis: The heated organic precursor molecules decompose in the absence of oxygen
- Growth of crystals is by chemical reaction.

MBE vs. MOCVD

	Strengths	Weakness	Remarks
MBE	• Abrupt interface • Simple process • Uniform • Mature In-situ monitoring	• Low growth rate • Maintenance: Long shutdown time • Regrowth on patterned samples	• Using phosphor needs extra care
MOCVD	• Most flexible • Regrowth on patterned samples • Large scale production • In-situ monitoring (limited) • Maintenance: Short shutdown time	• Many growth parameters • Expensive sources • Hazardous	• New In-situ monitoring available • No AsH_3 and PH_3 in our system

MOCVD (Metal-Organic Chemical Vapor Deposition)

Aixtron CCS III-N (GaN)/III-V (GaAs)
Dual application system

Substrates:
6x2” or 3x3” or 1x4” or 1x6”

Growth configuration:

- Two ammonia lines (GaN)
- Metal Organics lines:
  - Standard lines: TMIn (with epison), TEGa, TMSb, TBA, TBP
  - Double dilution, double outlet lines : TMGa, TMAl

This configuration enables the growth of variety of epi-structures including composite GaInAlN quantum well structures

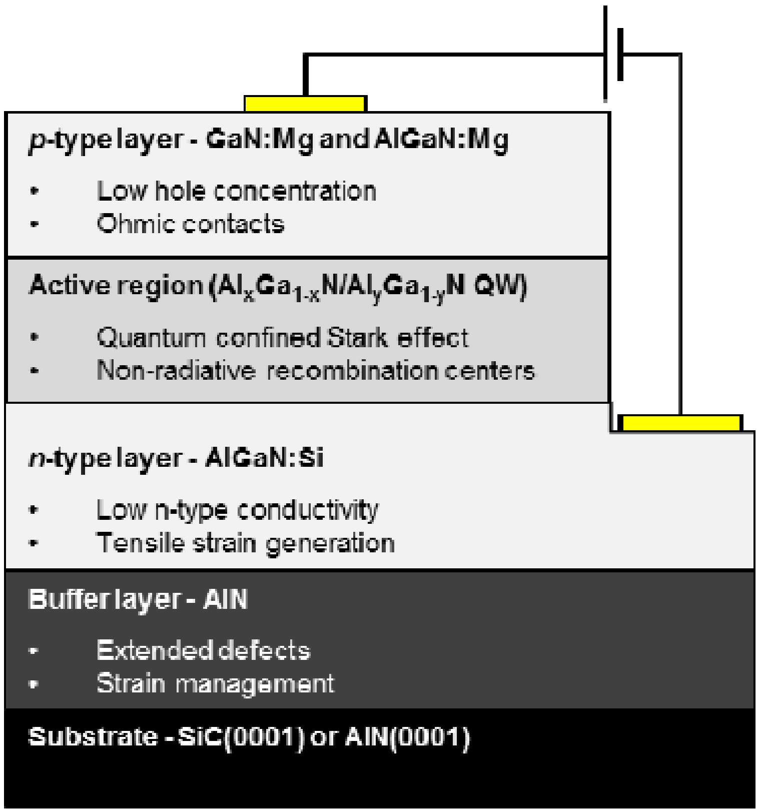
MOCVD (Cont..)

Dopants lines:

- Two double dilution Si (Silane-SiH_4, Disilan-SiH_6) sources
  (for low and high n type conductivity)
- Mg source *(p type doping)*
- Double dilution line: CBr_4 (carbon doping)
  *Enables growth of **semi-insulator layer***

Max. temperature: 1300C

*Enables **thick AlN buffer layers** which are important for some applications*



A schematic LED structure

MOCVD: In situ monitoring and controlling tools

- **EP curve TT**
  - Emissivity corrected pyrometry (Wafer/Wafer carrier temperature measurement)
  - Growth rate/thickness monitoring by high accuracy reflectance measurements
  - Wafer curvature measurements
- **Argus**

  A multi-channel pyrometer temperature profiler for real-time surface temperature measurement and mapping

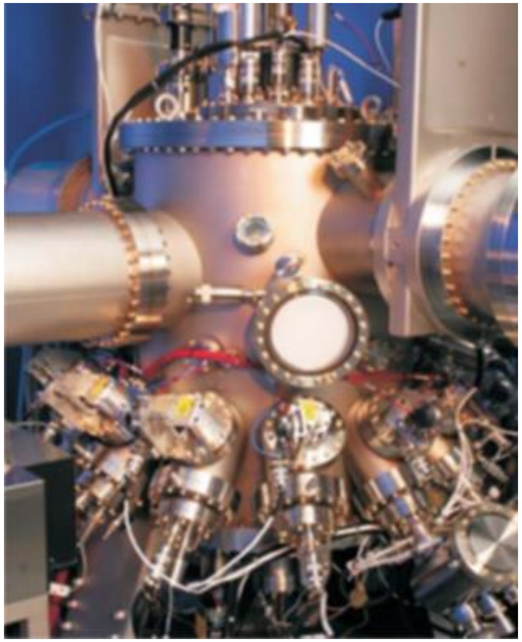
  Special feature

  Dynamic reactor height adjustments according to the growth parameters

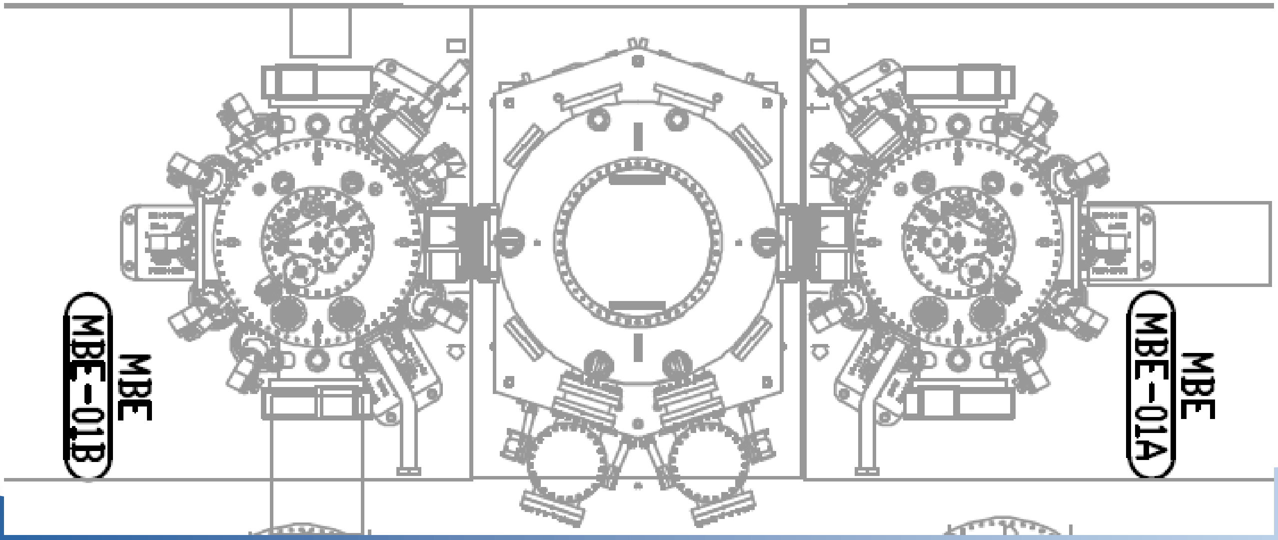
MBE (Molecular Beam Epitaxy)

Two UHV growth chambers and one central distribution chamber (CDC) with automatic wafer handling

- Chamber 1: III/V compounds
- Chamber 2: Nitride compounds



III-V chamber | Automatic Load lock | GaN chamber



MBE III-V (As/P/Sb) Chamber

Substrates: **3x2", 1x3" or 1x4"**

Effusion cells:

- 6 cells for Al/In/Ga
- 3 cells for As, P, Sb
- 2 cells for dopants (Si/Be, Te)

GaAs, InP, InAs, InSb, AlSb, AlGaAs, InGaAs, GaAsSb, InGaAsSb…..

Dual zone heater to 1200c

MBE Plasma Assisted (PA) nitrogen III-N (GaN) Chamber

Substrates: **3x2”, 1x3” or 1x4”**

Effusion cells:

- 3 cells for In/Ga
- 2 cells for Al
- 2 cells for dopants (Si, Mg)

GaN, GaAlN, GaInN, GaAnAlN

Dual zone heater to 1200c

MBE - In situ monitoring and controlling tools

- RHEED - Reflection High Energy Electron Diffraction
- RGA – Residual Gas Analyzer
- BMF - Beam Flux Monitor
- BandiT - Band Edge temperature real time monitoring

Epitaxial layers characterization tools at ICAP

On site

- HR-XRD mapping
- Photoluminescence (PL) mapping (0.3-2.6μm)
- CV profiler (Doping measurements of semiconductors)

A large variety of characterization tools in Soreq and Ben-Gurion Uni. will also be available

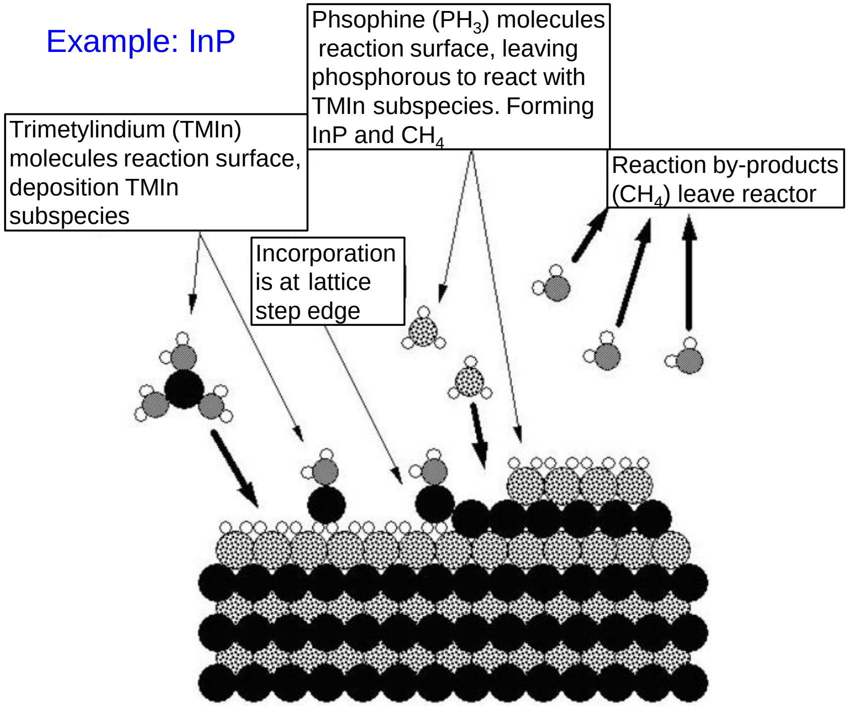
Israel Center for Advanced Photonics
המרכז הישראלי לפוטוניקה מתקדמת

SOREQ

תודה !

Thanks !

Example: InP



Phsophine (PH_3) molecules reaction surface, leaving phosphorous to react with TMIn subspecies. Forming InP and CH_4
Trimetylindium (TMIn) molecules reaction surface, deposition TMIn subspecies
Reaction by-products (CH_4) leave reactor
Incorporation is at lattice step edge