Processing and characterization of epitaxial grown GaAs radiation detectors

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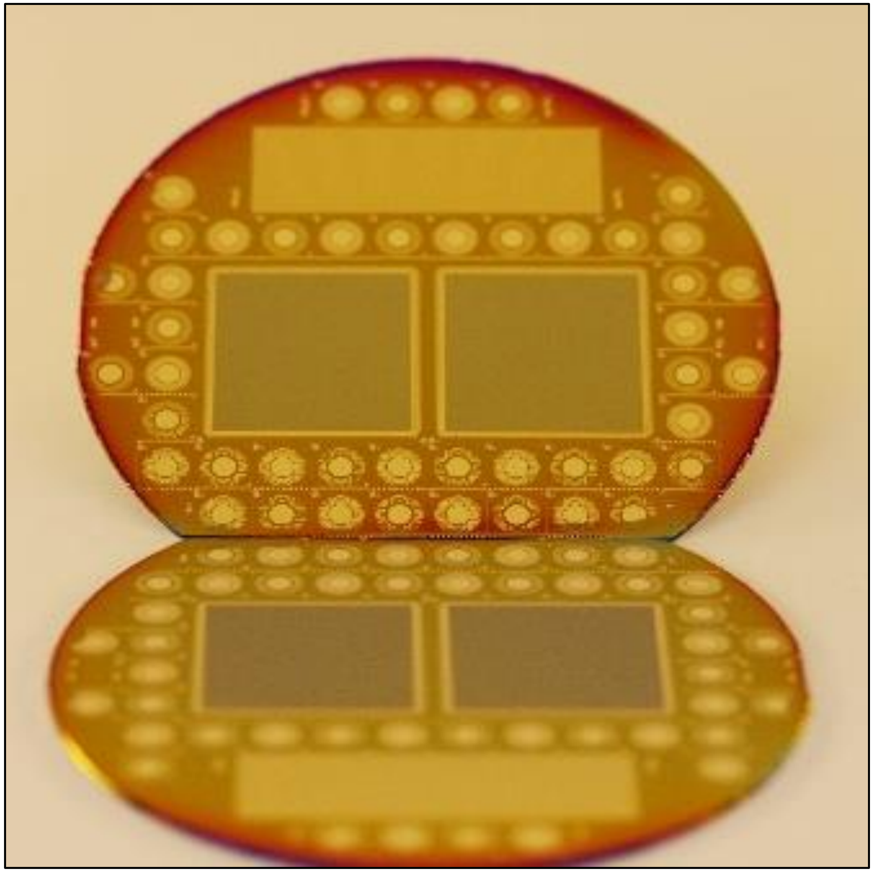
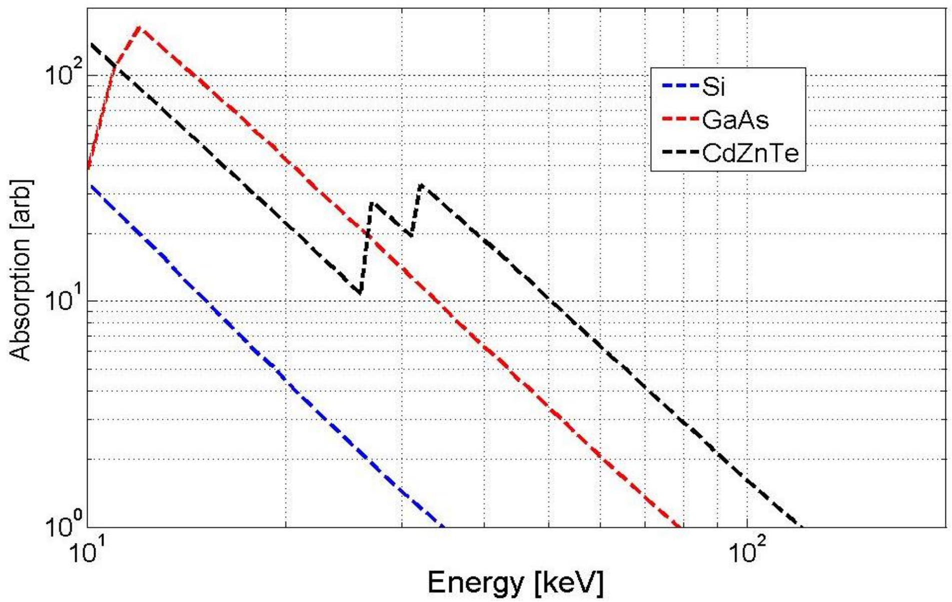


Processed GaAs wafer

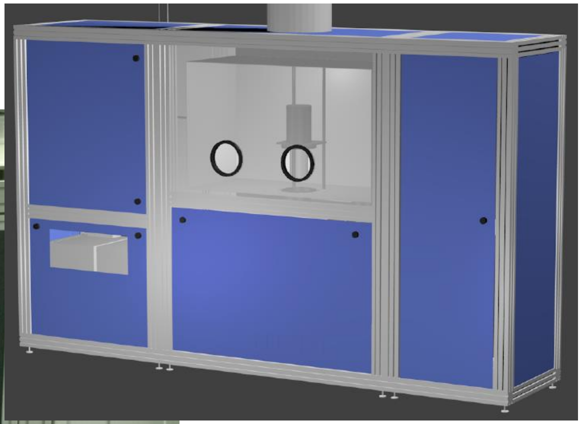
Motivation and background

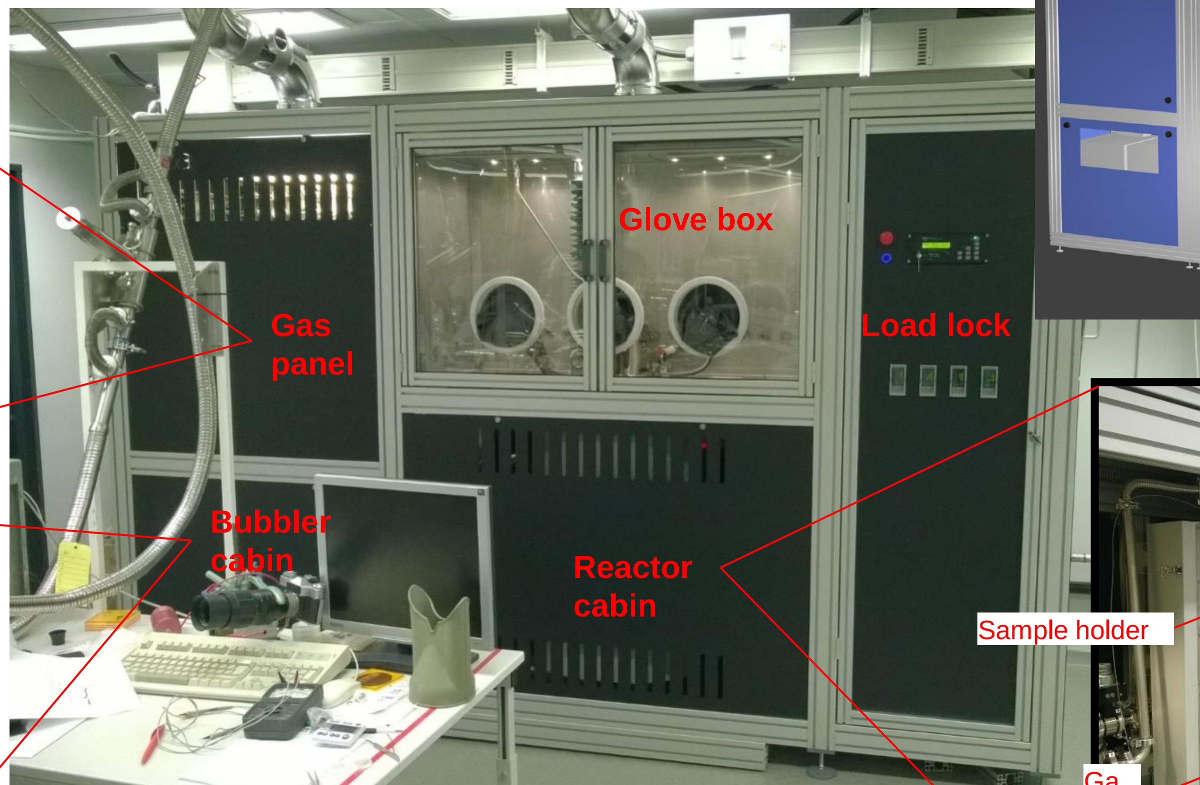
- ❑ Gallium arsenide (GaAs) vs. Silicon (Si)
  - High electron mobility (~5.7 times higher than Si)
  - High atomic numbers (Z=31, 33 vs Z=14 in Si), direct band and wide bandgap, high absorption efficiency and low leakage current at room temperature
- ❑ Detector-grade GaAs materials: epitaxial, semi-insulating
  - Technology well-established with respect e.g. CdZnTe

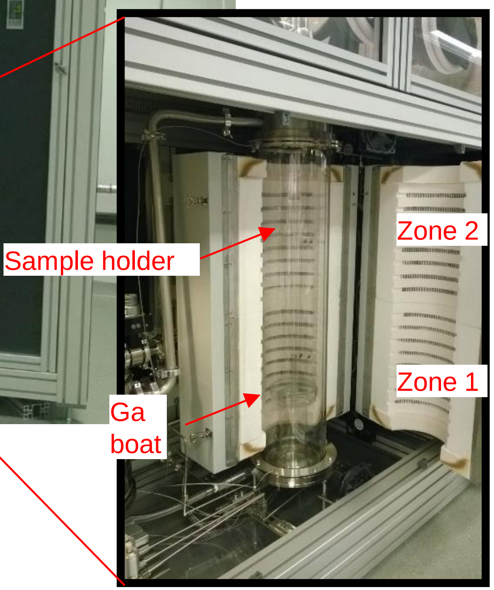
Simulated absorption efficiency vs X-ray photon energy:

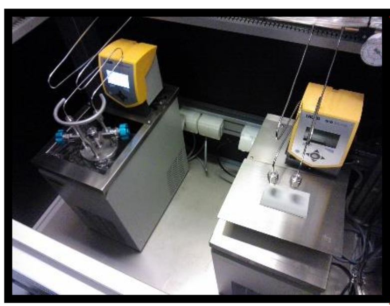


Vertical CVPE reactor: Implementation





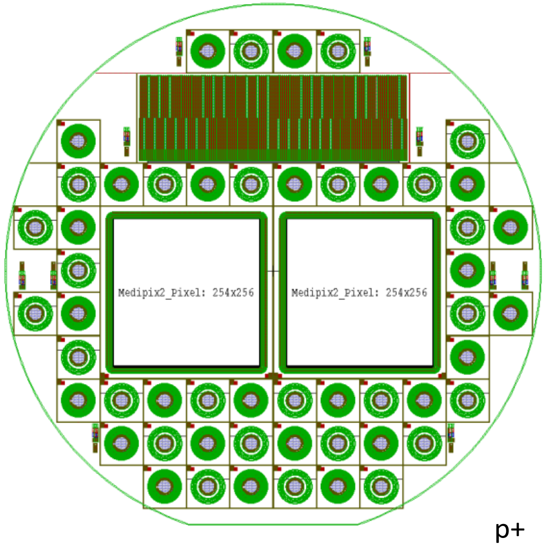




- **CVPE = Chloride Vapor Phase Epitaxy**
- **Growth rate ~10 µm/h → >100 µm layer thicknesses**

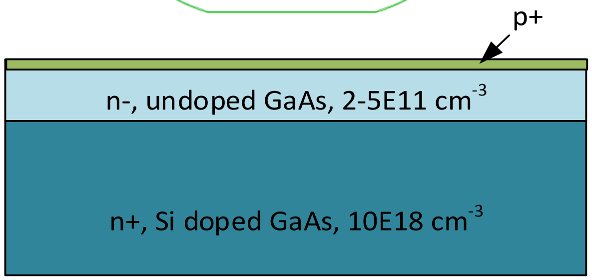
Processing of GaAs detectors: Wafers

- Five GaAs epitaxial wafers were brought from Ioffe physical technical Institute
- Two wafers were processed at VTT
    - Each wafer yields two Medipix sensors, one strip sensor and many diodes



Wafer no.	p+ layer	n-type epi-layer	n+ substrate
D167	1.5 – 2 µm	112 µm	460 µm
D168	1.5 – 2 µm	130 µm	460 µm

Detector structure:

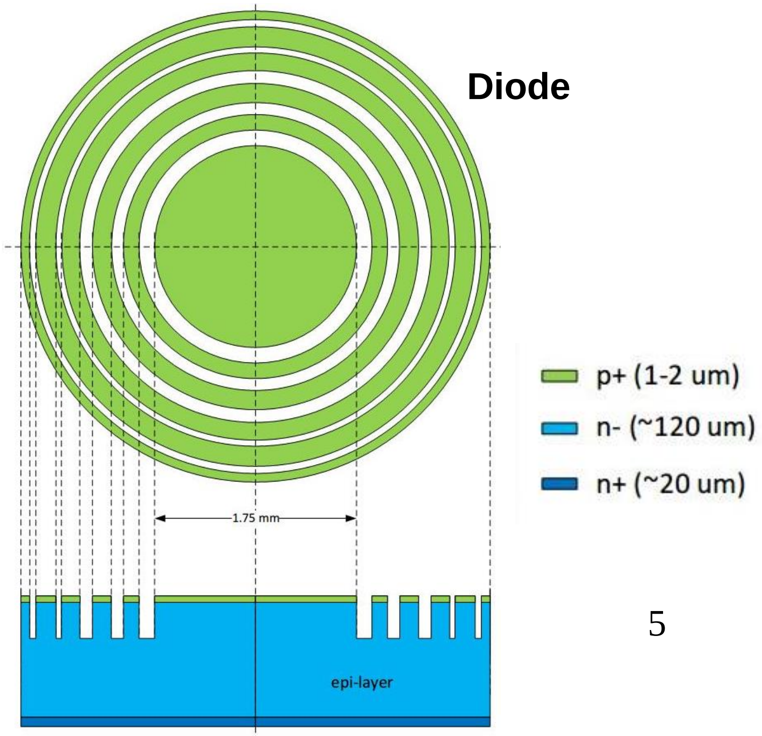


Why not $n^+/p^-/p^+$ detectors:

❑ Reason for growing n^- layer instead of p^-:

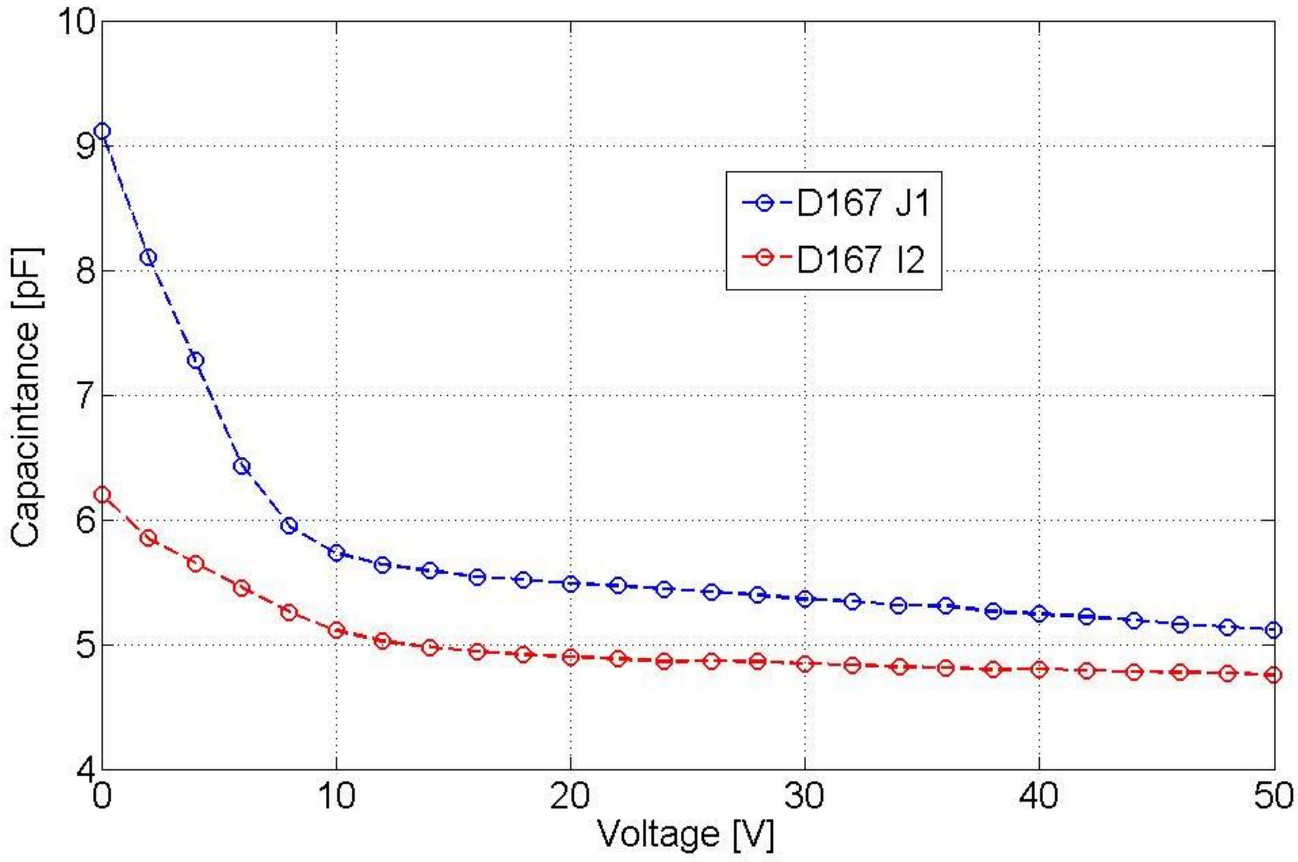
- CVPE grown GaAs is intrinsically n^- type
- Controlling the growth of p^- layer at very low doping concentrations is difficult (or impossible)
- Unavoidable Zn diffusion from the p^+ substrate might dope the p^- layer too much
- N-type dopant diffusion (usually Si), in contrast, is very weak.

Diode



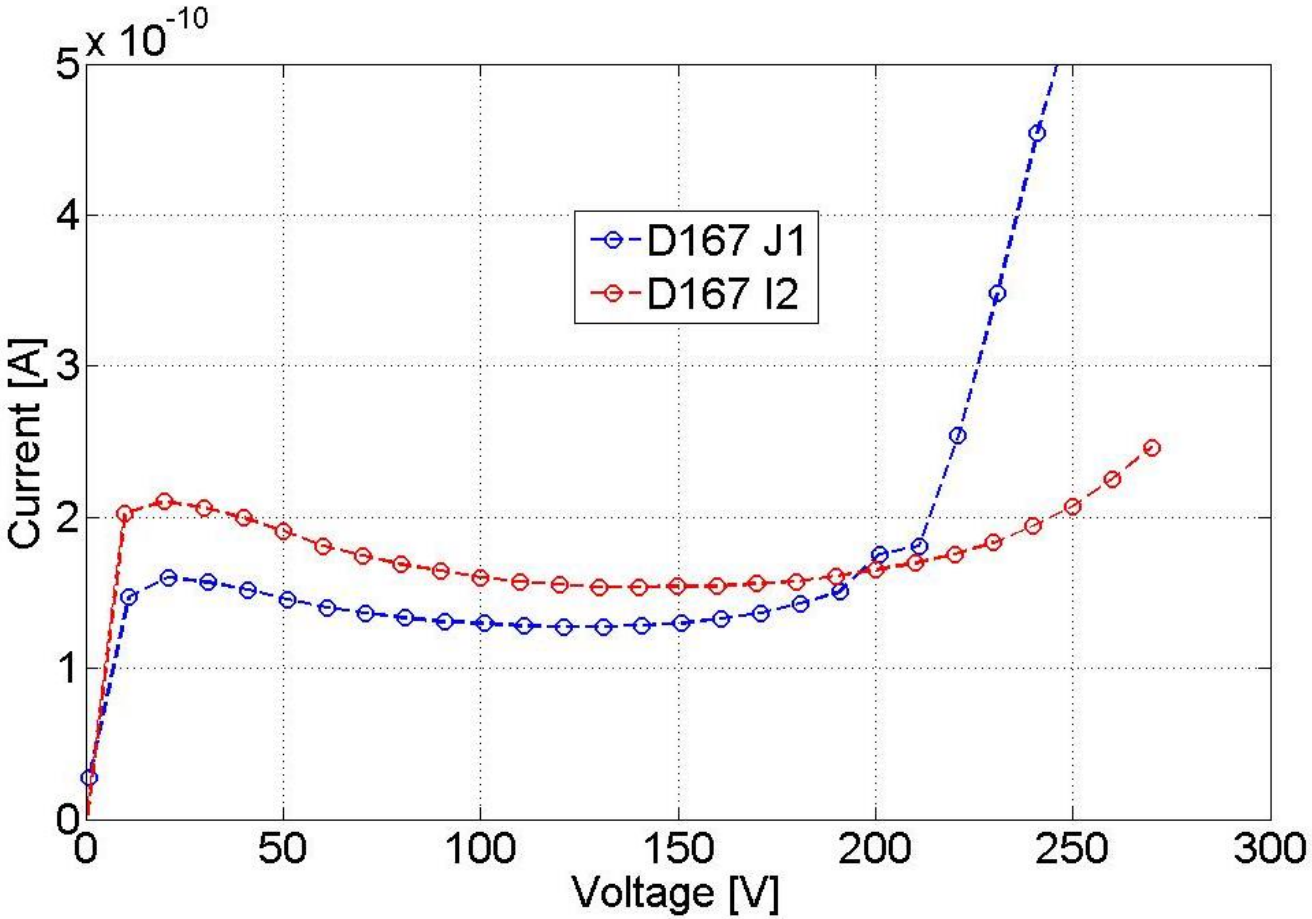
Characterization – CV/IV

- ❑ V_{fd} ~ 20 - 25V
- ❑ Clear capacitance saturation not apparent
  - Most likely due to device structure (no guard rings)

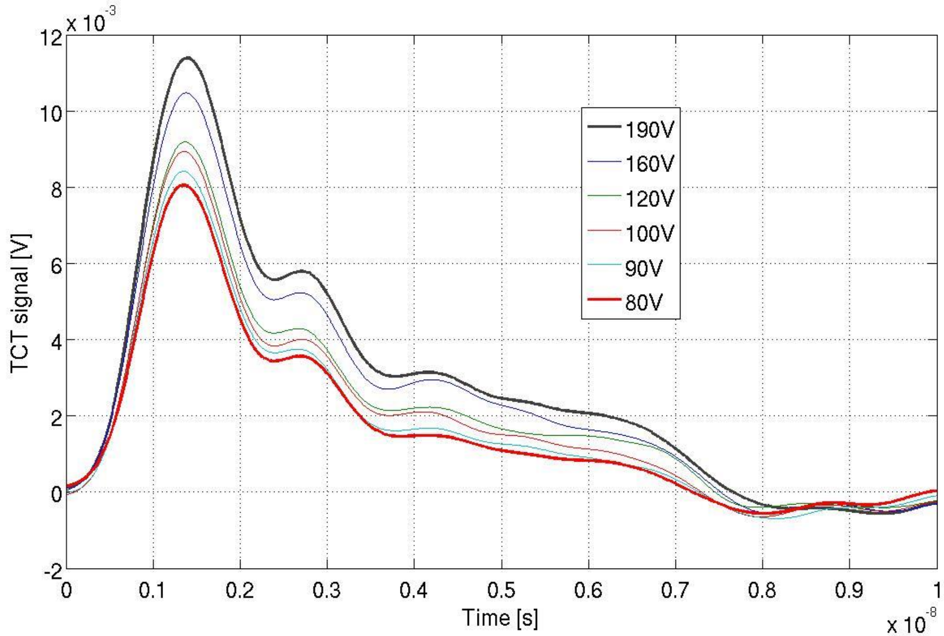


Characterization – CV/IV

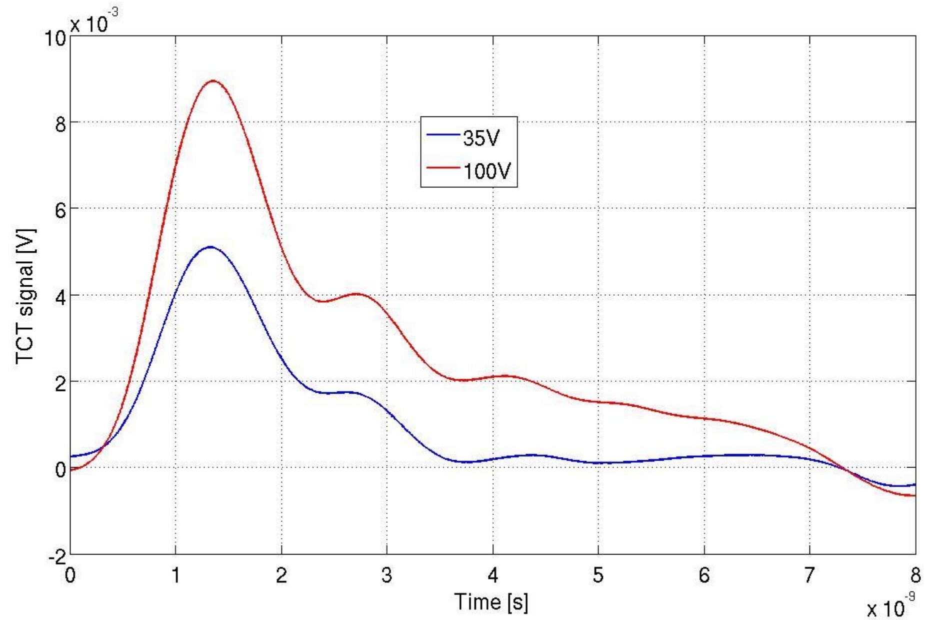
- Leakage current I_{leak} ~ 100 - 200 pA
- Current density J ≈ 10 nA/cm^2



Characterization – TCT



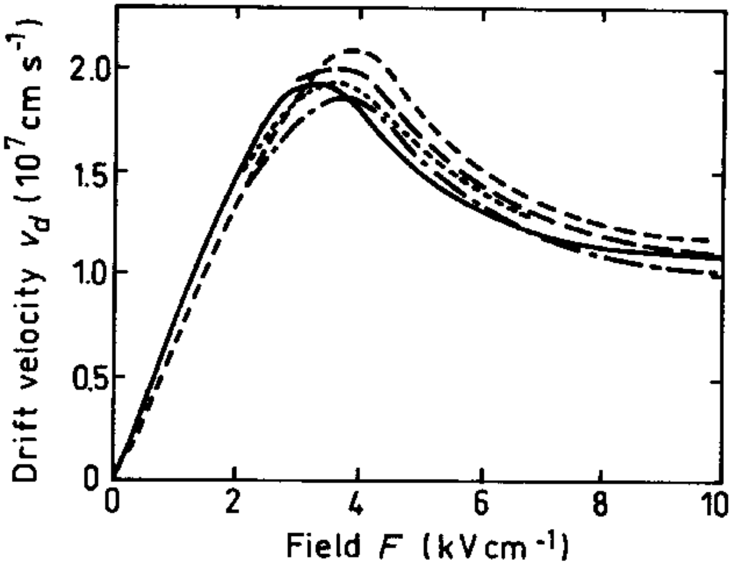
High electric field, $t_{transit}$≈ 8 ns



Low electric field, $t_{transit}$≈ 4 ns

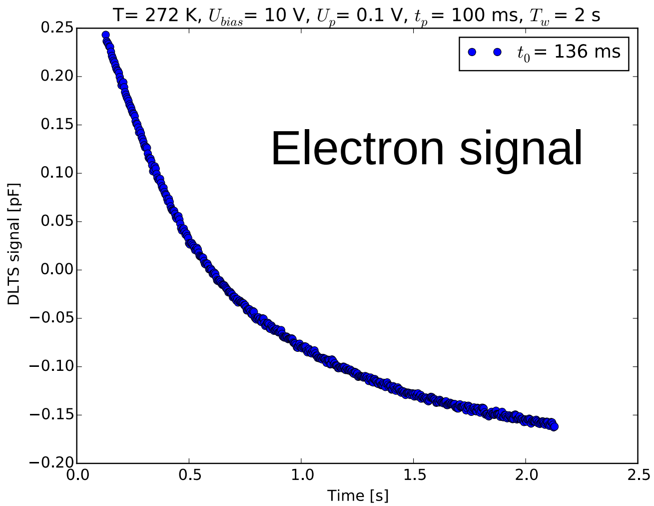
❑ **Field dependences of the electron drift velocity** (Blakemore[1982])

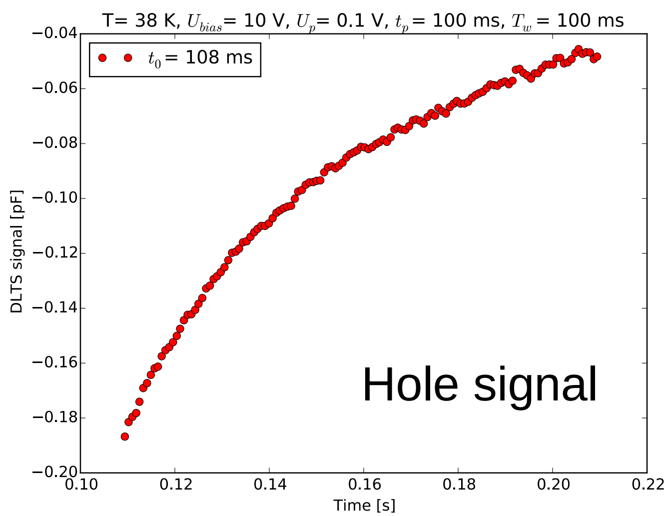
- Solid curve calculated by (Pozhela and Reklaitis[1980])
- Dashed and dotted curves are measured data, 300 K

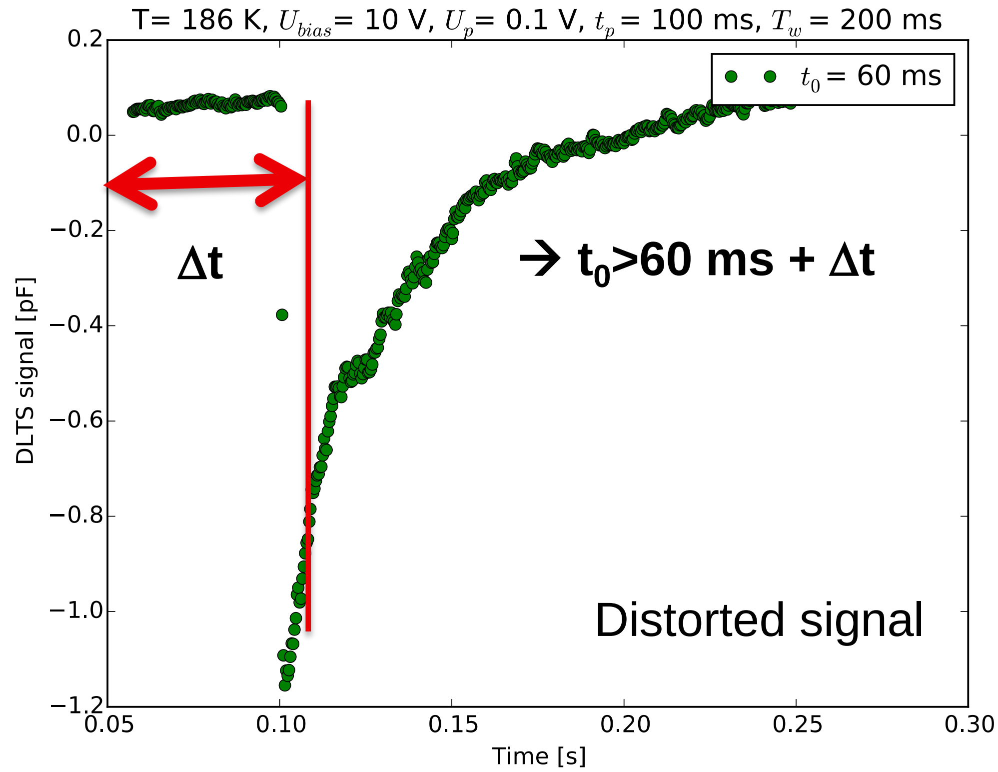


http://www.ioffe.ru/SVA/NSM/Semicond/GaAs/electric.html#Transport

DLTS - Parameters

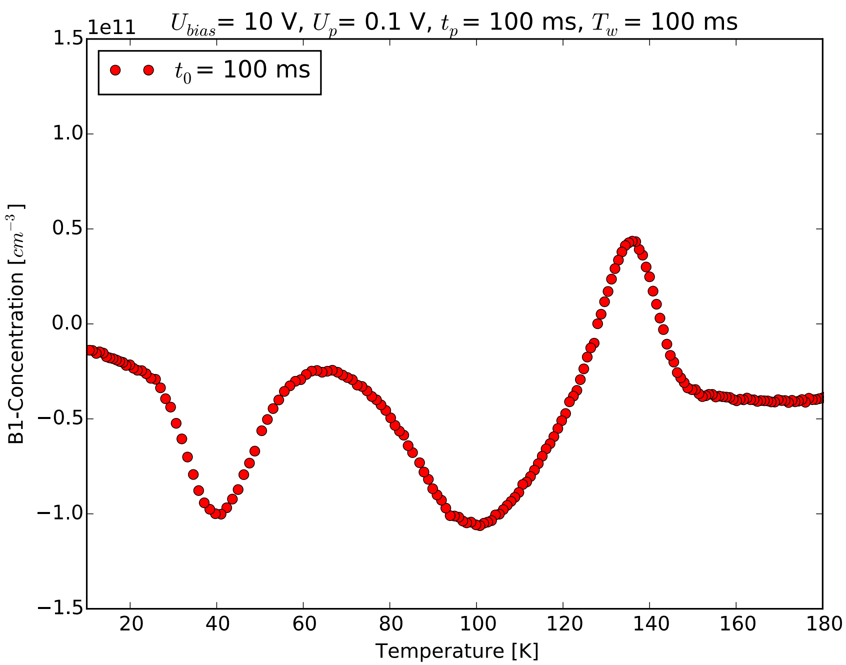


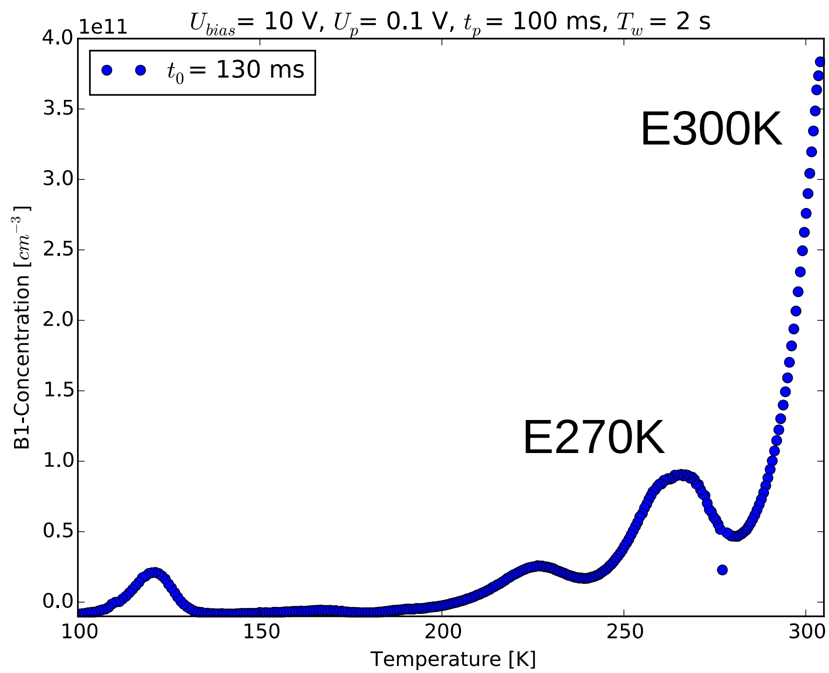




"Charge up effect"?
Prolong bridge recovery time (t_0) for stable measurement
→ Careful adjustment required or cut into signal !

Traps in the band gap





Shallow hole traps
Not visible for high t_0
→ Fast emission
→ Concentration few x 10^{10} cm^{-3}

Deep electron traps
Concentration up to few x 10^{11} cm^{-3}
→ Need to go to 350 K for full peak

- ❑ Deep electron traps could also be lattice distortions, further analysis needed for confirmation

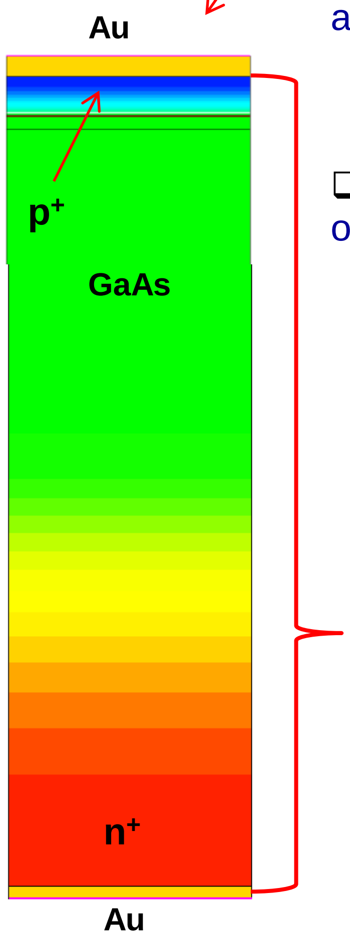
Trap	E_a [eV]	σ [cm^2]	N_t [cm^{-3}]
E270K	0.700	$2x10^{13}$	$1x10^{11}$
Very preliminary: E300K (from fit)	0.970	$1x10^{13}$	$5Ex10^{11}$

TCAD simulations - structure & parameters

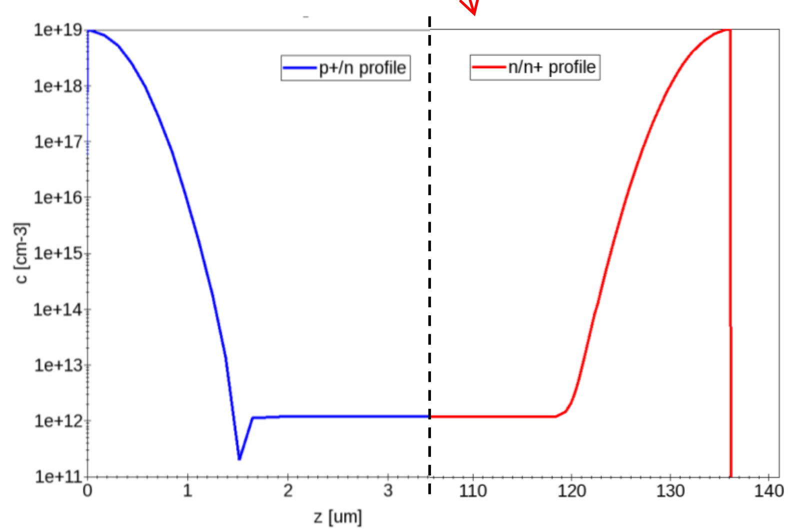
- 10x1x136 μm^3 diode structure
- Dc-coupled gold contacts d = 500 nm

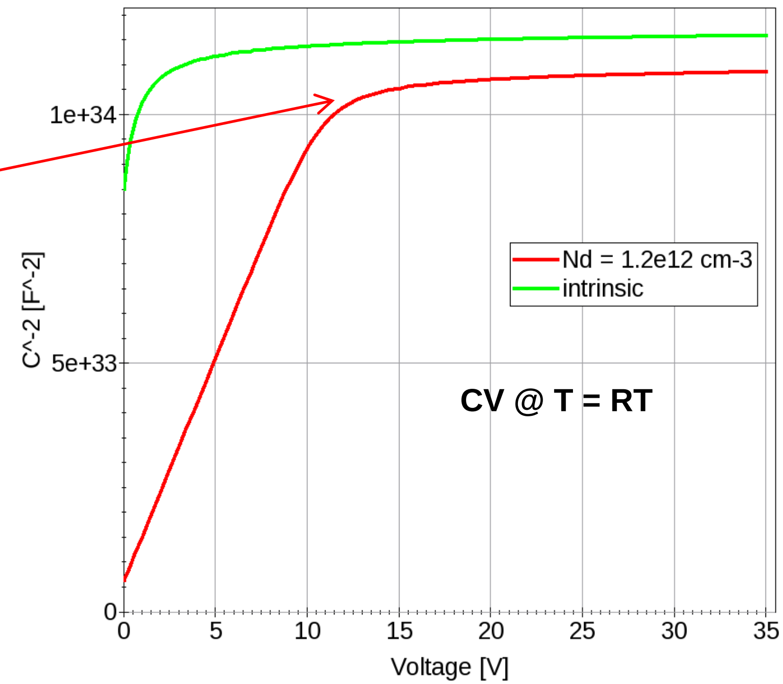
- Initial structure p-i-n → V_{fd} ≈ 15 V reached by arsenic doping $1.2 \cdot 10^{12}$ cm^{-3}

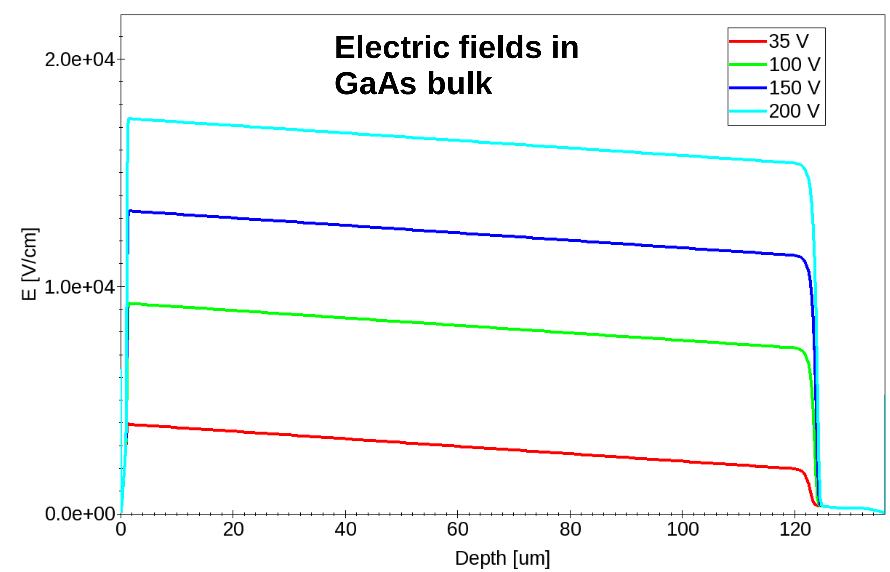
- Epi-layers modelled by varying the depth of p^+ and n^+ doping profiles



Simulated diode structure (not in scale)







TCAD simulations - Gunn effect

- **Gunn effect:** E-field in the material reaches a threshold level → mobility of electrons starts to decrease with higher E-field due to transferred electrons from one valley in the conduction band to another (small → large effective mass & very high → very low mobility)

- Charge injection from front surface d ≈ 4 μm → transient signal from electron drift

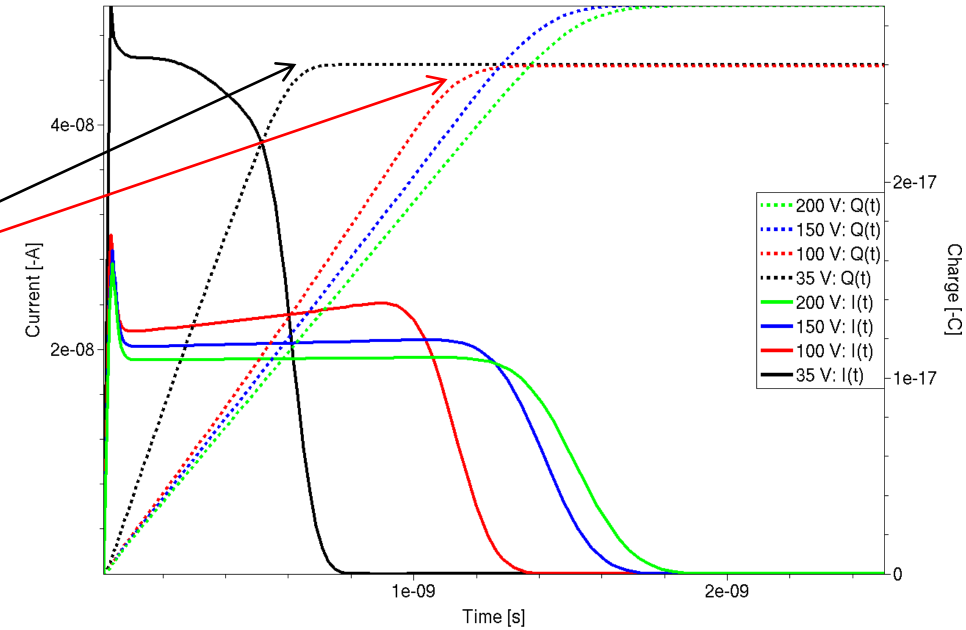
- Gunn effect reproduced

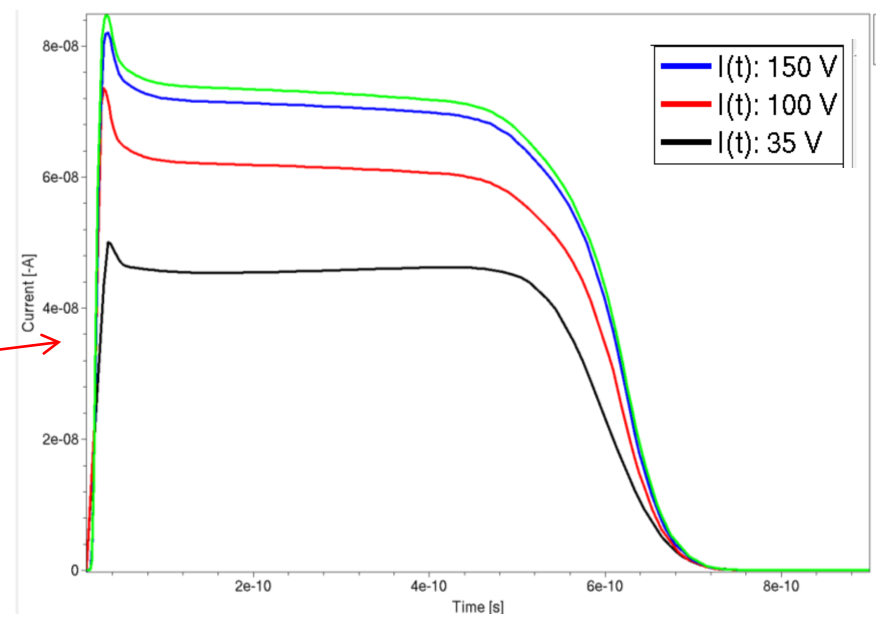
- Measured collection time (t_{coll}) rate t(100 V)/t(35 V) ≈ 2 is reproduced

- t_{coll} starts to saturate at high V as in measurement

- Absolute t_{coll} & transient current shapes are not reproduced → need to insert deep level traps to the simulation

- **Preliminary:** Deep level traps (deep donors from slide 10) are introduced to the GaAs bulk





Conclusions

- GaAs X-ray detectors for mammographic applications have succesfully been processed at Micronova nano-fabrication center
- GaAs pixel detectors have been flip-chip assembled to Medipix readout

- Thickness of semi-insulating GaAs layer is ~110 µm, grown by CVPE
- $V_{fd} \approx 25$ V and $J_{leak} \approx 10$ nA/cm^2
- Electron transient time measured by TCT is ~7-8 ns, i.e. less than radiative recombination lifetime
- DLTS results reveal several defects or lattice distortions:
  - N_t(deep e traps) ~5e11 cm^{-3}, N_t(shallow h traps) ~5e10 cm^{-3}
  - Further investigations needed to determine the nature of defects (related to impurities or lattice deformations?)
- TCAD simulations agree with experimental data
  - Further TCT tuning by inserting traps

- **More information:** X. Wu et al., *Radiation Detectors Fabricated on High-purity GaAs Epitaxial Materials*, iWoRID 2014, June 2014, Trieste, Italy