National Research
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Capability of FEL TSU in the field of HR GaAs:Cr sensor technology

Anton Tyazhev

Functional electronics laboratory,
Tomsk State University


Зоны Internet
СЕВЕРНАЯ АМЕРИКА
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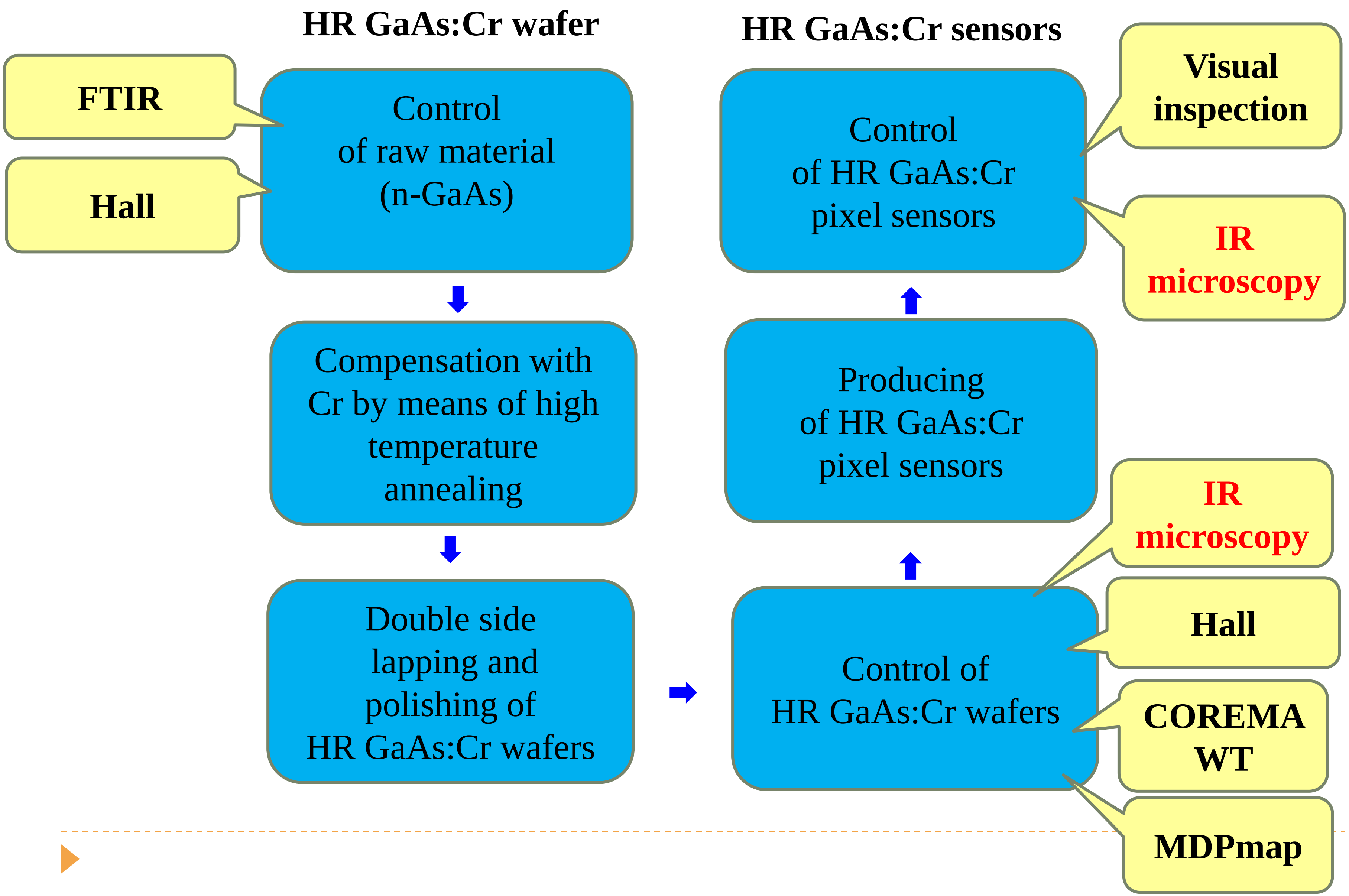
ТОМСКАЯ ГОСУДАРСТВЕННАЯ ФИЛАРМОНИЯ


HOTEL

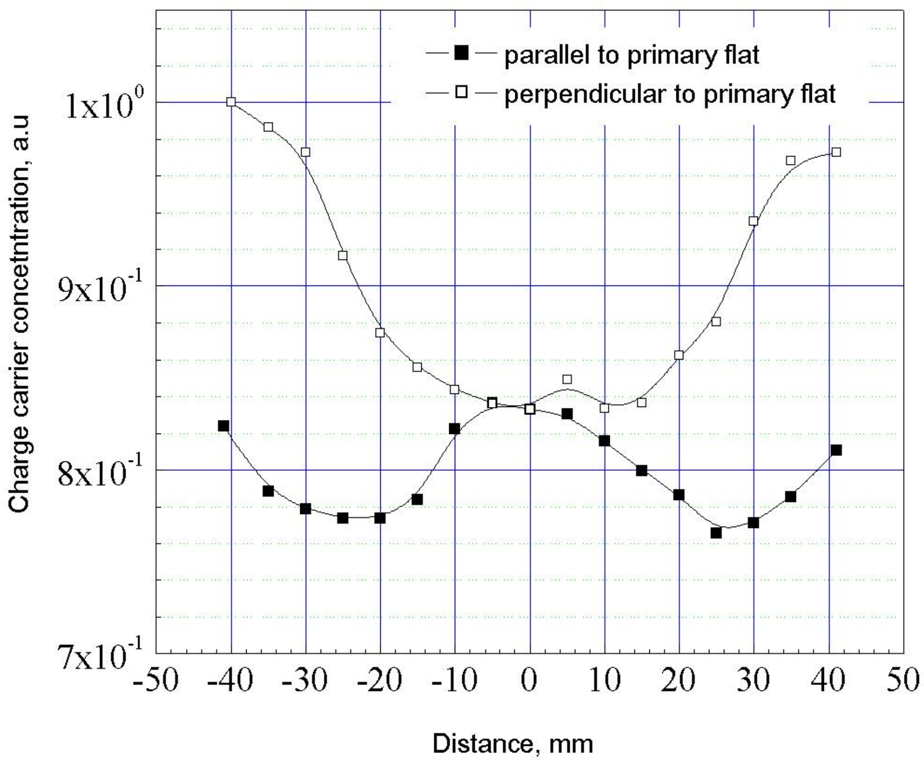
R&D activities of FEL TSU

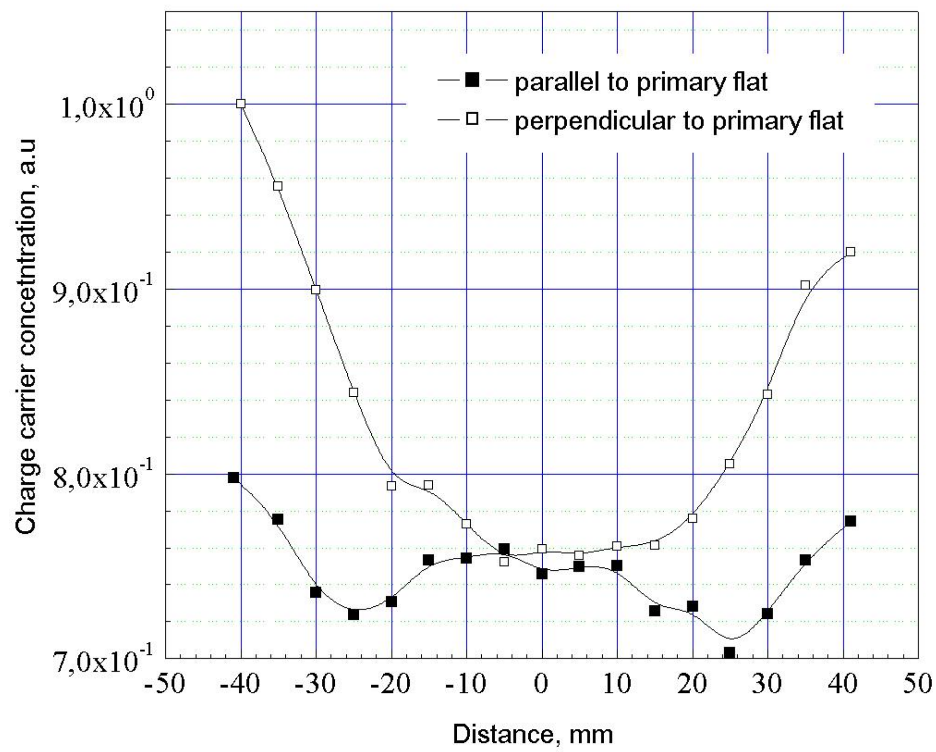
- Superfast GaAs avalanche switches
- Nonlinear crystal growth and terahertz spectroscopy
- Semiconductor sensors of different gases
- HR GaAs:Cr sensors of ionizing radiation

HR GaAs:Cr sensor technology



Charge carrier (CC) mapping. LEC n-GaAs



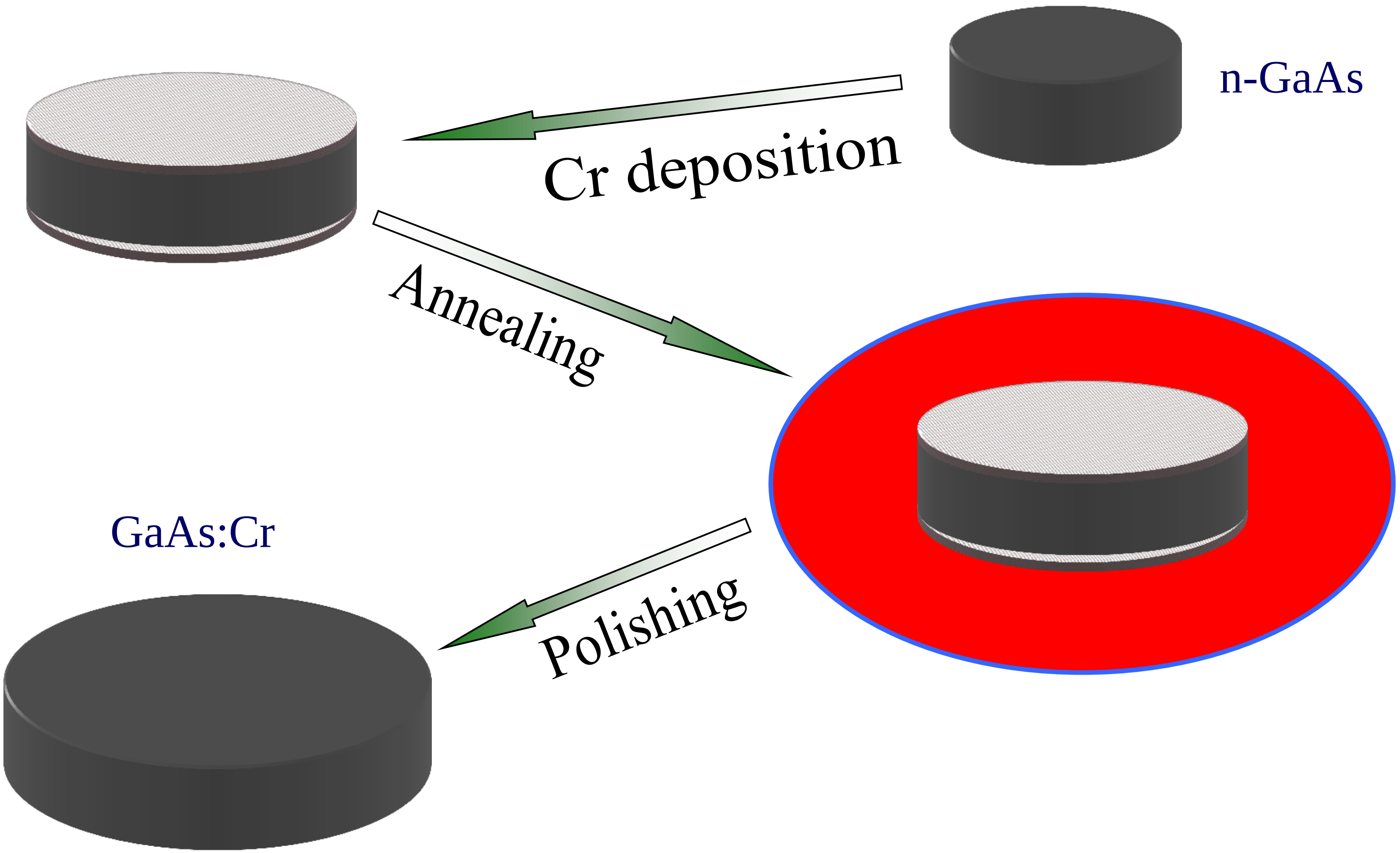


wafer # 1, seed end

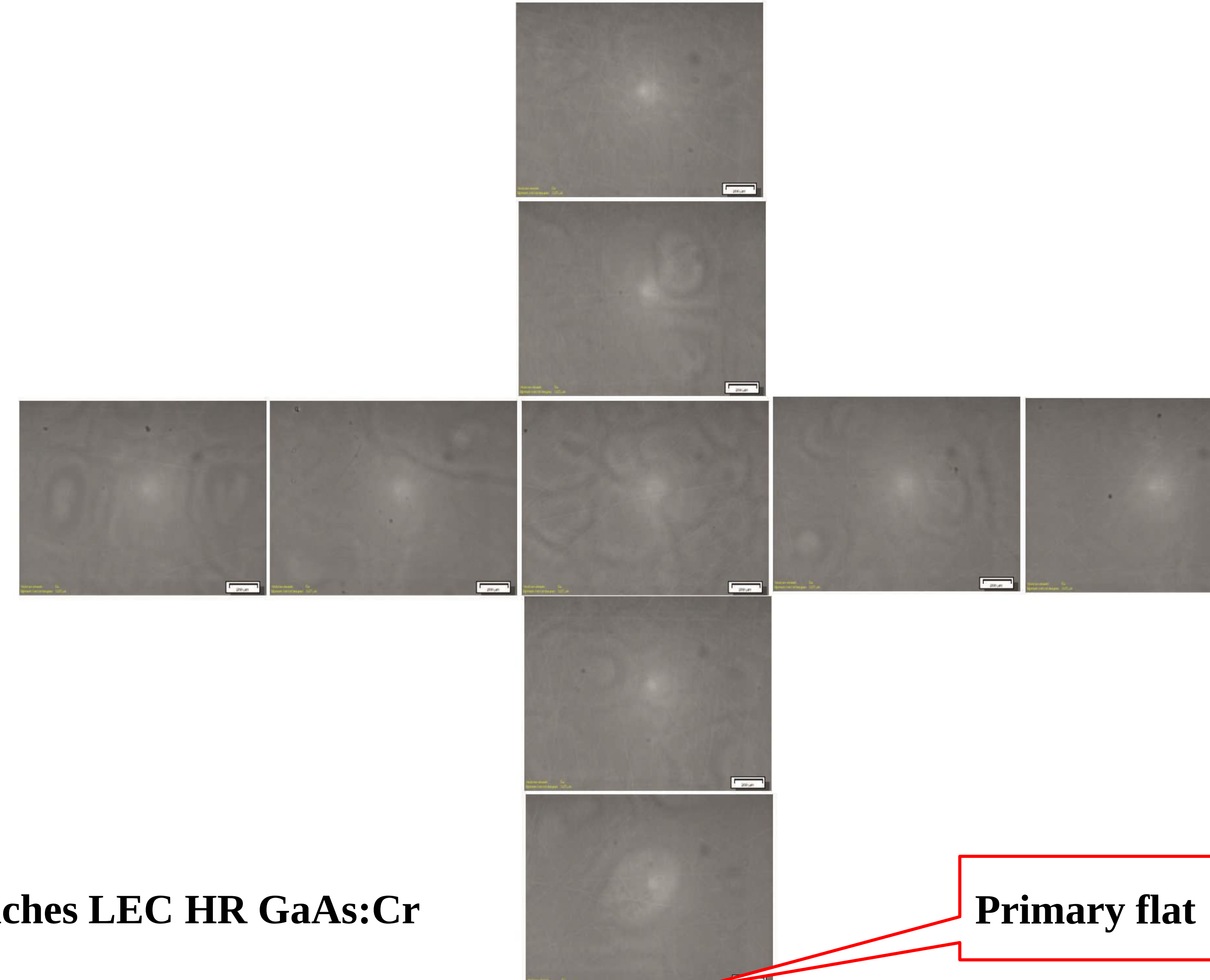
wafer # 132, tail end

4 inches LEC n-GaAs ingot

Technology of HR GaAs:Cr



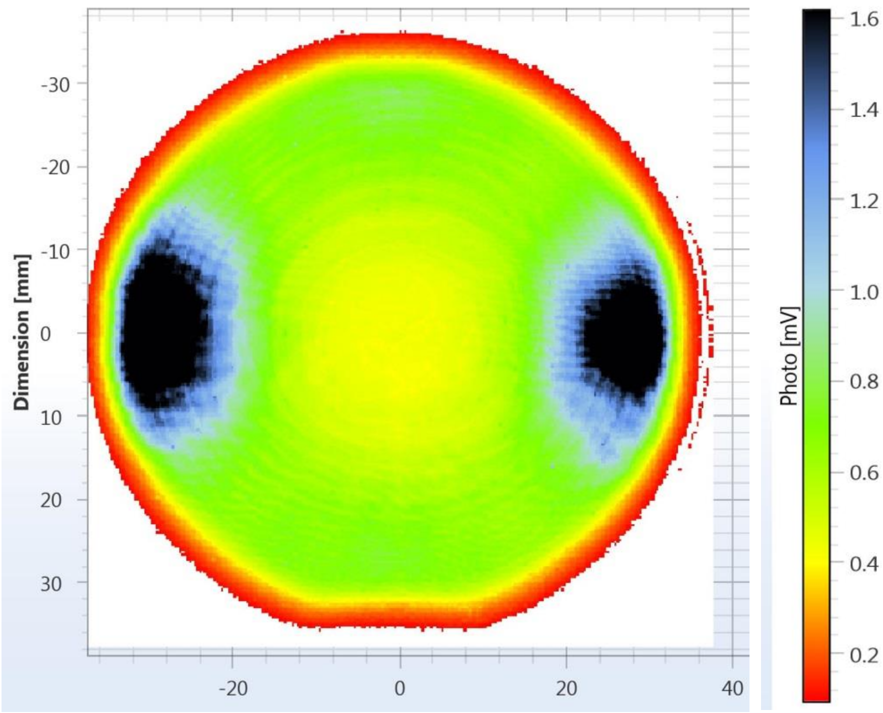
IR transmission image



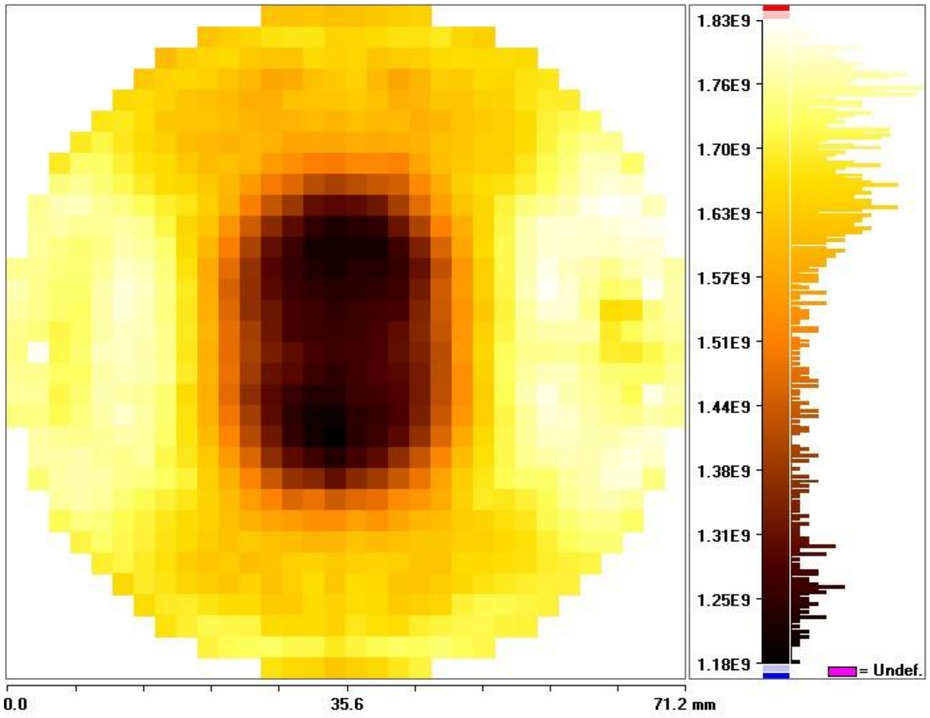
3 inches LEC HR GaAs:Cr

Contactless mapping of photoconductivity

Photoconductivity



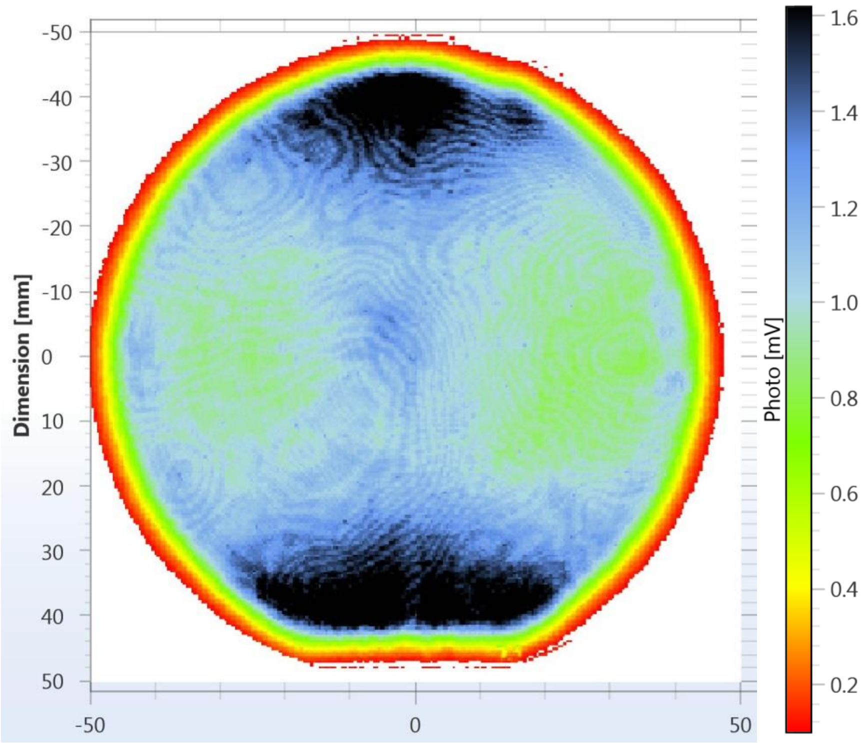
Resistivity



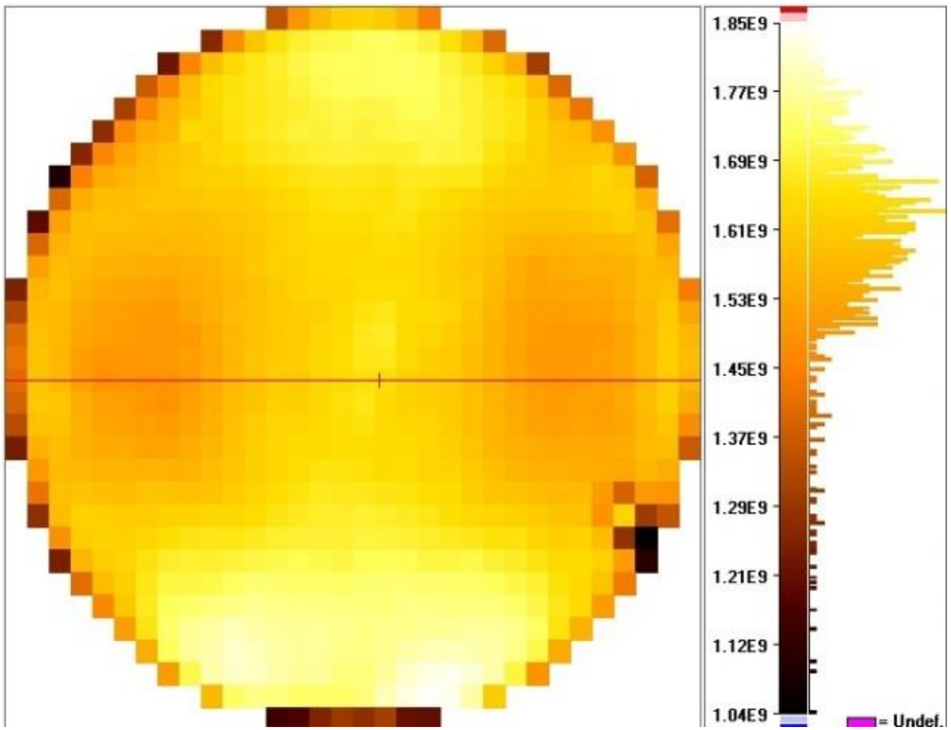
3 inches LEC HR GaAs:Cr

Contactless characterization of HR GaAs:Cr wafers

Photoconductivity



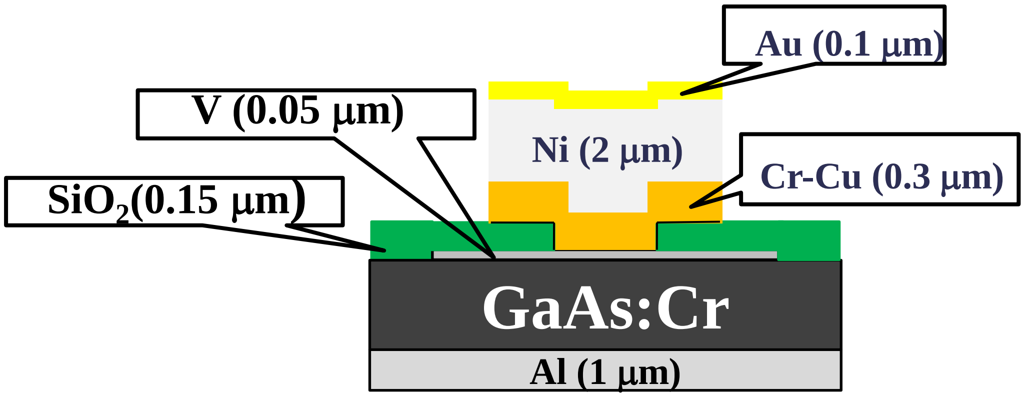
Resistivity

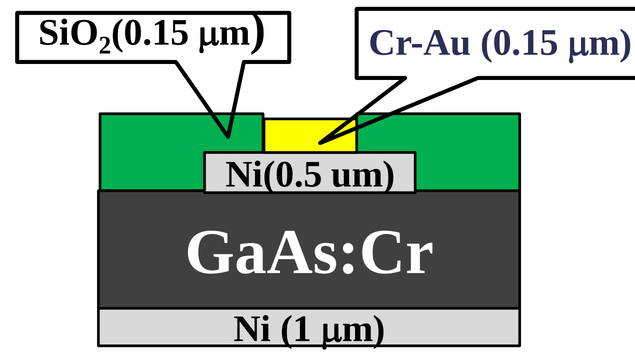


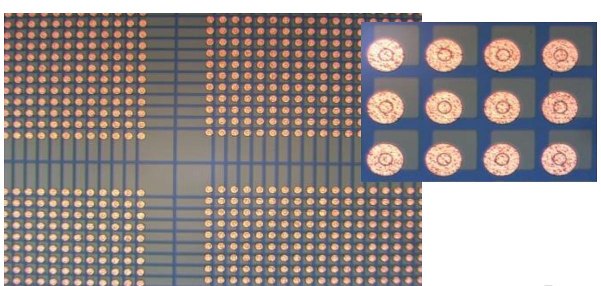
4 inches LEC HR GaAs:Cr

HR GaAs:Cr sensors

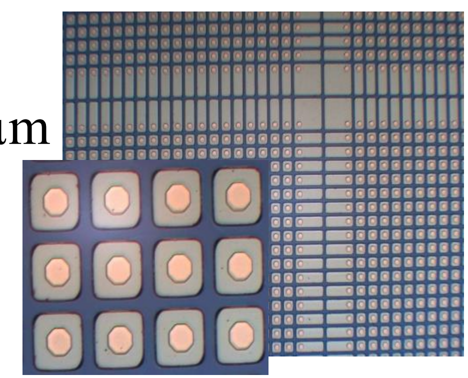
Pixel sensors: pitch size – down to 35 µm,
number of pixels –
up to 512x1536 at 55 µm pitch





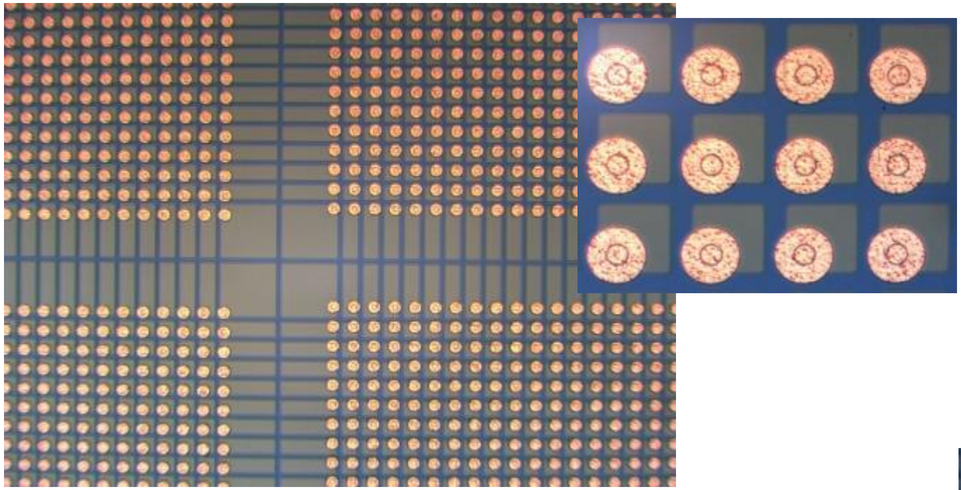


Pitch -55 µm, UBM-30 µm

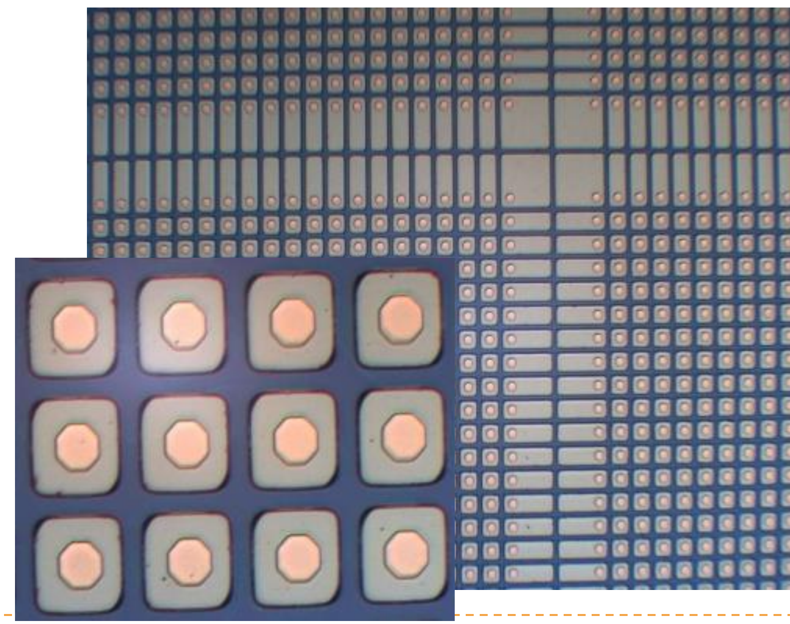


Pitch -55 µm, UBM-20 µm

HR GaAs:Cr sensors



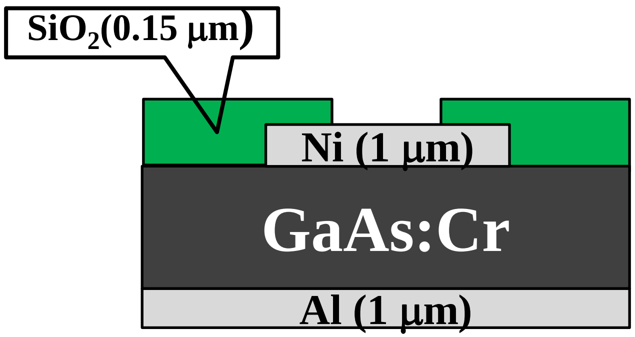
UBM for PbSn bump bonding @200 ^{o}C

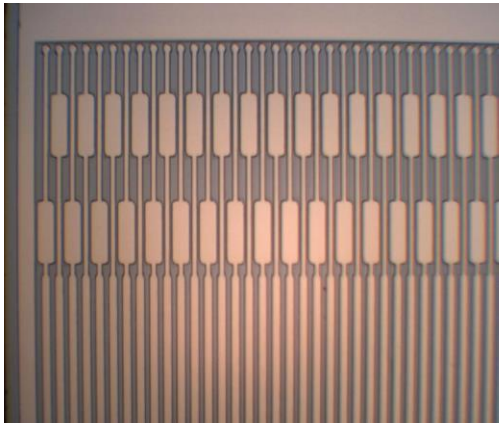


UBM for In bump bonding @ RT

HR GaAs:Cr sensors

Strip sensors: pitch size – down to 50 µm,
number of channels– up to 1800

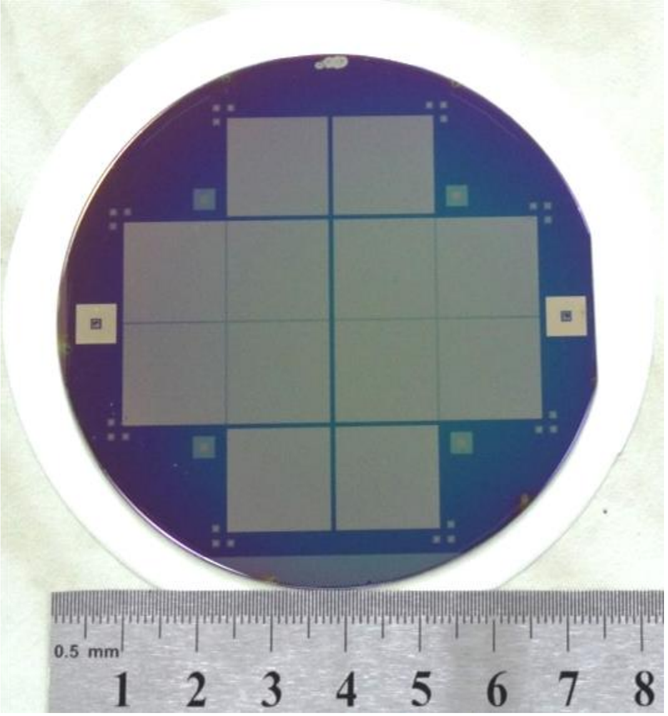


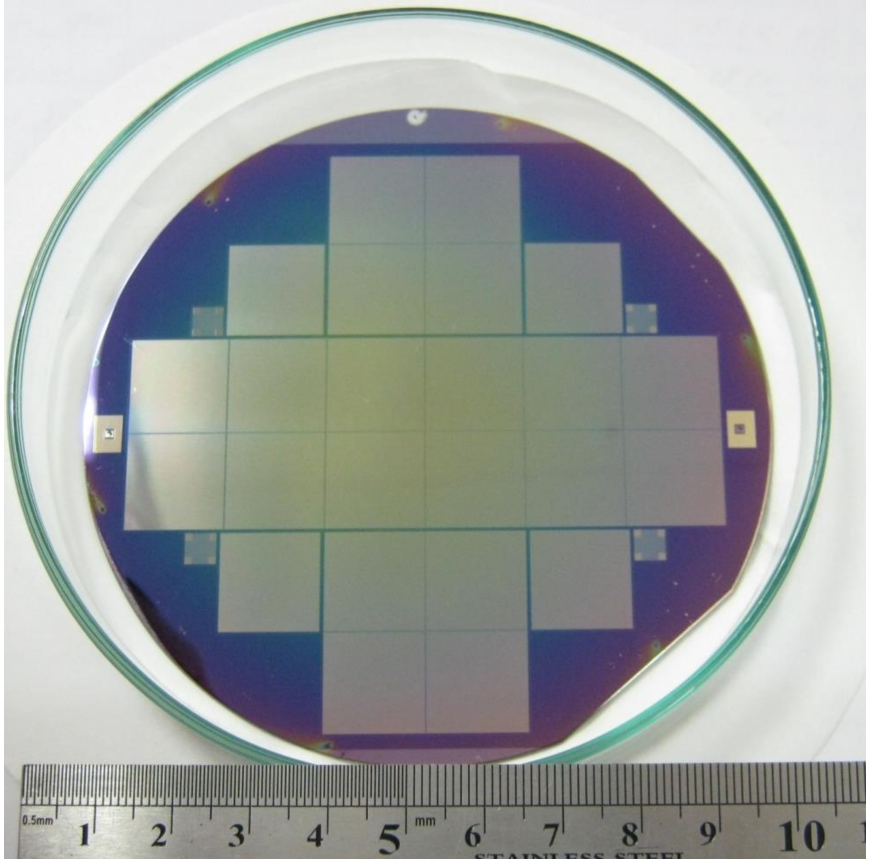


Pitch -50 µm, strip width-25 µm

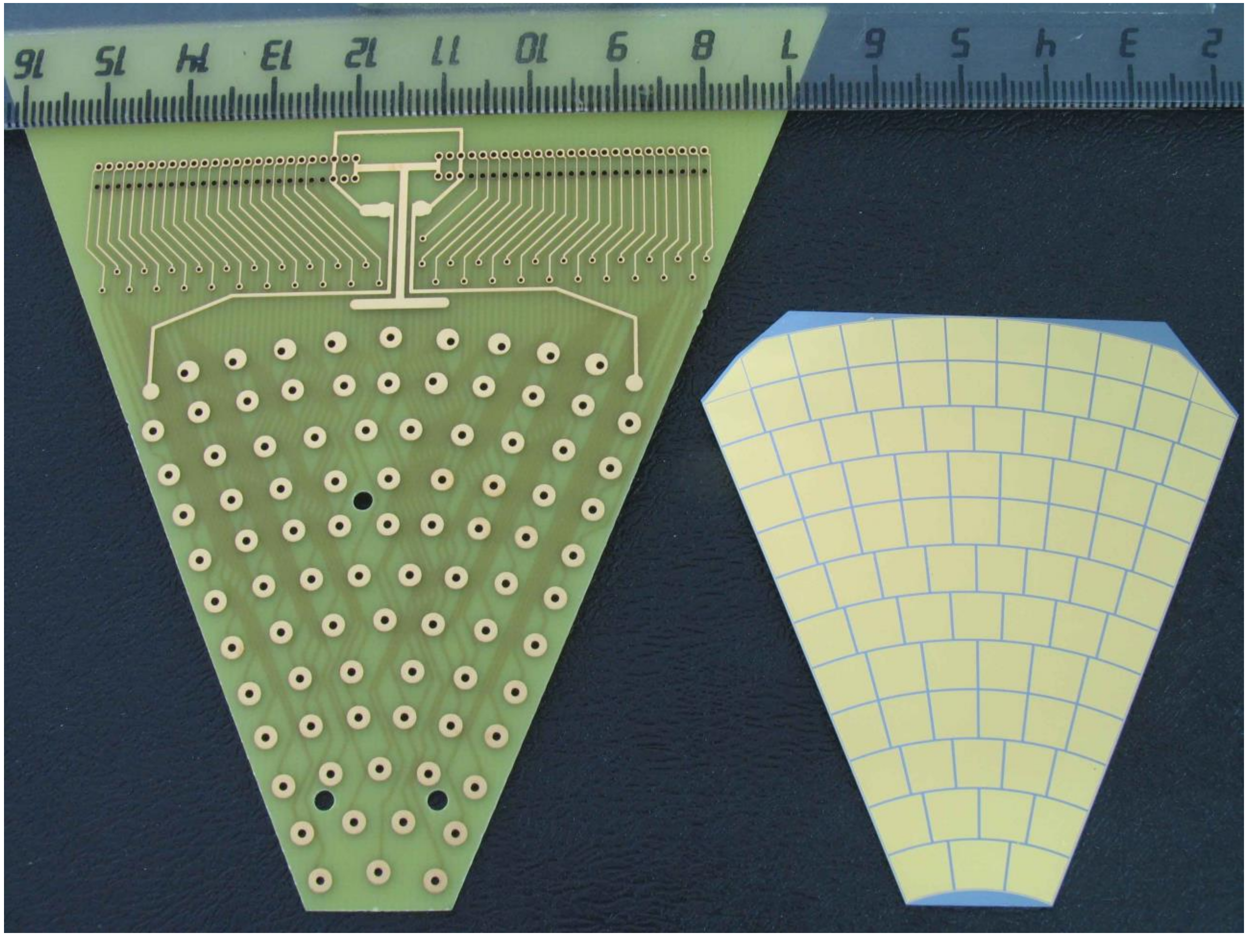
Pixelated wafer capacity

Double HEXA pixel sensor on
HR GaAs:Cr 4 inch wafer





HR GaAs:Cr sector sensor for β-particle registration



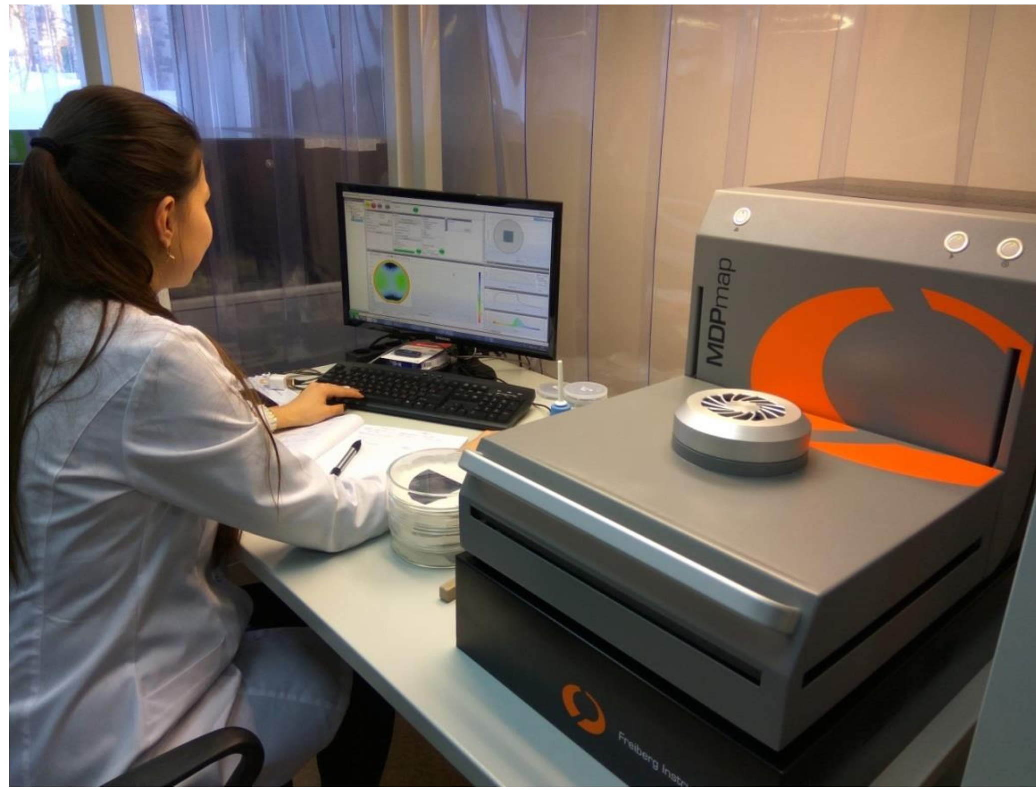
Technology center

You Are Welcome to FEL !

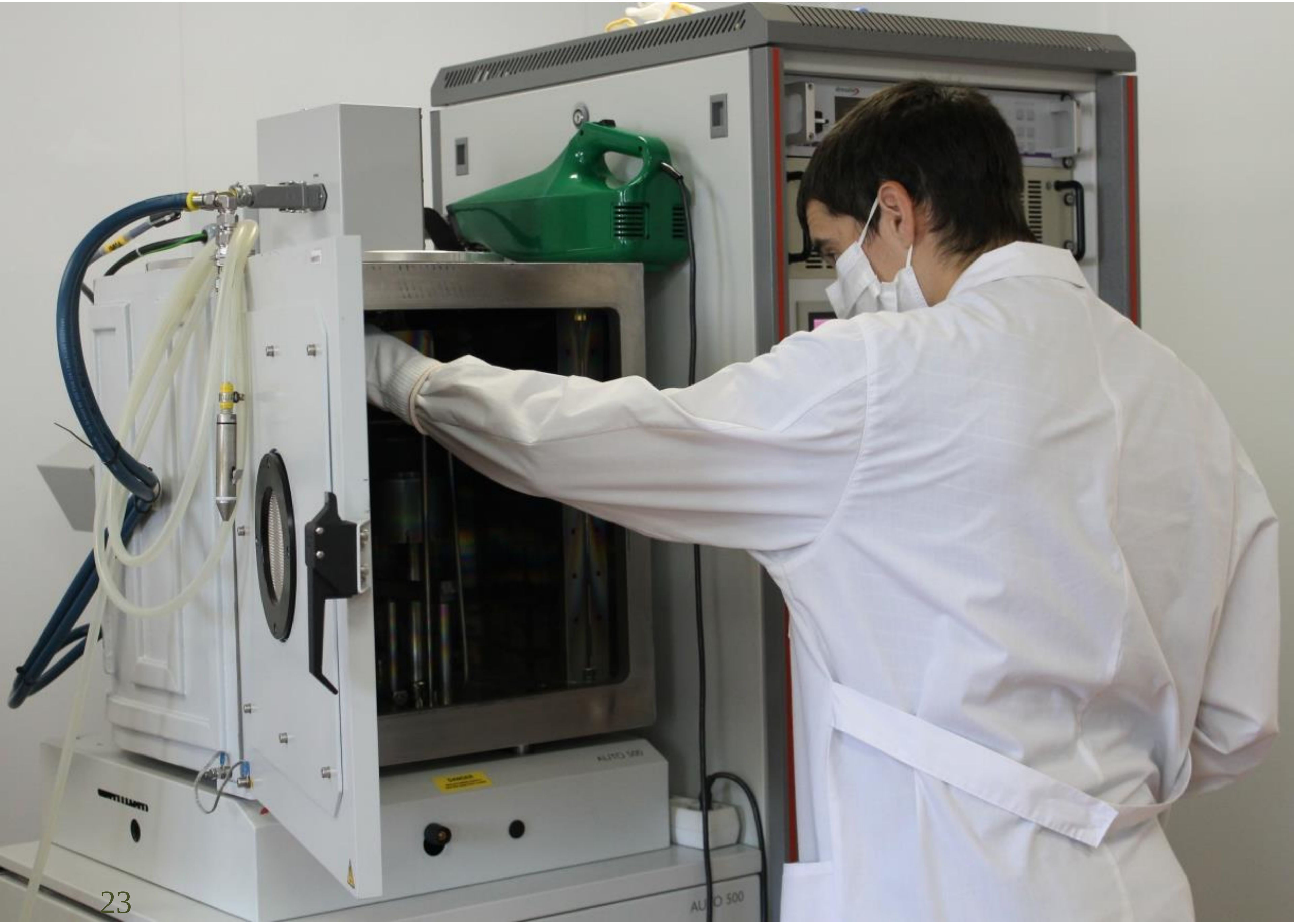
Clean rooms

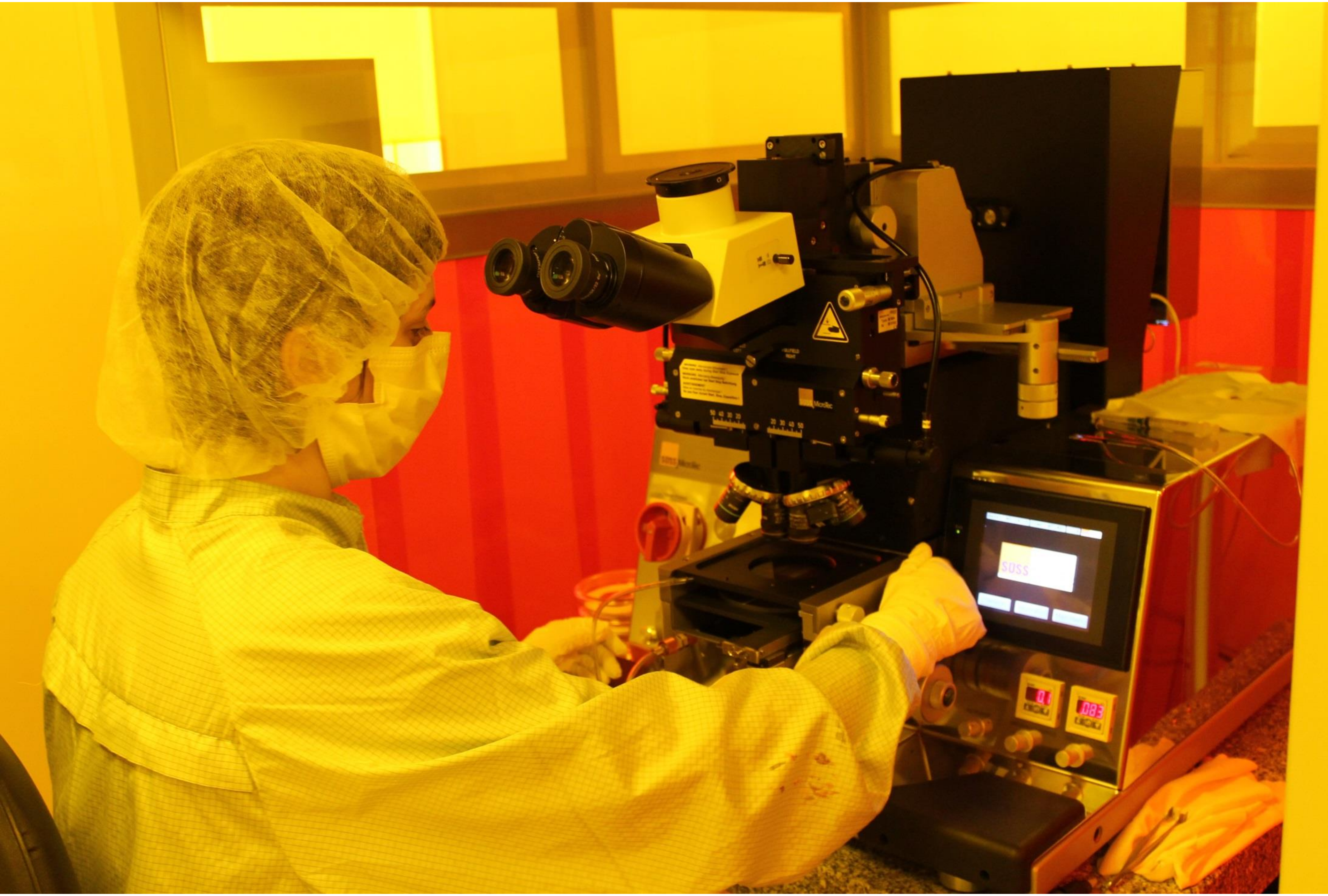

HR GaAs:Cr wafer

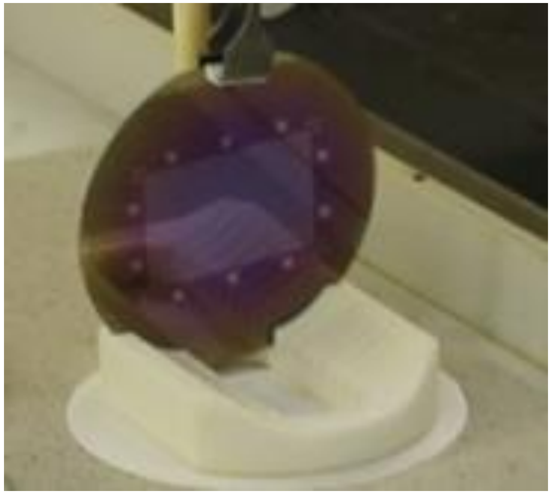
Resistivity



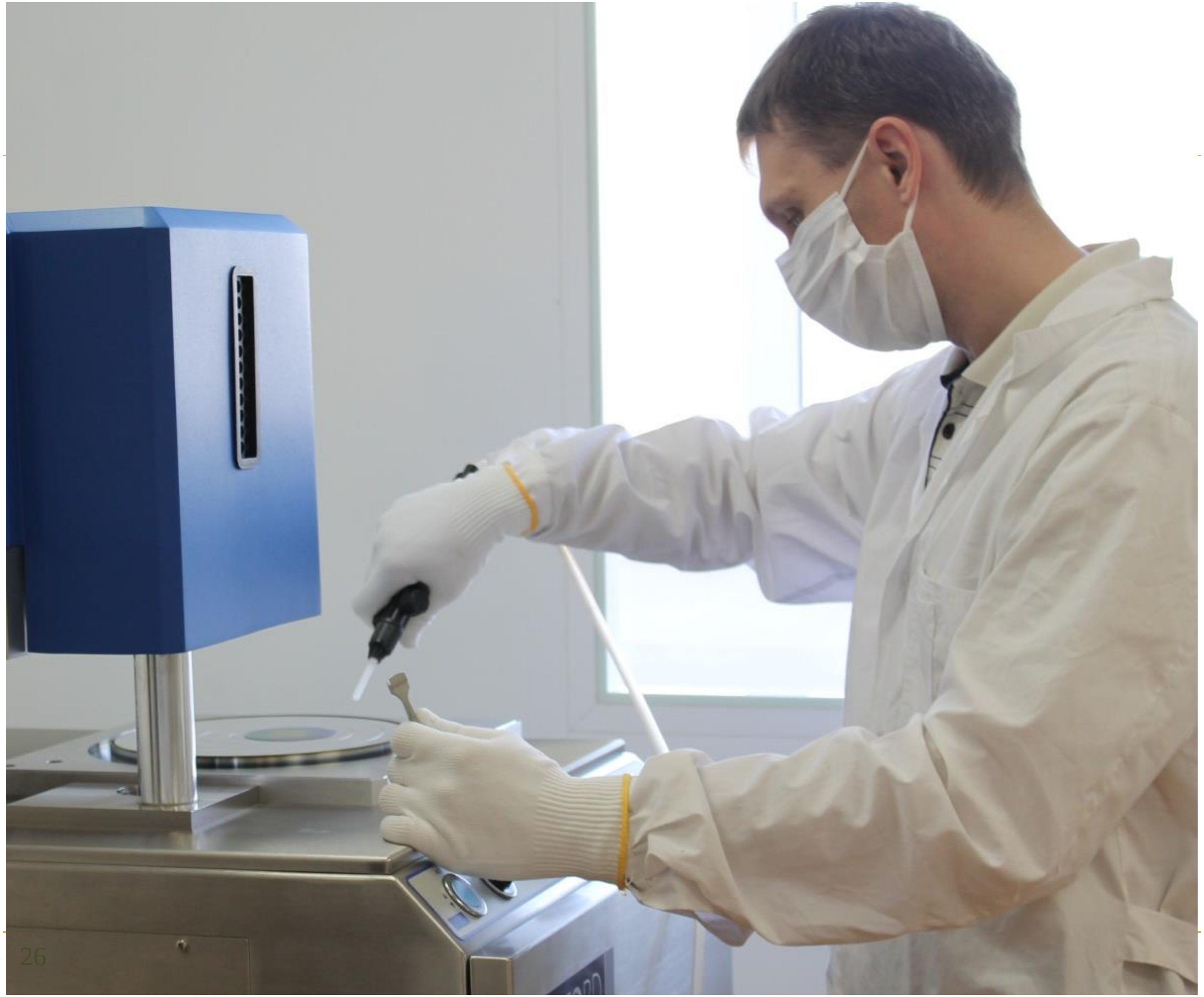
Photoconductivity


AUTO 500

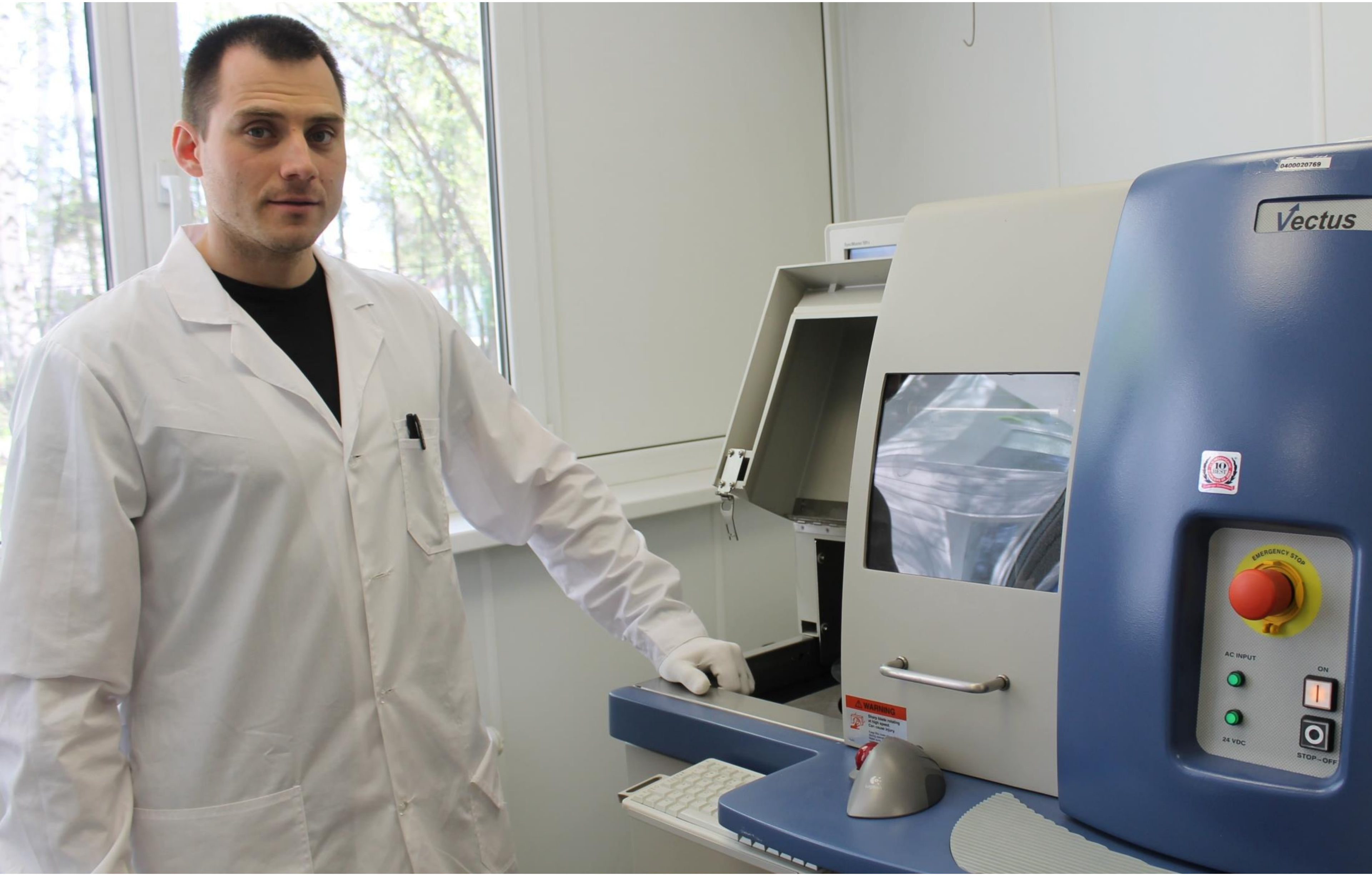

SUSS



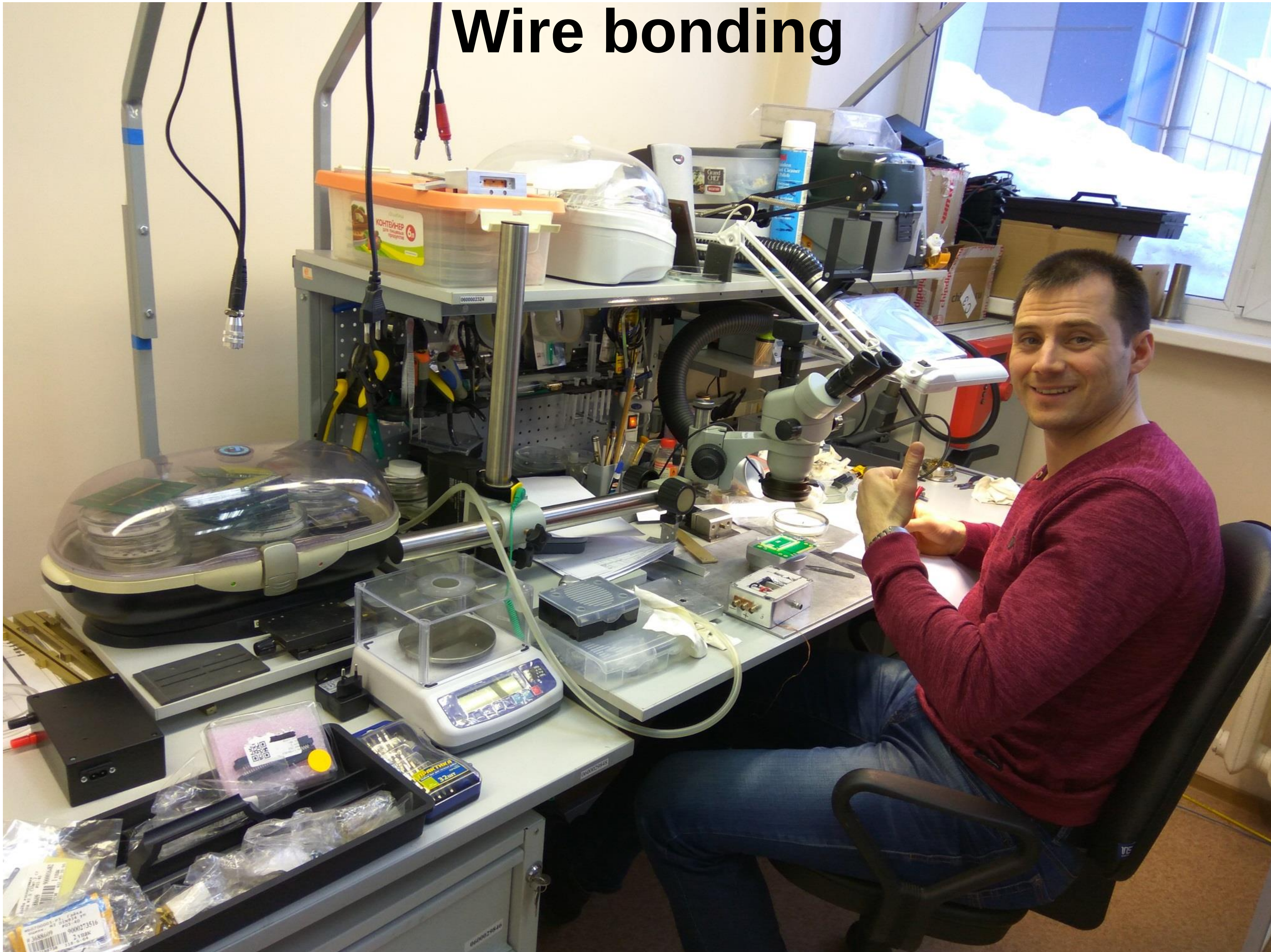

Время 1
ЦС 2

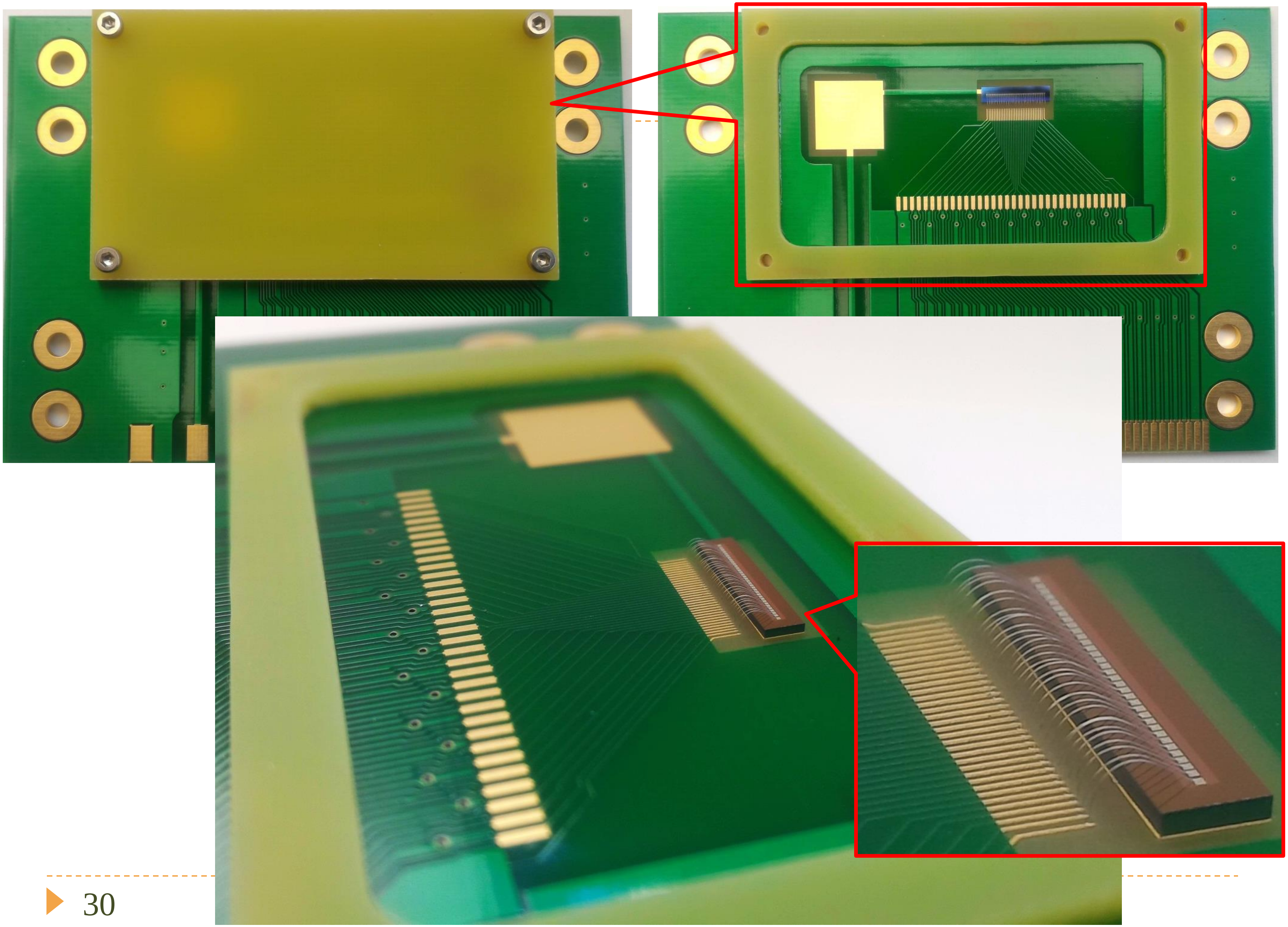


We check wafer before shipping


Vectus
EMERGENCY STOP
AC INPUT
ON
24 VDC
STOP→OFF
WARNING

Wire bonding





Spatial resolution of 256×256 HR GaAs Timepix ASIC pixel detector

Image of a lead ‘besom test’ pattern

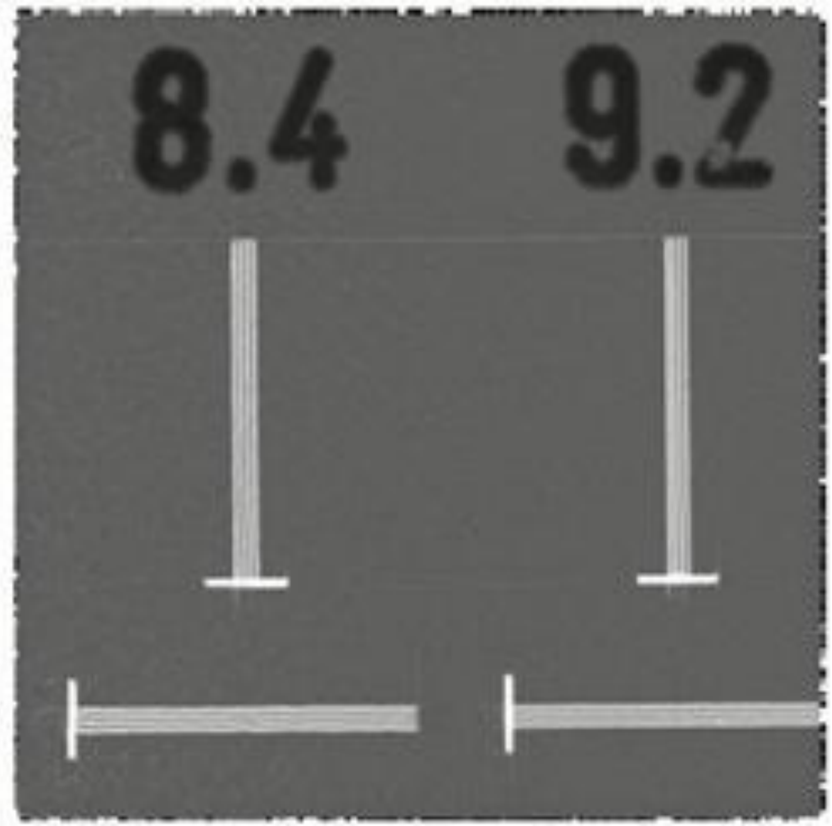
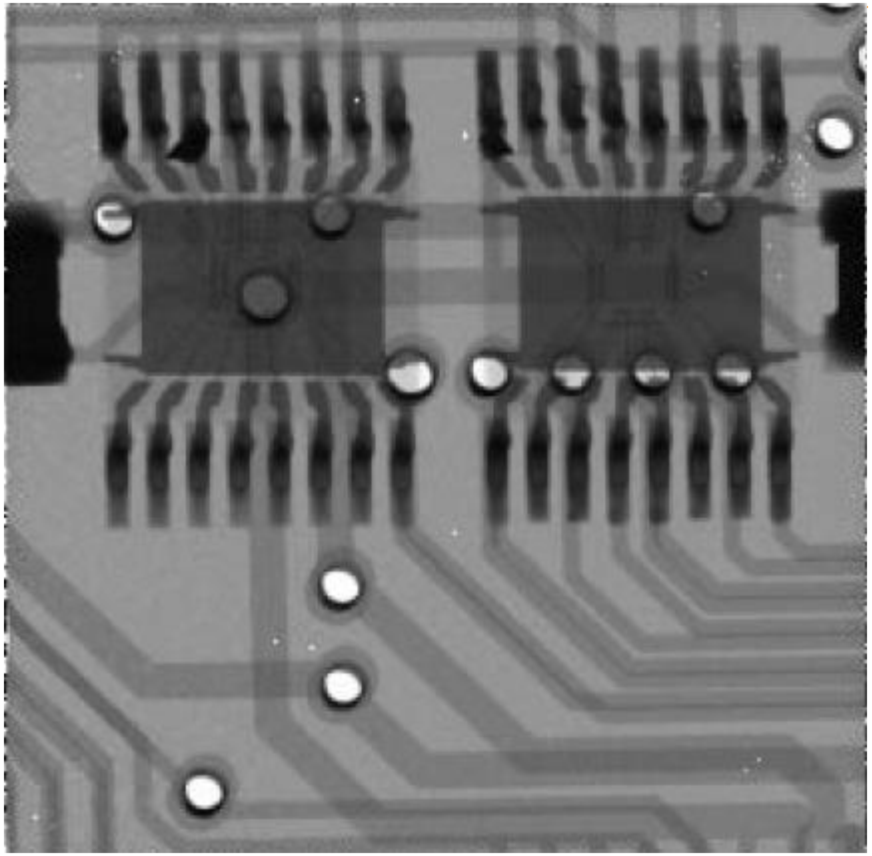


Image of a line pair pattern. The numbers indicate spatial frequencies in mm^{-1}

Procured by E. Hamann (IPS, Karlsruhe Institute of Technology, Germany)

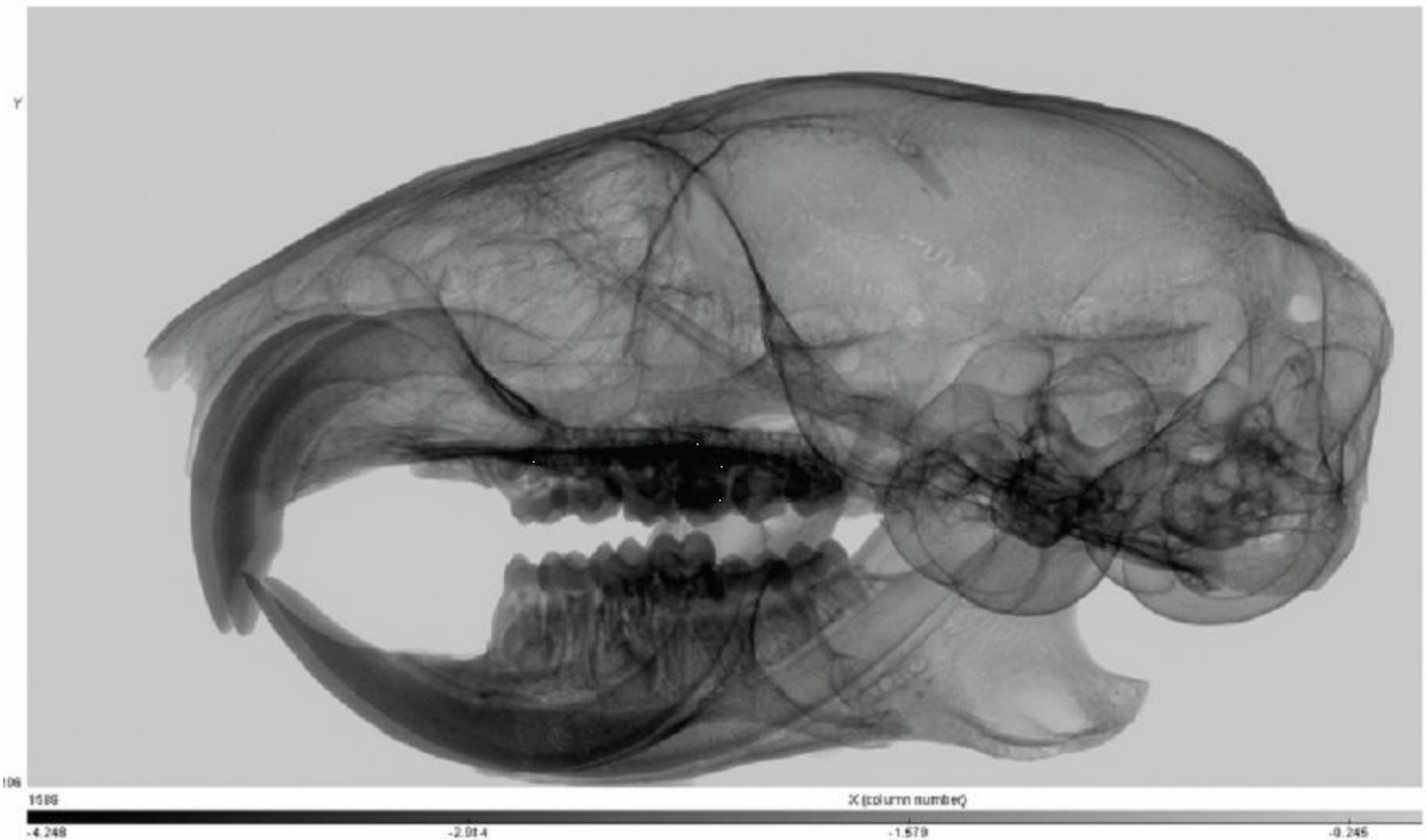
X-ray images of test objects



Flatfield corrected X-ray image of an integrated circuit on a PCB[1]

Flatfield corrected image of a lead test pattern for spatial resolution tests [1]

1- *http://iopscience.iop.org/1742-6596/425/6/062015, E Hamann et al.*



MPX3 assembly 25 kV – 200 V TH0 6 keV

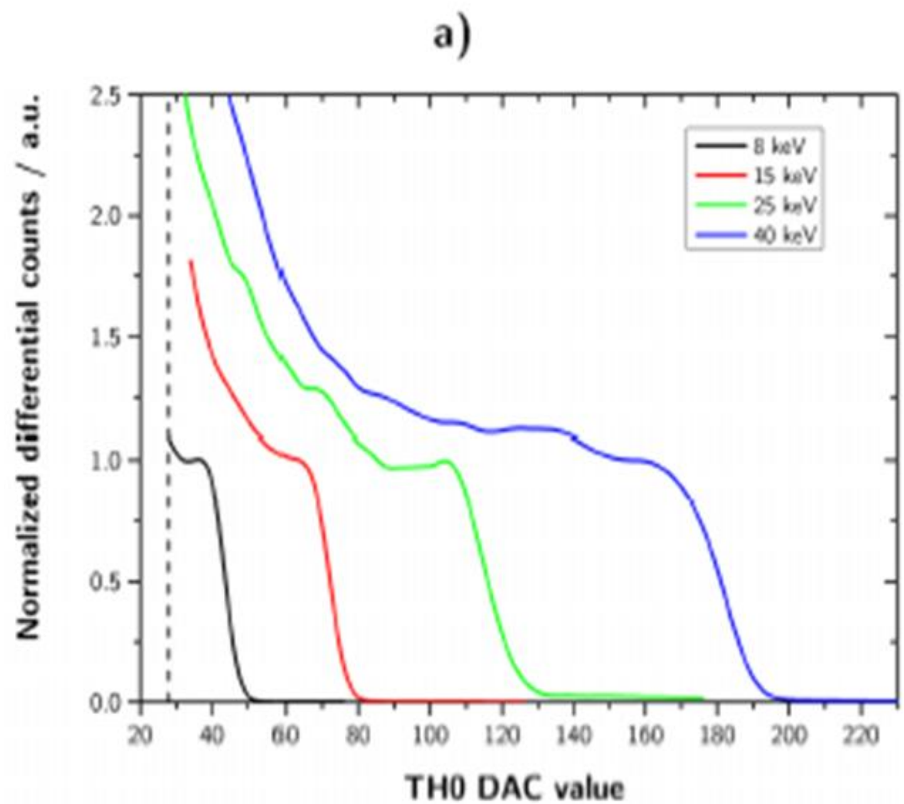
Procured by Simon Procz, FMF, Albert-Ludwigs-University, Germany

MTF for all combinations of photon energies and threshold levels*

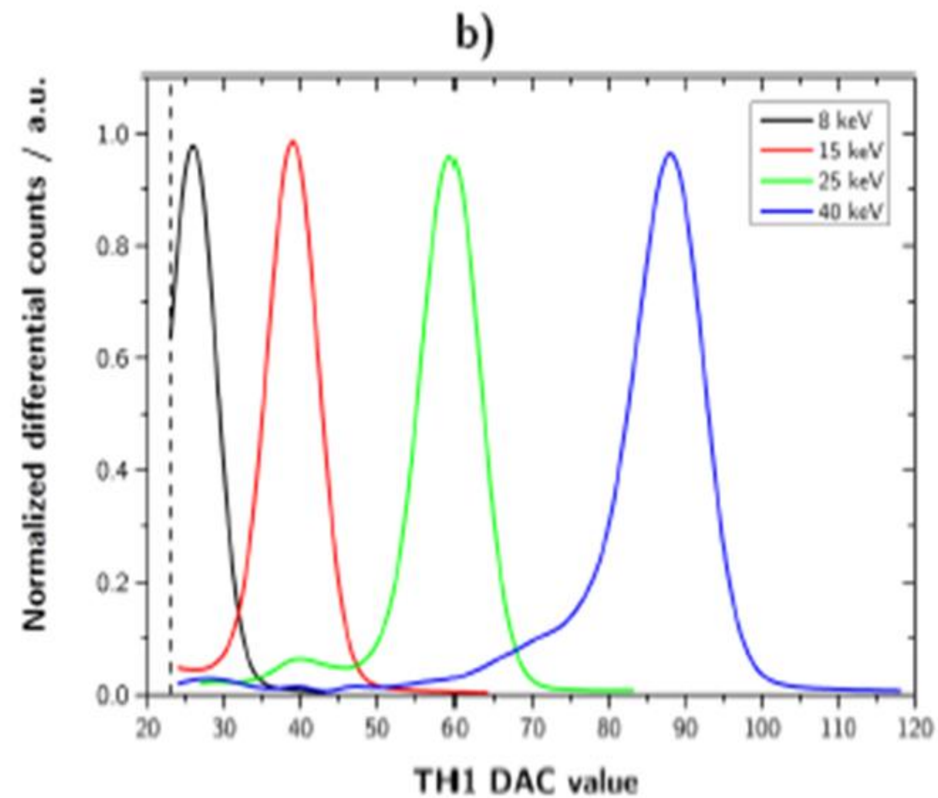
Photon energy: Threshold:	10 keV 8.5 keV	15 keV 8.5 keV	15 keV 12 keV	25 keV 8.5 keV	25 keV 12 keV	25 keV 15 keV
70% MTF	9 mm^{-1}	6.8 mm^{-1}	9.5 mm^{-1}	6.2 mm^{-1}	7.5 mm^{-1}	8.7 mm^{-1}
30% MTF	16.5 mm^{-1}	12.5 mm^{-1}	17.5 mm^{-1}	11.4 mm^{-1}	13.8 mm^{-1}	15.9 mm^{-1}
MTF @ $f_{Nyquist}$	69%	53%	72%	46%	59%	67%

*E. Hamann "Characterization of High Resistivity GaAs as Sensor Material for Photon Counting Semiconductor Pixel Detectors", PhD thesis, University of Freiburg, 2013

500 um thick HR GaAs:Cr & Medipix3RX ASIC



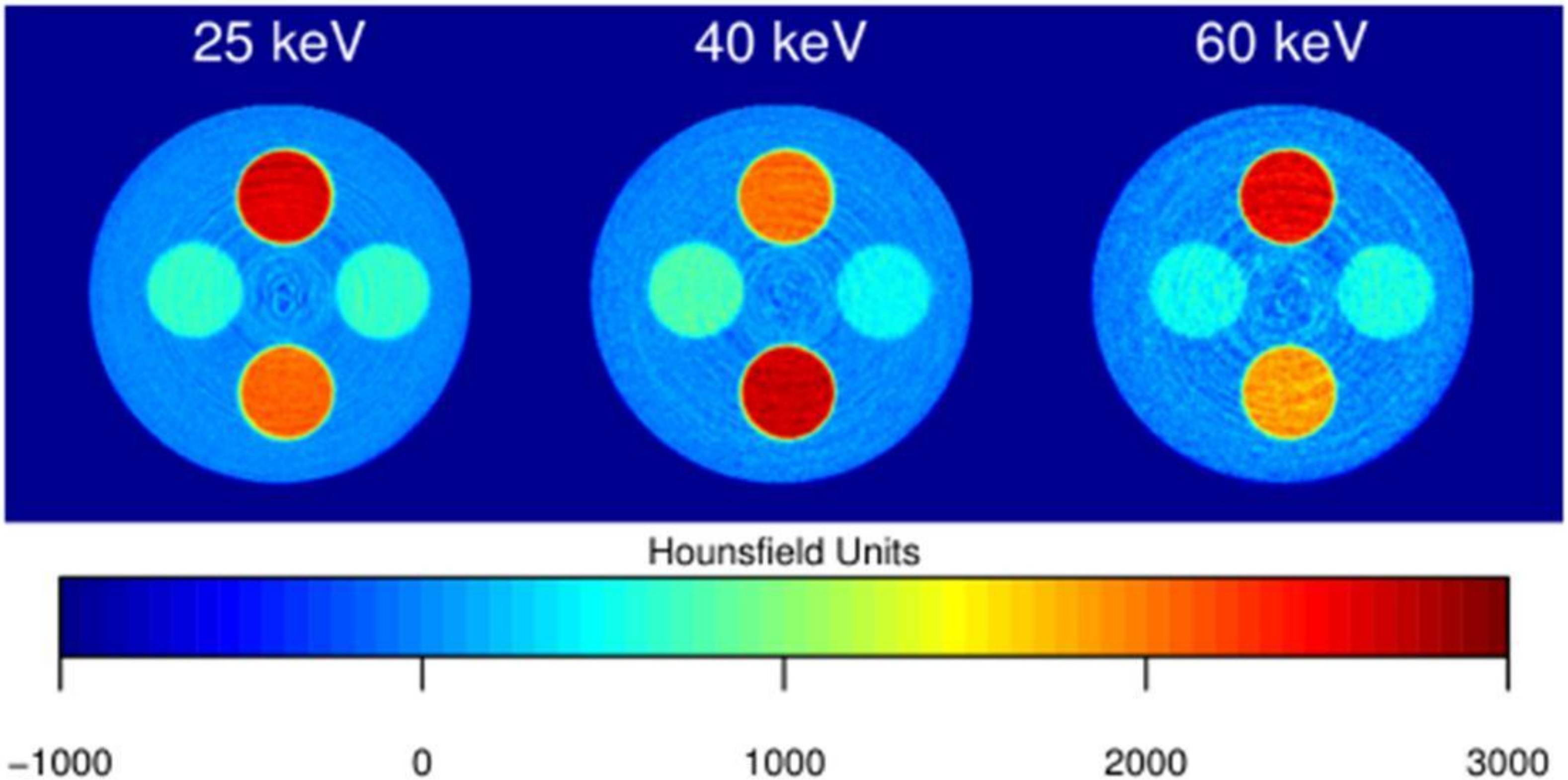
Single Photon t Mode
(SPM)



Charge Summing Mode
(CSM)

E. Hamann "Characterization of High Resistivity GaAs as Sensor Material for Photon Counting Semiconductor Pixel Detectors", PhD thesis, University of Freiburg, 2013

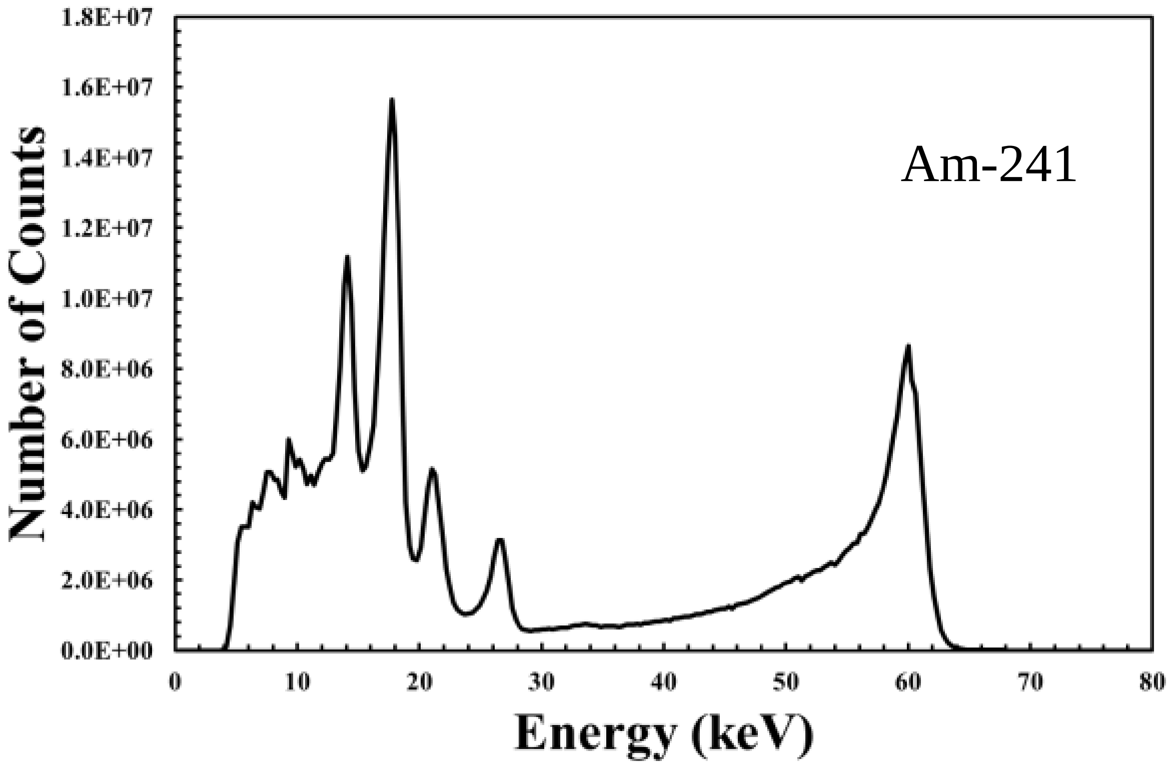
X-ray spectroscopic images of test objects



Bottom capillary: iodine (250 µmol/ml); Left: iodine (50 µmol/ml);
Top: gadolinium (250 µmol/ml); Right: gadolinium (50 µmol/ml)

E. Hamann et al. Performance of a Medipix3RX Spectroscopic Pixel Detector With a High-Resistivity Gallium Arsenide Sensor, IEEE Transactions on Medical Imaging, Volume 34, Issue 3, 2015, Article number 6797893, Pages 707-715, DOI : 10.1109/TMI.2014.2317314

500 um thick HR GaAs:Cr & HEXITEC ASIC



$FWHM_{@60keV}$ = 3.0 +/- 0.5 keV (10%)

Typical V_{bias} = 300 V

T = 7^0 C

Pixel sizes: 200*200 um^2

M.C. Veale et al. “Chromium compensated gallium arsenide detectors for X-ray and γ-ray spectroscopic imaging”, Nuclear Instruments and Methods in Physics Research, A752 (2014) 6–14

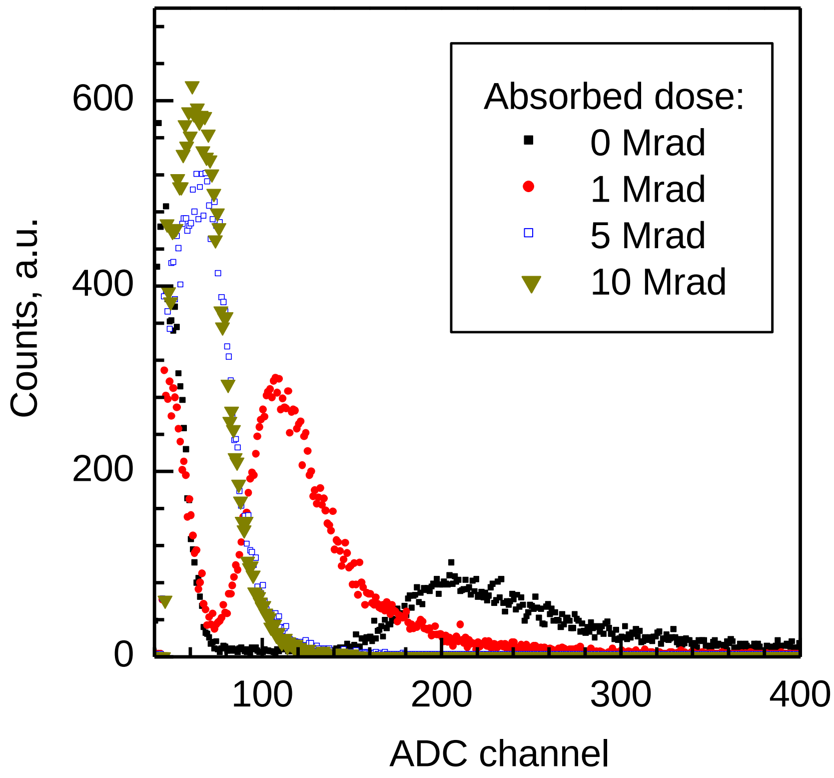
Energy resolution HR GaAs pixel sensors

Table 9.1: Energy resolution (absolute and relative FWHM) of the CSM peaks for different photon energies as shown in Figure 9.13 b) and a Cd-109 source.

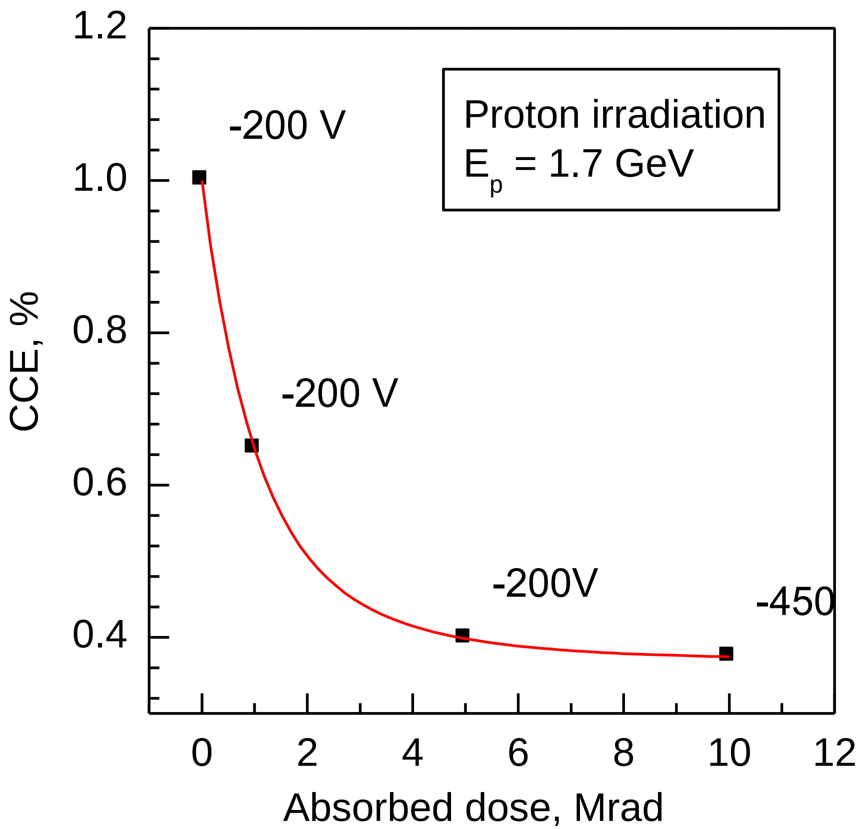
Photon energy / keV	8	15	22.5	25	40
FWHM / keV	2.8	3.4	4.34	4.16	4.5
FWHM / %	34.6	22.8	19.3	16.7	11.2

E. Hamann "Characterization of High Resistivity GaAs as Sensor Material for Photon Counting Semiconductor Pixel Detectors", PhD thesis, University of Freiburg, 2013

1.7GeV proton exposure

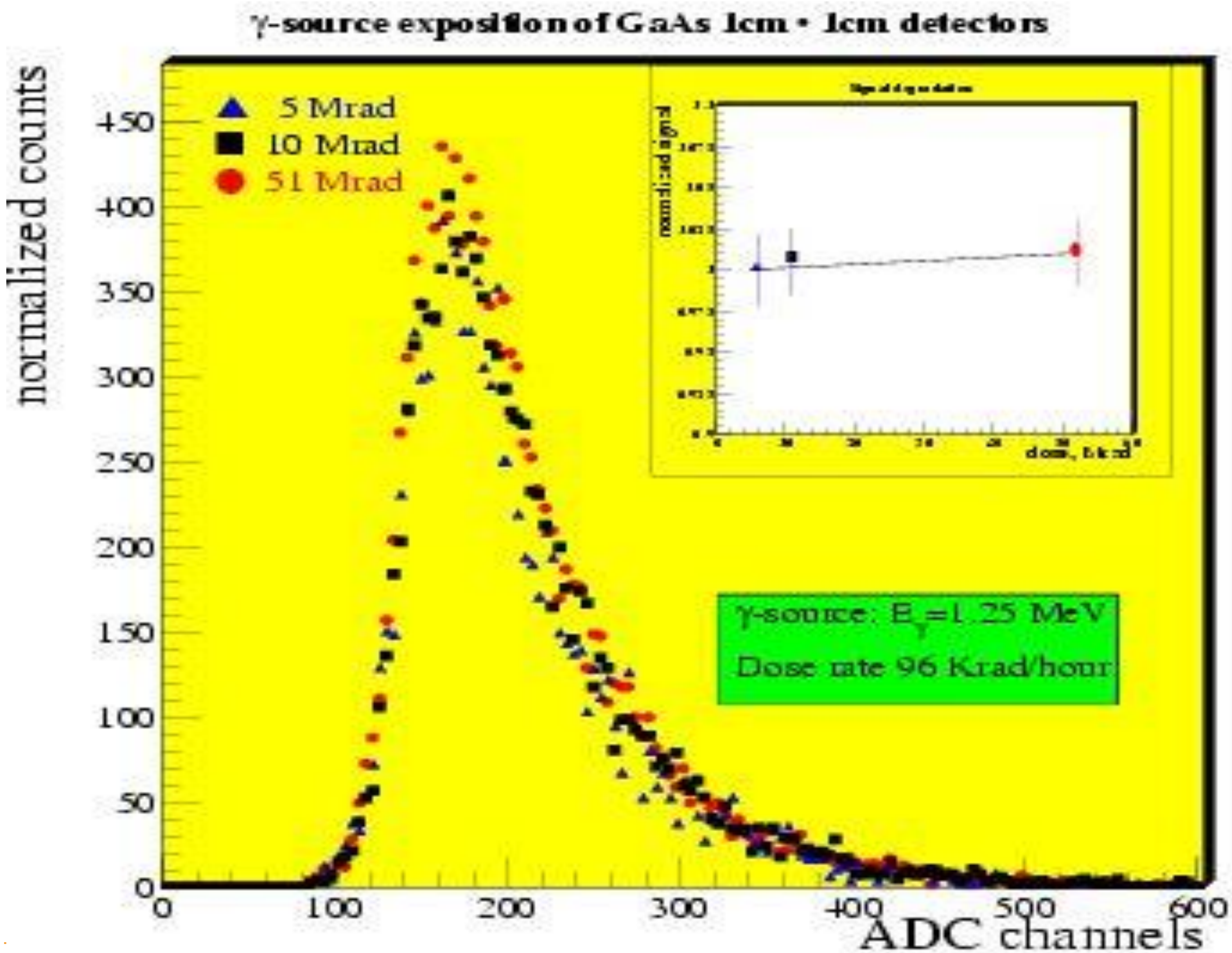


Dependence of the pulse height distribution on the absorbed dose.

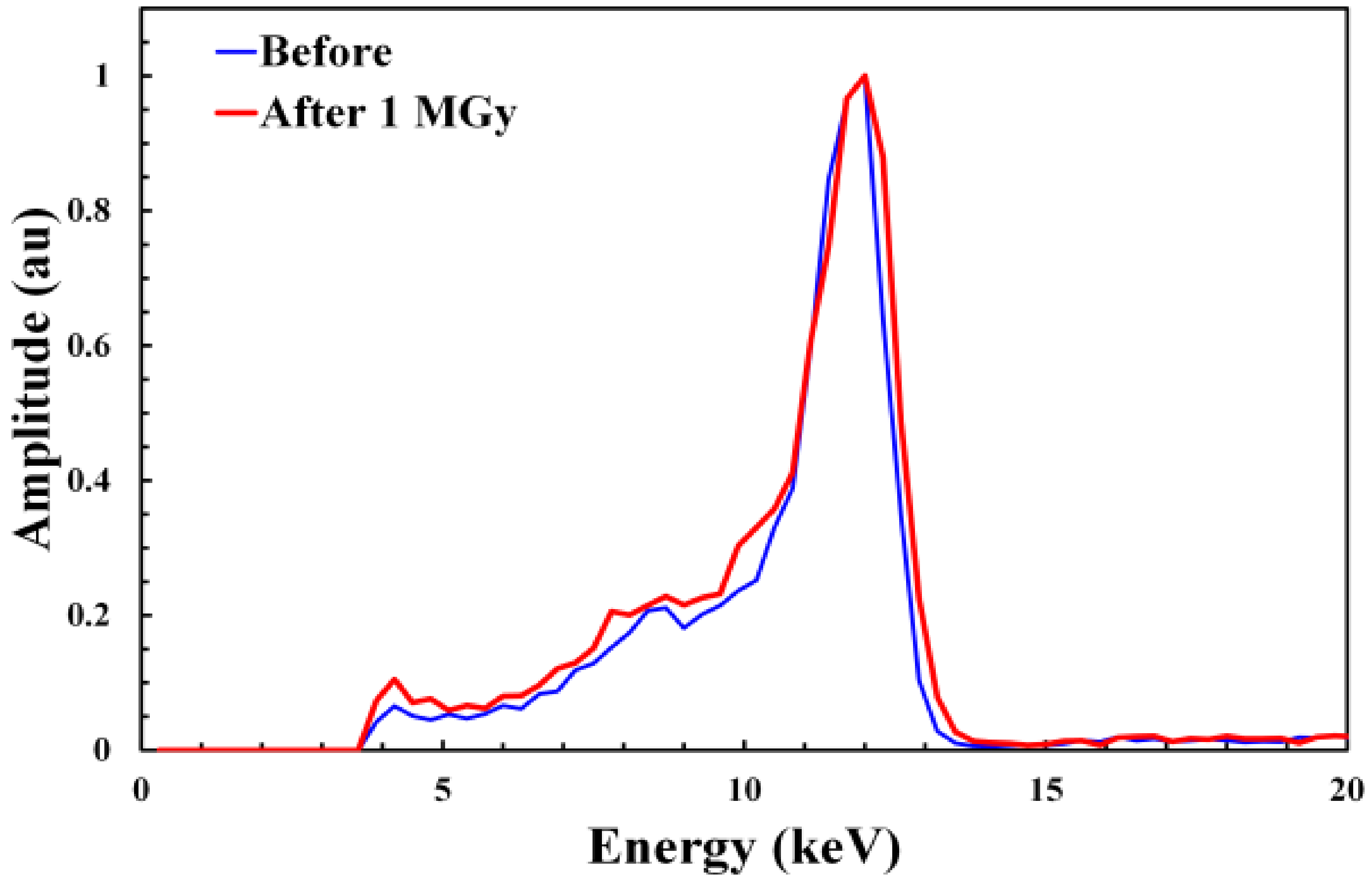


Dependence of the charge collection efficiency on the absorbed dose.

Irradiation with 1.25 MeV γ-quanta



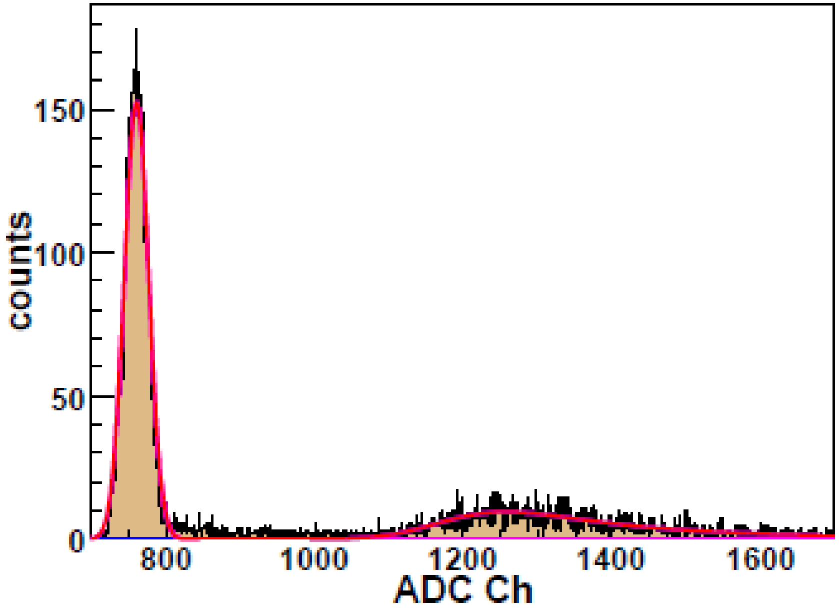
Irradiation with 12 KeV γ-quanta



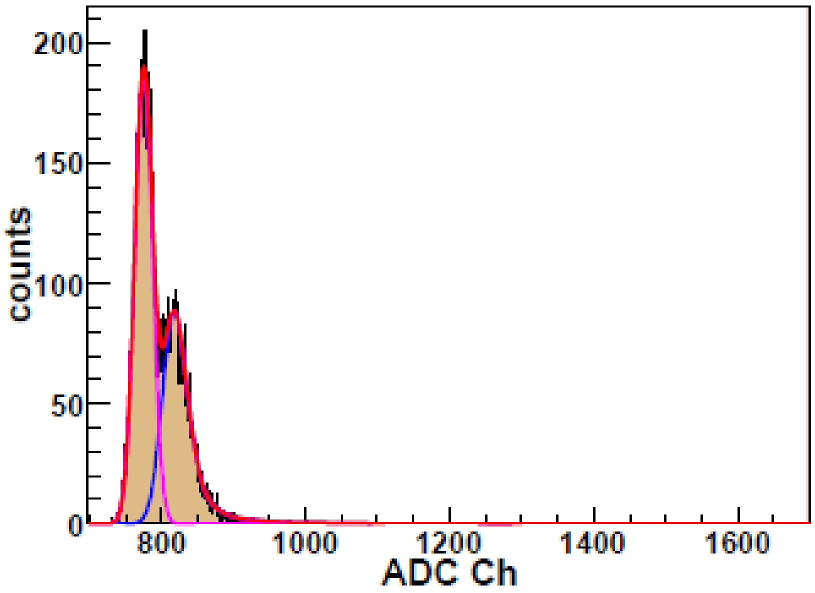
The spectrum of the 12 keV measured before and after a 1 MGy exposure, HR GaAs:Cr + HEXITEC ASIC detector

*M. C. Veale et all “Investigating the suitability of GaAs:Cr material for high flux X-ray imaging”, Journal of Instrumentation. DOI: 10.1088/1748-0221/9/12/C12047

Irradiation with 8-10 MeV β-particles



Non-irradiated HR GaAs:Cr sensor



The same sensor after absorbing a dose of 1.5MGy

K. Afanaciev et al., JINST, 2012, Investigation of the radiation hardness of GaAs sensors in an electron beam doi:10.1088/1748-0221/7/11/P11022

Summary & perspectives

- Technologies of 4 inches HR GaAs:Cr wafers and pixel sensors
- Technology of «low Z» metal contact for HR GaAs:Cr sensors (1 um, Al)
- Wire bonding of sensors with sizes of bonding pads of 60×100 um^2

In co-operation with JINR (Dubna, Russia):

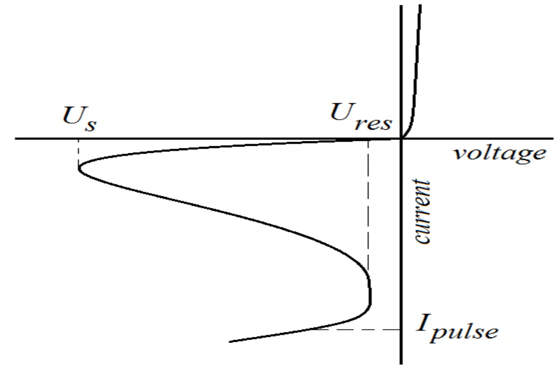
- Improvement of HR GaAs:Cr material technology to increase radiation hardness for β - particles
- Investigation of radiation hardness of improved HR GaAs:Cr pad sensors irradiated with β - particles

Thank you for your listening!

Superfast GaAs avalanche switches

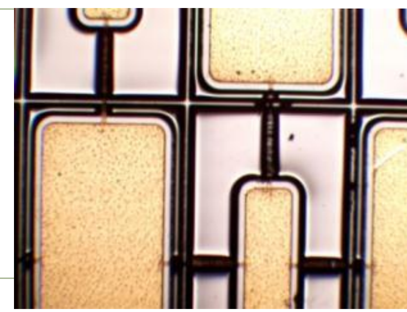
Application:

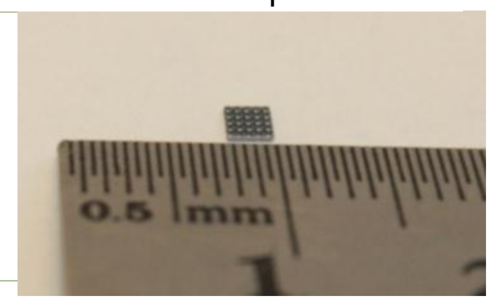
Compact generators of short pulses for ultrawideband and optical rangefinders, ultrawideband radars, and lidars (*LiDAR for 3D Mapping, LiDAR for Non-Automotive Autonomous Vehicle, Laser Scanners, Fiber Optic Integrity Instruments*).



Characteristics:

Switching voltage (U_s): 50 – 1500 V
Pulse current (I_{pulse}): 0.1-50 A
Residual voltage (U_{res}): $0.15 \cdot U_s$
Switching time: 50 – 1000 ps
Maximum repetitive frequencies: 1–1000 kHz
Size: 0.5 mm x 1mm x 2 mm



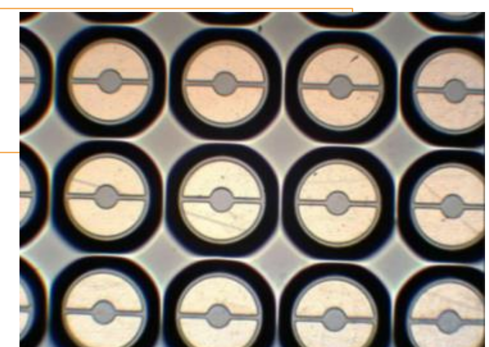


Publications:

IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. 65, NO. 8, AUGUST 2018 3339

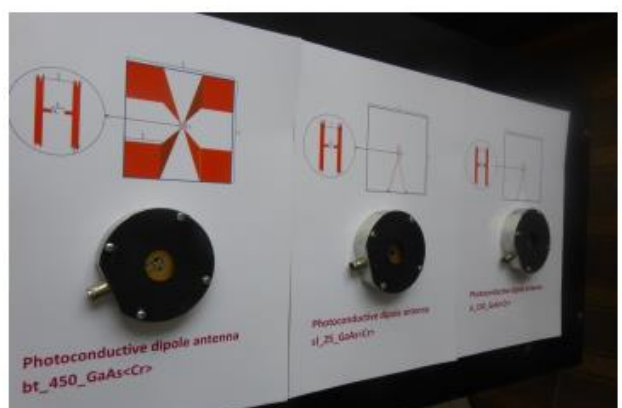
The Mechanism of Superfast Switching of Avalanche *S*-Diodes Based on GaAs Doped With Cr and Fe

Ilya A. Prudaev, Vladimir L. Oleinik, Tatyana E. Smirnova, Viktor V. Kopyev, Maksim G. Verkholetov, Evgeny V. Balzovsky, and Oleg P. Tolbanov



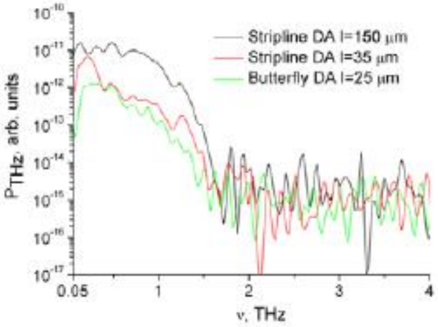
Nonlinear crystal growth and terahertz spectroscopy

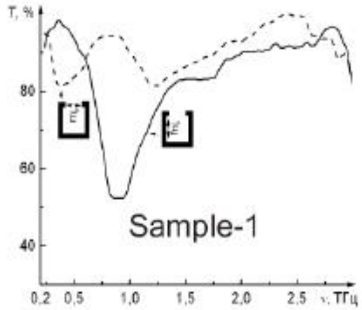
1. Growth and study of properties and applications of nonlinear optical materials like GaSe, $CdSiP_2$, Ga_2O_3
2. Terahertz time-domain spectroscopy and components (photomixers, dipole antennas, filters etc.)
3. Terahertz emission spectroscopy of semiconductor surfaces.
4. Designing of element and material science basis for THz range (non-linear crystal growth, dipole antennas, filters and absorbers).
5. Designing of tunable sources of cw and pulsed terahertz and IR radiation.
6. Synthesis and study of of nanolayered (quasi -2D) systems of III-VI semiconductor compounds (GaSe, GaTe, InSe и GaS).



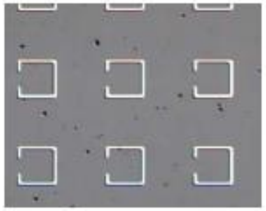
Nonlinear crystal growth and terahertz spectroscopy

Designing and study of photoconductive dipole antennas and terahertz filters



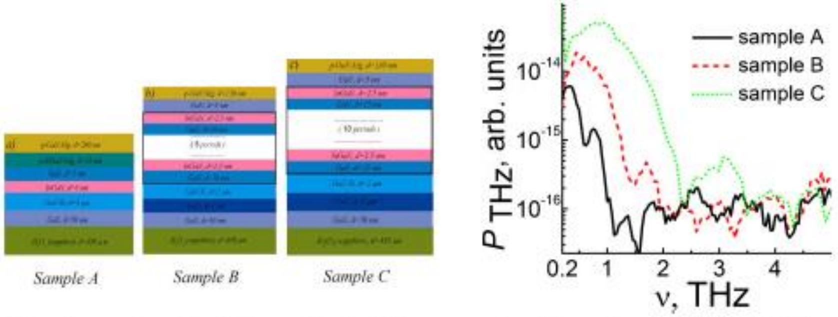


Sarkisov S.Y., Safiullin F.D., Skakunov M.S., Tolbanov O.P., Tyazhev A.V., Nazarov M.M., Shkurinov A.P. // Russian Phys. J. – 2013. – vol. 55, N 8. - pp. 890-898.



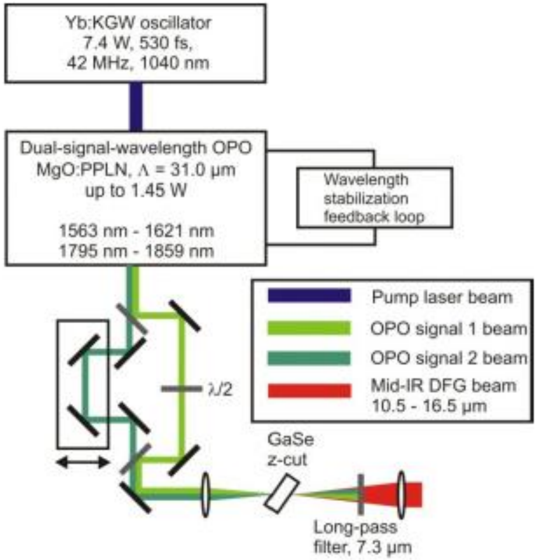
Nazarov M.M., Zarubin A.N., Sarkisov S.Y., Tolbanov O.P., Tyazhev A.V// Russian Phys. J. – 2015. – vol. 58, N 4. - pp. 562-566.

Emission terahertz spectroscopy of semiconductor structures



Prudaev I., Sarkisov S., Tolbanov O., Kosobutsky A. // Phys. Stat. Sol. B. - 2015. - vol. 252, N 5. - P. 946-951.

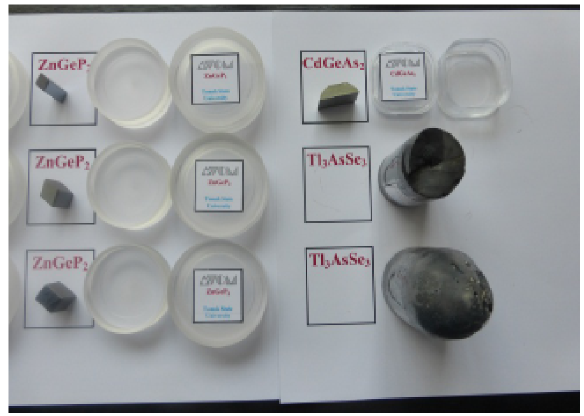
Generation of widely tunable mid-IR



Hegenbarth R., Steinmann A., Sarkisov S., Giessen H. // Opt. Lett. – 2012. – vol. 37, N 17. - pp. 3513-3515.

Nonlinear crystal growth and terahertz spectroscopy

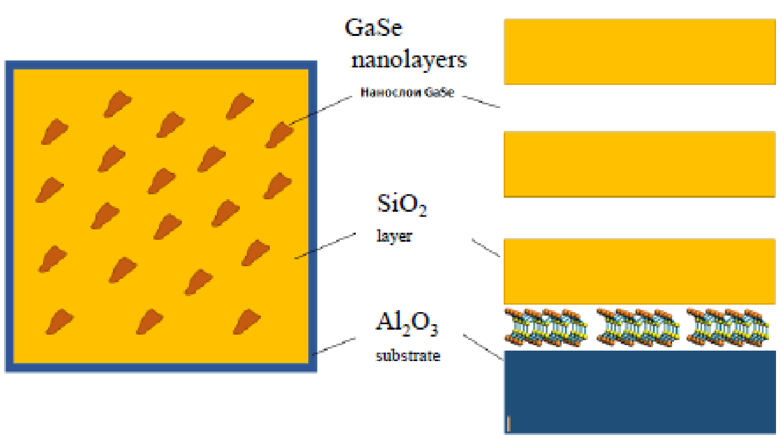
Designing of growth technology and modification of properties of nonlinear optical crystals $CdGeAs_2$, $CdSiP_2$, $ZnGeP_2$, GaSe etc.

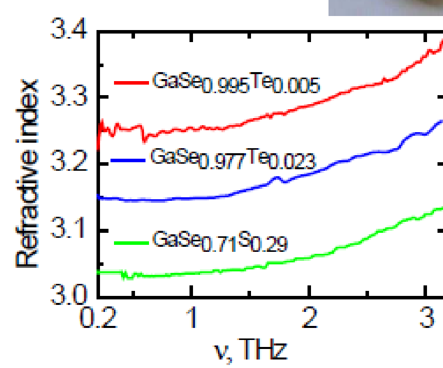


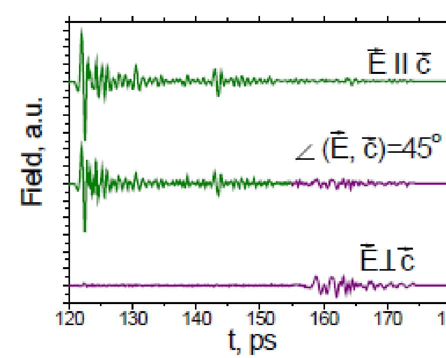
Atuchin V.V., Bereznaya S.A., Beisel N.F., Korotchenko Z.V., Kruchinin V.N., Pokrovsky L.D., Saprykin A.I., Sarkisov S.Yu. // Mat. Chem. Phys. – 2014. – vol. 146. - P. 12-17.

Study of terahertz dielectric properties and applications of mixed $GaSe_{1-x}S_x$ and $GaSe_{1-x}Te_x$ crystals

Synthesis and study of nanolayered (quasi -2D) systems of III-VI semiconductor compounds (GaSe, GaTe, InSe и







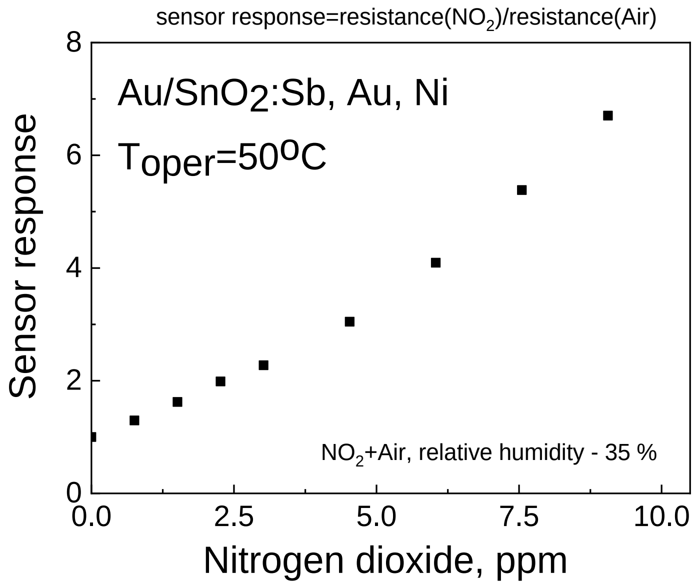
Nazarov M.M., Sarkisov S.Yu., Shkurinov A.P., Tolbanov O.P.// Appl. Phys. Lett. – 2011. – vol. 99. - P. 081105.

Thin films semiconductor sensors of different gases

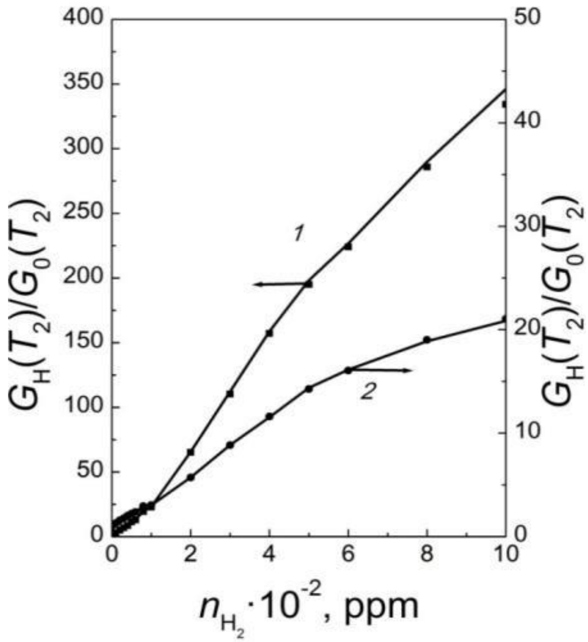
Detecting gases

- **CH_4** (methane)
- **CO** (carbon monoxide)
- Natural gas and other hydrocarbons
- Alcohol vapors and nitrogen oxides
- H_2S (hydrogen sulphide)
- NH_3 (ammonia)
- H_2 (hydrogen)
- O_2 (oxygen)
- O_3 (ozone)
- Cl_2 (chlorine)

- <u>Sensors of low concentration of nitrogen oxides</u>
- search of sensor material (metal oxides, chalcogenides, plasmonic sensors)



- <u>Development of hydrogen test method for analysis of expired mixture</u>
- diagnosis of lactose intolerance
- Tin dioxide sensors



The dependence of the sensor response on the H_2 concentration, T_2=400 ^{o}C, RH=40%
1-Pt/Pd/SnO_2:Sb,Ag,Y 2-Ag/SnO_2:Sb,Ag,Y

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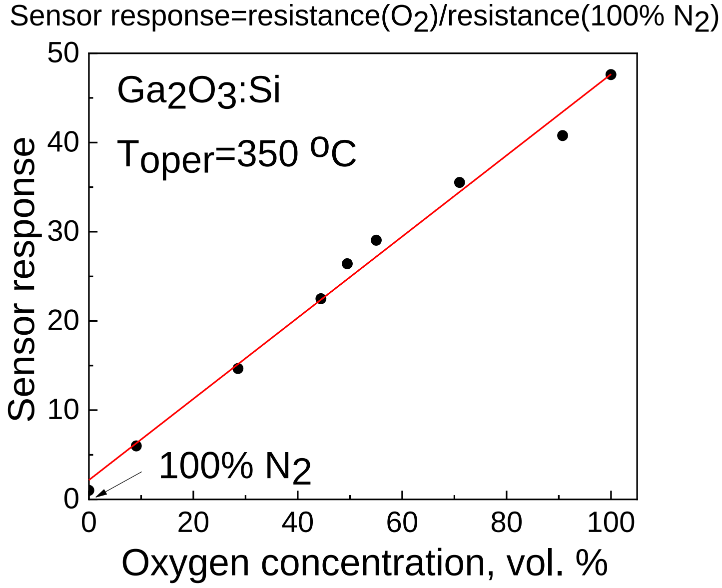
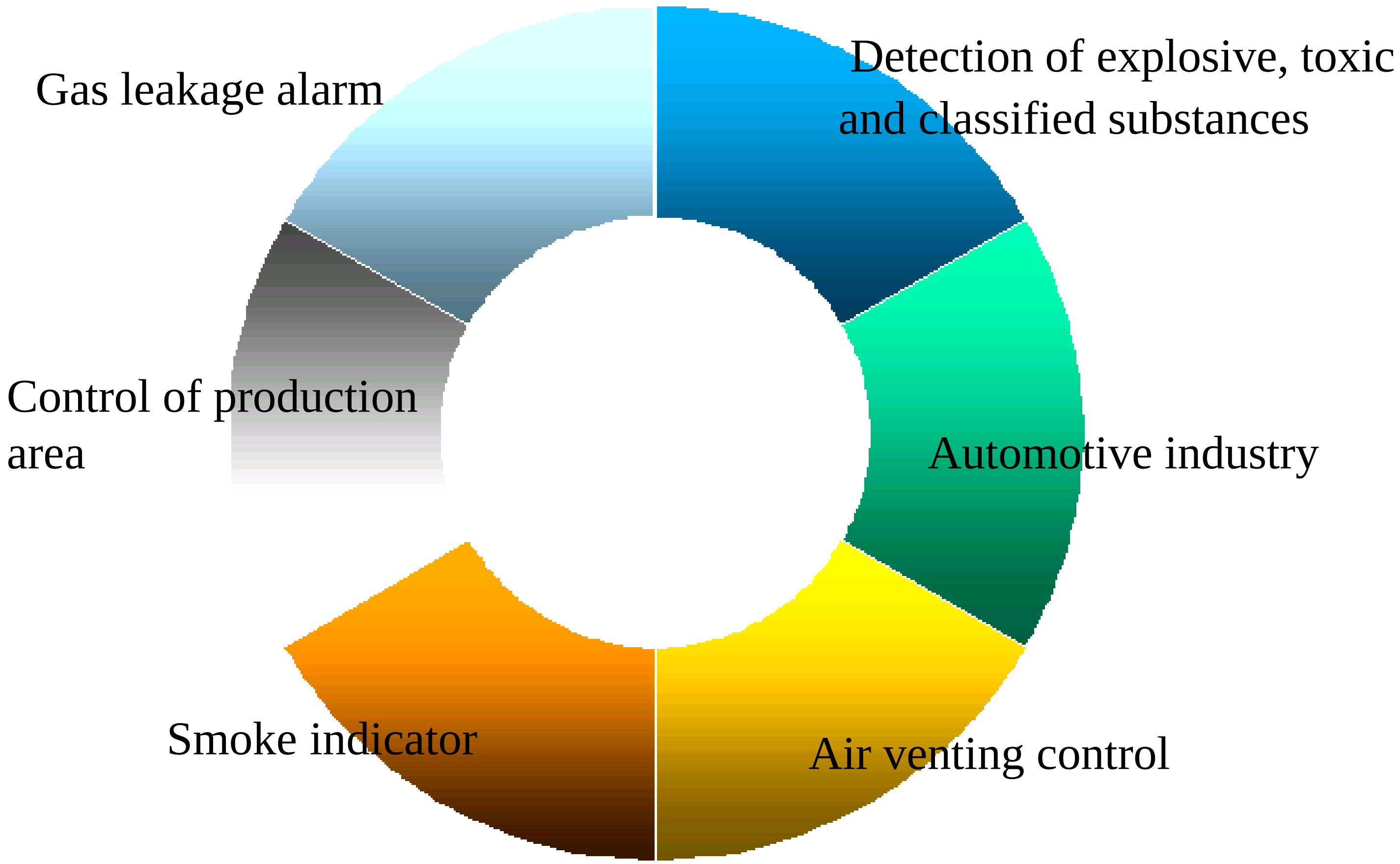
Advanced sensor materials for gas analysis



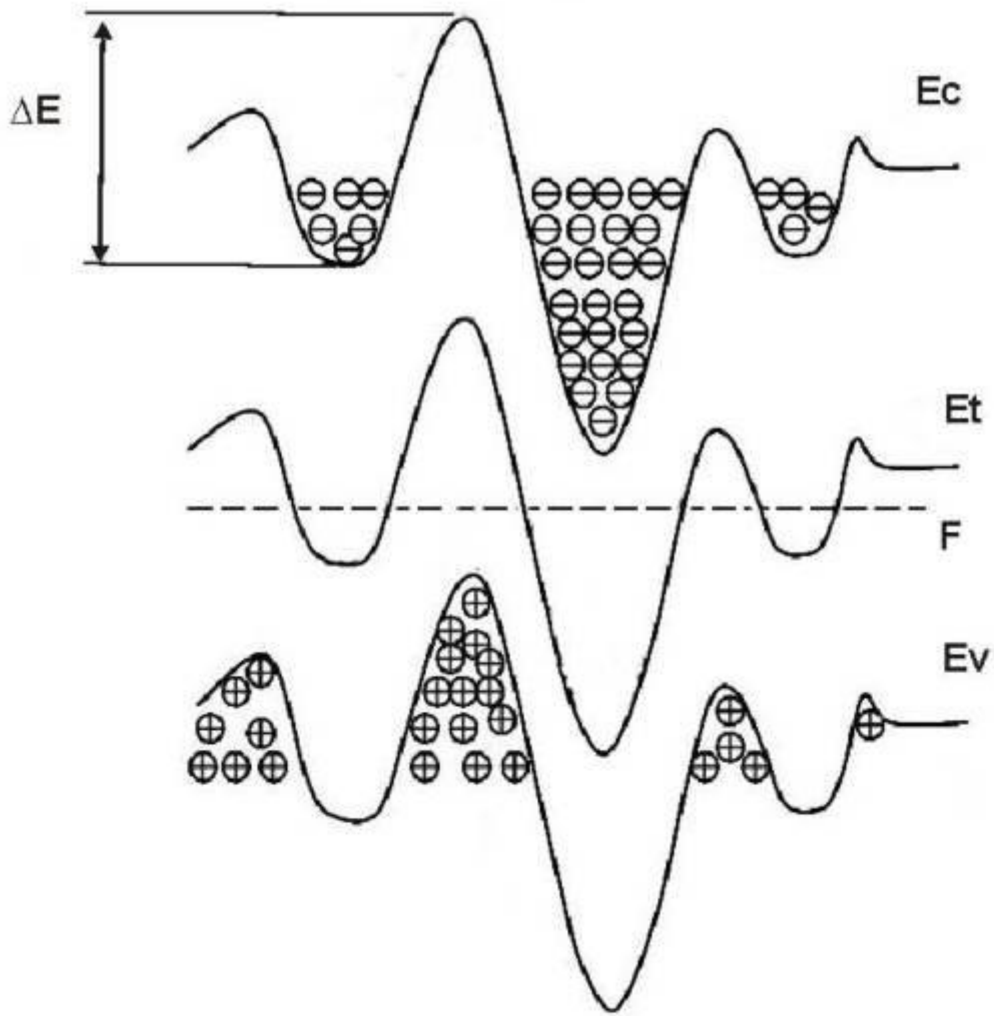
- <u>Oxygen sensors based on thin films of gallium oxide</u>
  - DC magnetron sputtering
  - Ga_2O_3:Si, Ga_2O_3:Cr
  - Operating temperature – 300 – 700 ^oC
  - Concentration range – 0 – 100 vol. %

- <u>Research of the spectral characteristics of noise of the metal oxides thin films on exposure to gases</u>
  - The measured resistance of the sensors is an integral value; a lot of work need to the development of reliable ways to separate the responses of sensors to different gases using a resistive method of gas detection. It is known that the adsorption – desorption processes of gases on the surface of semiconductors are stochastic in nature, which generates the so-called A-D noise. It is proposed to use the analysis of spectral characteristics of noise of thin films of metal oxide semiconductors instead of measuring the resistance of sensors for gas detection.
  - Development of selective gas sensors based on metal oxides

Areas of application



Band gap modification



Analysis of
CCE $_{\beta,\gamma}$ = f(Ubias)

$\mu_n\tau_n$: up to 10^{-4} cm^2/ V

$\mu_p\,\tau_p$: 10^{-6} cm^2/ V

τ_n: 50 ns,
τ_p: 3 ns.

$$\tau = \tau_0 \cdot \exp(\frac{\Delta E}{k \cdot T})$$

$$\Delta E \approx 0.2eV$$