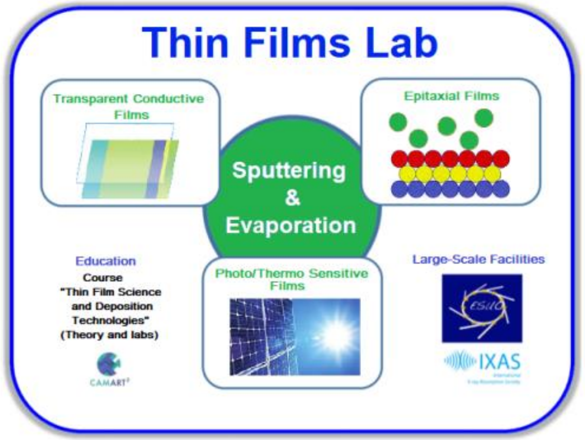


THIN FILMS TECHNOLOGIES AT ISSP UL

Dr. hab.phys. Juris Purāns

Institute of Solid State Physics University of Latvia
Riga, Latvia

Internet: http://www.cfi.lv/
http://www.dragon.lv/tfl

E-mail: purans@cfi.lu.lv

ISSP UL => 30 years of experience
ISSP UL + "thin films" => 350 SCI papers h-idex 34

Thin Films Laboratory has been established in 2017 to focus on thin films science and technology.

Head of the Laboratory: Dr. hab.phys. Juris Purans

SCIENTIFIC STAFF:
Juris Purans, *Dr.hab.phys.*, *Leading Researcher*
Boris Polyakov, *Dr.phys.*, *Leading Researcher*
Andris Azens, *Dr.phys.*, *Leading Researcher*
Lauris Dimitrocenko, *Dr.phys.*, *Leading Researcher*
Vera Skvortsova, *Dr.phys.*, *Leading Researcher*
Ilze Aulika, *Dr.phys.*, *Guest Researcher*
Martins Zubkins, *Dr.phys.*, *Leading Researcher*
Edgars Butanovs, *Dr.phys.*, *Leading Researcher*
Andrejs Ogurcovs, *Dr.phys.*, *Post.doc.*

TECHNICAL STAFF:
Kaspars Staltans-Vilnis, *Laboratory Assistant*
Jelena Arhipova, *Laboratory Assistant*
Alberts Eiduss, *IT engineer*

Ph.D. STUDENTS:
Halil Arslan, *Phd student*
Kevon Kadiwala, *PhD student*
Aleksandrs Novikovs, *PhD student*

3 MSc & 1 BSc STUDENTS

Thin Films Laboratory web page: www.dragon.lv/tfl

THE AIM

of this presentation is to give an overview of vailable facilities, knowledge and experience in the Thin Films related research at ISSP UL as well as examples of ongoing research activities including:

- Smart Metal Oxide Nanocoatings and HIPIMS Technology
- Functional ultrawide bandgap gallium oxide and zinc gallate thin films and novel deposition technologies
- Large area deposition technologies of multifunctional antibacterial and antiviral nanocoatings

THE OFFER

is aimed at users from academia and industries promoting both service and collaborative research. The Thin Films Laboratory is focused on thin film deposition and nanocoating of a wide variety of inorganic materials, using different deposition techniques from existing and new tools, including:

PVD vacuum multifunctional R&D cluster SAF25/50 (thermal, e-beam and magnetron sputtering), magnetron sputtering G500M cluster including High Power Impulse Magnetron Sputtering (HiPIMS), PLD (Pulsed Laser Deposition), MOCVD (Metal Organic Chemical Vapour Deposition), and ALD (Atomic Layer Deposition).

SAF50 cluster HIPIMS, e-beam, organic-inorganic evaporation

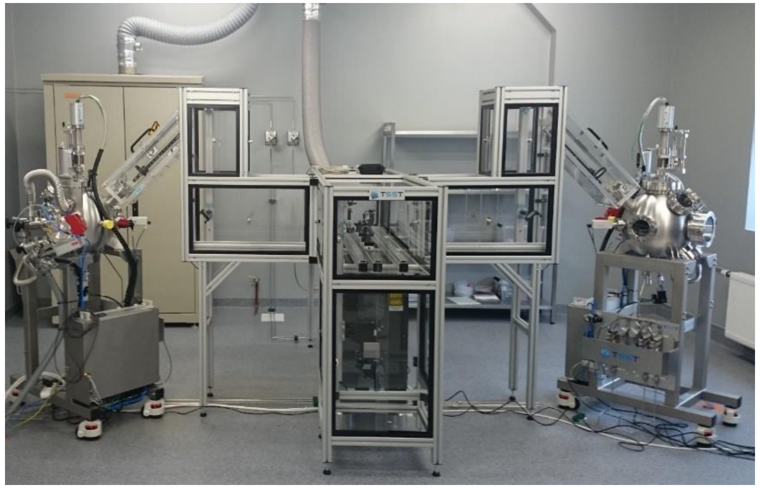
2022

Deposition Technologies R&D

Dual Magnetron Sputtering:

HIPIMS, DC, RF: O_2, Ar, H_2
HT 800 C epitaxial TF Ga_2O_3
LNT meta phases ZnO_2

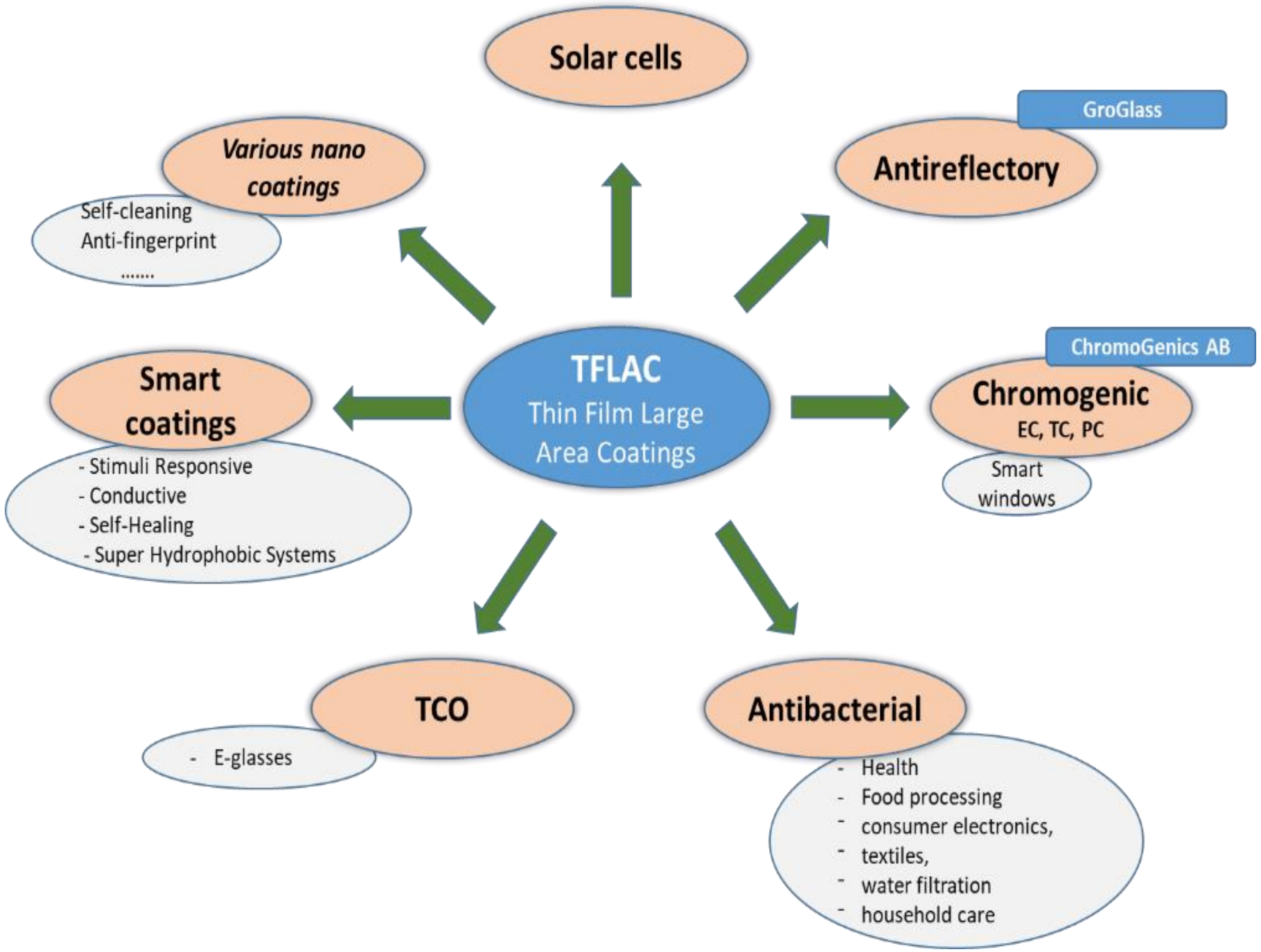
PLD (oxides & sulfides)



AP-CVD

MOCVD, ALD

Nano coatings represent diverse application areas



Global market application of Nanocoatings area and proposed H2020 Twinning scope

LU FMOF study course (Fizi5117) - 6 ECTS

CAMART^2

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INSTITUTE OF SOLID STATE PHYSICS
UNIVERSITY OF LATVIA

UNIVERSITY OF LATVIA

Thin Film Science and Deposition Technologies

Course responsibles: Dr. Edgars Butanovs, Dr. Martins Zubkins

Authors: Juris Purans, Boris Polyakov, Leonid Chugunov, Halil Arslan, Vera Skvortsova, Lauris Dimitrocenko, Martins Zubkins, Edgars Butanovs

Contents:

1. Introduction to thin films science
2. Introduction to thin film deposition techniques
3. Thin films growth
4. Surface preparation and cleaning procedures
5. Introduction to vacuum technologies
6. Vacuum production and control
7. Thermal evaporation
8. E-beam and ion-beam assisted evaporation

9.&10. Lab exercise Thermal evaporation

11. Pulsed laser deposition
12. Molecular beam epitaxy
13. Plasma characterization
14. Magnetron sputtering Part 1

15.&16. Lab exercise Plasma Optical Emission Spectroscopy

17. Magnetron sputtering Part 2
18. Reactive magnetron sputtering

19.&20. Lab exercise Vacuum Deposition

21. High Power Impulse Magnetron Sputtering (HIPIMS)
22. Magnetron sputtering of transparent conducting oxides

23.&24. Lab exercise Reactive magnetron sputtering and HiPIMS

25. CVD introduction and principles
26. CVD equipment, precursors and process control

27.&28. Lab exercise MOCVD

29. Applications of CVD grown thin films
30. Non-vacuum deposition techniques
31. Solution-based deposition techniques
32. Lab exercise Spin-coating

Collaboration and Achievements

SIA SIDRABE

**EU regional development grant ERAF-073 " Smart Metal Oxide Nanocoatings and HIPIMS Technology "
2019-2022**

EU regional development grant ERAF-088 "Innovative glass coatings" 2010-2014

IEGULDĪJUMS TAVĀ NĀKOTNĒ

EIROPAS SAVIENĪBA

ERAF

EIROPAS REĢIONĀLĀS ATTĪSTĪBAS FONDS

AS GROGLASS

EU regional development grant
5 Collaboration Projects
BKC centre Nanotechnology
ISSP + SIA SIDRABE
ISSP + AS GROGLASS

IEGULDĪJUMS TAVĀ NĀKOTNĒ

EIROPAS SAVIENĪBA

ERAF

EIROPAS REĢIONĀLĀS ATTĪSTĪBAS FONDS

LZP, ERAF, Post-doc projects 2022-2024

Nr.	Projekta vadītājs no LU CFI	Projekta nosaukums; projekta izstrādes laiks	Finansējums LU CFI uz visu izstrādes periodu, EUR
1.	J. Purāns	Smart Metal Oxide Nanocoatings and HIPIMS Technology; ERAF -1.1.1.1/18/A/073 01.03.2019- 01.-28.02.2022	648 750 80% ISSP
2.	J. Purans	Large area deposition technologies of multifunctional antibacterial and antiviral nanocoatings ; ERAF-1.1.1.1/21/A/050 01.12.2022-30.11.2023	500 000 60% ISSP
3.	A.Ogurcovs	PORTABLE DIAGNOSTIC DEVICE BASED ON A BIOSENSOR ARRAY OF 2D MATERIAL SENSING ELEMENTS Nr. 1.1.1.2/VIAA/4/20/590 01.01.2021-30.06.2023	111 505 100% ISSP

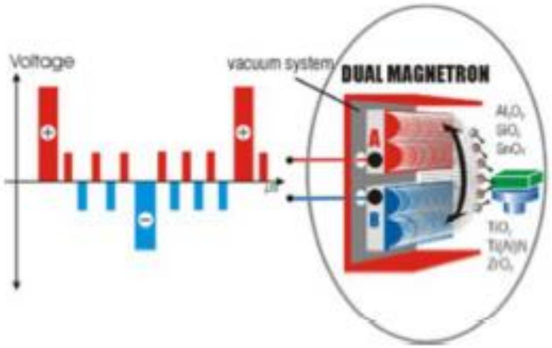
Nr.	Projekta vadītājs no LU CFI un darbinieku ieguldījums projekta tapšanā (%)	Projekta nosaukums; grants/ERAF; projekta izstrādes laiks	Finansējums LU CFI uz visu izstrādes periodu, EUR
4.	J. Purāns	Funkcionālas Platzonas Gallija Oksīda un Cinka Gallāta Plānas Kārtiņas un Jaunas Uzklāšanas Tehnoloģijas; ERAF - Nr.1.1.1.1/20/A/057 ; 01.01.2021-30.06.2023	537 004
5.	J. Purāns	Epitaksiālas Ga2O3 plānas kārtiņas kā platzonas topoloģiski caurspīdīgi elektrodi ultravioletai optoelektronikai; LZP- 2020/1-0345 01.01.2021-31.12.2023	281 478
6.	B. Poļakovs	Kodola-apvalka nanovadu heterostruktūras no lādiņa blīvuma viļņu materiāliem optoelektronikas pielietojumiem (Nr. lzp-2020/1-0261) 01.01.2021-31.12.2023	299 991

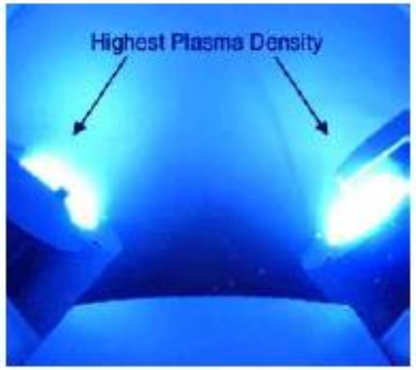
HIGHLY IONISED PULSE PLASMA PROCESS G5000

MELEC GmbH

HPPMS♦HIPIMS

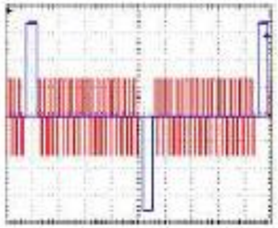
JOIN OUR SIPP – SUPERIMPOSED PULSE POWER – TECHNOLOGY



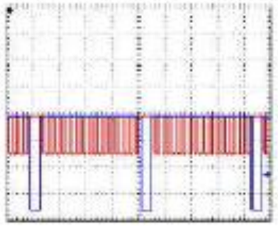


picture: Helmholtz-Zentrum Dresden-Rossendorf, Germany

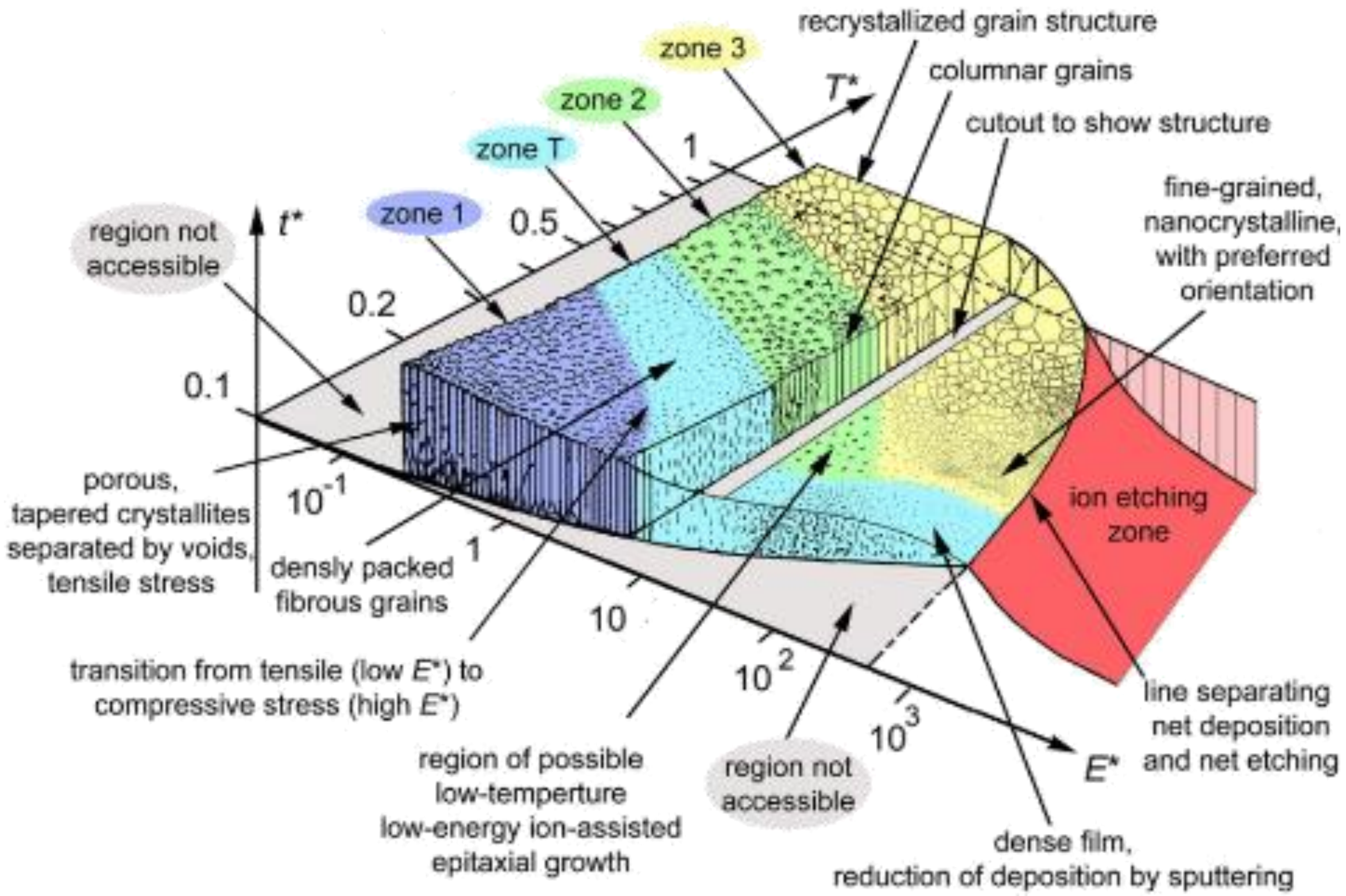
High Power Pulse Magnetron Sputtering(HPPMS), also known as High Power Impulse Magnetron Sputtering (HiPIMS) is a novel pulse plasma technology for coating applications. New developments in DC pulse power controllers allow very high peak power pulses. Combining DC power or medium frequency (MF) pulse power to HPPMS / HiPIMS processes offers significant advantages in the plasma and surface technologies. This technology is appropriate for single and dual magnetron applications and synchronized pulsed bias. It allows higher process rates for metallic and reactive sputtering applications. Processes such as Co-Sputtering with different target materials using Dual Magnetron Systems and asymmetric bipolar pulse modes are possible. Applicable HPPMS / HiPIMS Pulse packages with superimposed DC or MF sputtering open a new field of applications. MELEC opens a new field of High Pulse Power Plasma Engineering using LabVIEW and National Instruments Components (Win XP or Real-Time Processing).



Trigger signal of SuperImposed Pulse Power BIPOLAR HiPIMS / HPPMS + MF



Trigger signal of SuperImposed Pulse Power UNIPOLAR HiPIMS / HPPMS minus + MF



Illustrative structure zone diagram (SZD) applicable to energetic deposition; T - generalized film growth T; E* - kinetic energy defined as an energy flux associated with arriving particles, and t* represents the net thickness.*

A. Anders, Thin Solid Films 518 (**2010**) 4087

M. Zubkins, et al., Surface and Coatings Technology 369 (**2019**) 156-164

A. Anders, Thin Solid Films 518 (**2010**) 4087

R&D CLUSTER TOOL SAF

CLUSTER TOOL SAF

SIDRABE

SIMPLE

Easy and simple tool control and maintenance

ADJUSTABLE

Customized configuration and setup

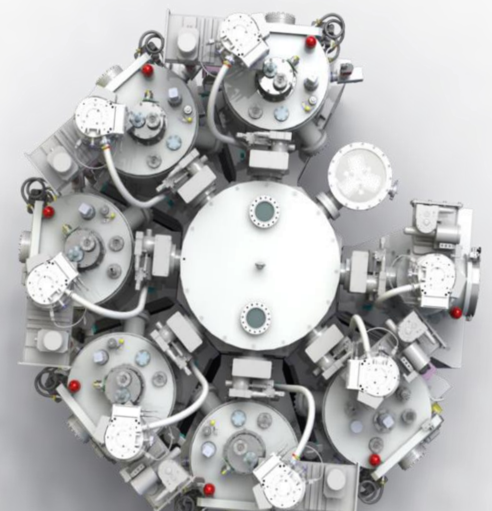
FLEXIBLE

Wide spectrum of possible technological processes

SAF CONFIGURATION

THE CENTRAL CHAMBER IS EQUIPPED WITH 8 FLANGES FOR CHAMBERS OF YOUR CHOICE:

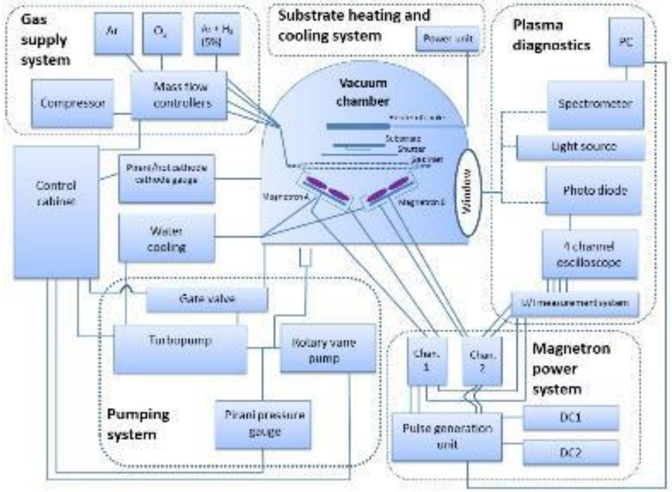
- **Substrate loading/unloading and pre-treatment**
- **Substrate storage**
- **Deposition process chambers:**
  - **Electron beam evaporation**
  - **Thermal evaporation**
  - **Thermal sublimation**
  - **Magnetron sputtering**
  - **Other deposition processes**

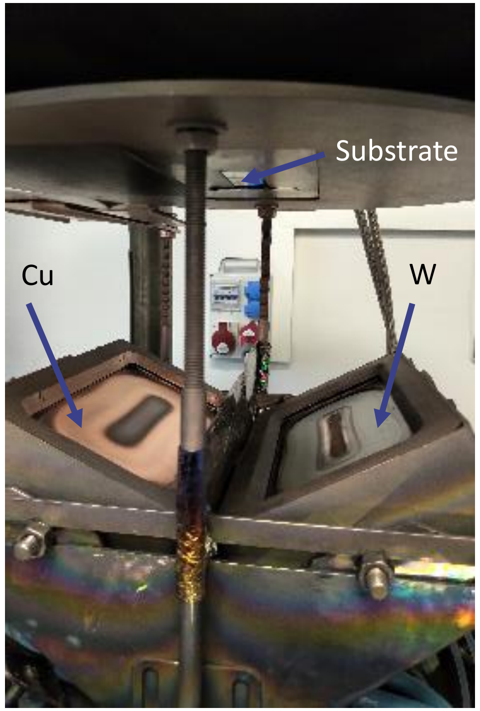


equipment

To optimised deposition parameters and to improve antimicrobial properties a vacuum coater has been prepared and the first test samples have been deposited.

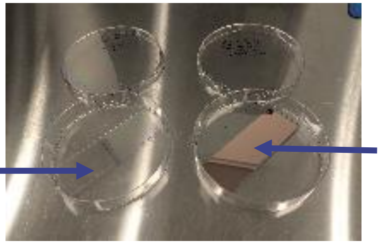
Scheme:





First test samples:

WO_{3-x} (200 nm)

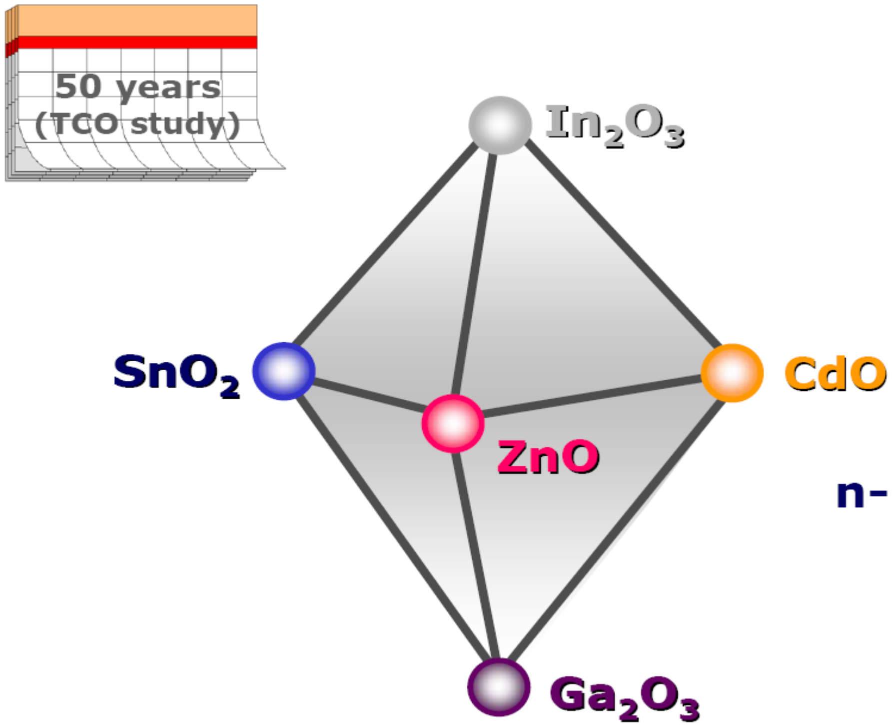


Cu (56 nm)

Low cost Transparent Conductive Oxides (TCO)

From 1980 =>n-type TCOs, with good optical and electrical properties

From 2000 => Low cost TCO
Green Technology
Sputtering technology

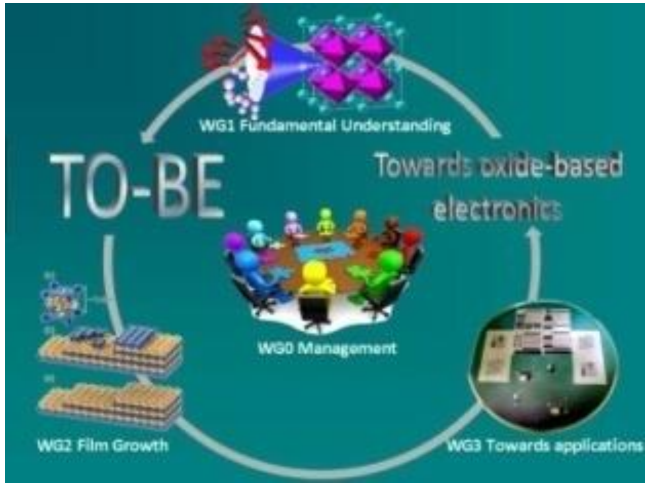


http://www.iesl.forth.gr/conferences/tco2006/index.aspx

J.Purans – ISSP,LU

Thin Films

(Mixed Metal Oxides)



1. *TCO - Low cost transparent conductive oxide n-type (ZnO:Al) and p-type coating and sputtering technology.*

2. *TH - Thermochromic (VO_2:WO_2…) coatings. ERA-CHAIR*

3. *EHE - Solid state thin film electro-chromic coatings and dynamic sputtering technology.*

Recent publications related to this field:

Zubkins, M., Purans J. *et al.* Changes in structure and conduction type upon addition of Ir to ZnO thin films. *Thin Solid Films* 636, 694–701 **(2017)**

Zubkins, M., Arslan, H., Bikse, L. & Purans, J. High power impulse magnetron sputtering of Zn/Al target in an Ar and Ar/O2 atmosphere: The study of sputtering process and AZO films. *Surf. Coatings Technol.* 369, 156–164 **(2019)**

Zubkins M.,Timoshenko J., Gabrusenoks J., Pudzs K., Azens A., Wang Q., Purans J. Amorphous p-Type Conducting Zn–xIr Oxide (x > 0.13) Thin Films Deposited by Reactive Magnetron Cosputtering. Physica Status Solidi (B) Basic Research **2022**, 259(2), 2100374

Polyakov, B. *et al.* Unraveling the Structure and Properties of Layered and Mixed ReO3-WO3 Thin Films Deposited by Reactive DC Magnetron Sputtering. *ACS Omega* **2022,** 7, 2, 1827–1837.

Polyakov, B. *et al.* Understanding the Conversion Process of Magnetron-Deposited Thin Films of Amorphous ReOx to Crystalline ReO3 upon Thermal Annealing. Cryst. Growth Des. 20, 6147–6156 (**2020)**

Aulika, I., Zubkins, M., Butikova, J., Purans, J. Enhanced Reflectivity Change and Phase Shift of Polarized Light: Double Parameter Multilayer Sensor, *Physica Status Solidi (A)* ***2022****,* 219(4),2100424

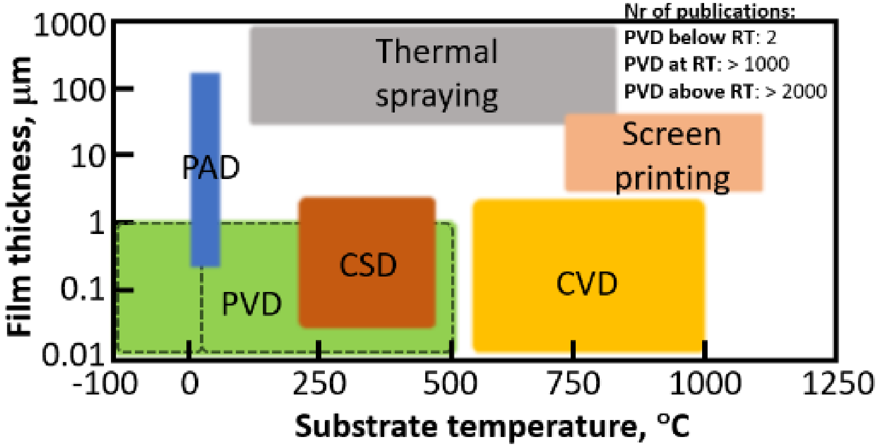
A comprehensive study of structure and properties of nanocrystalline zinc peroxide Bocharov, D., Chesnokov, A., Chikvaidze, G., (...), Zubkins, M., Purans, J. J.Physics and Chemistry of Solids, **2022**, 160,110318

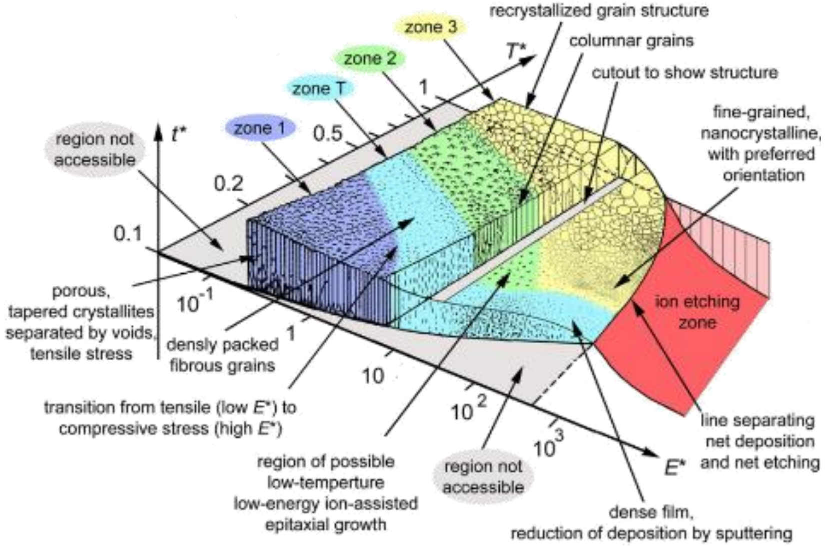
Reactive magnetron sputtering of advanced metal oxide thin films with antibacterial and antiviral properties

Objectives of the project:

- Develop cryogenic PVD technology of advanced doped and undoped ABAV MO thin films (*a*-ZnO_2, *a*-TiO_2, porous TiO_2, and new/metastable structures);
- Development of visible-active TiO_2 based materials;
- Investigate the possibility to deposit *c*-ZnO_2 thin films on various substrates and compare aBaV properties with *a*-ZnO_2 and TiO_2.

Comparison of different MO film coating techniques (using open literature, Scopus). PVD - only technology reporting on thin film growth in CrT ranges.

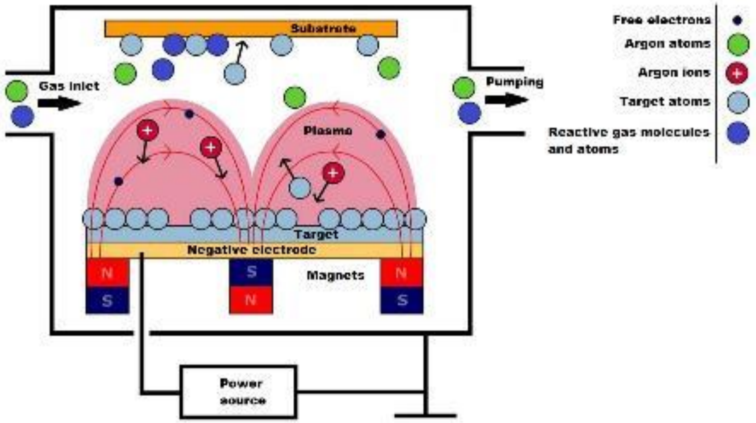




Illustrative structure zone diagram (SZD) applicable to energetic deposition; T - generalized film growth T; E* - kinetic energy defined as an energy flux associated with arriving particles, and t* represents the net thickness.*

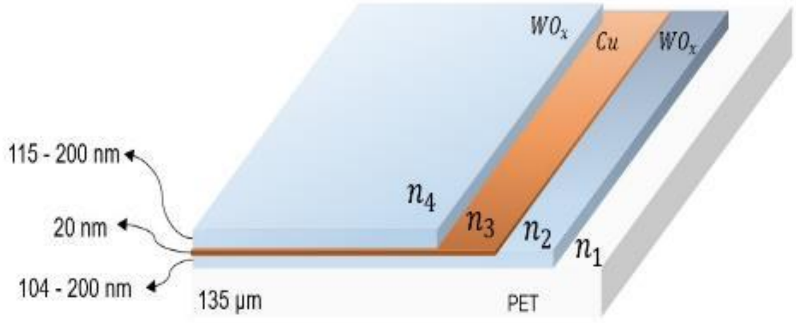
M. Zubkins, et al., Surface and Coatings Technology 369 (**2019**) 156-164
A. Anders, Thin Solid Films 518 (**2010**) 4087

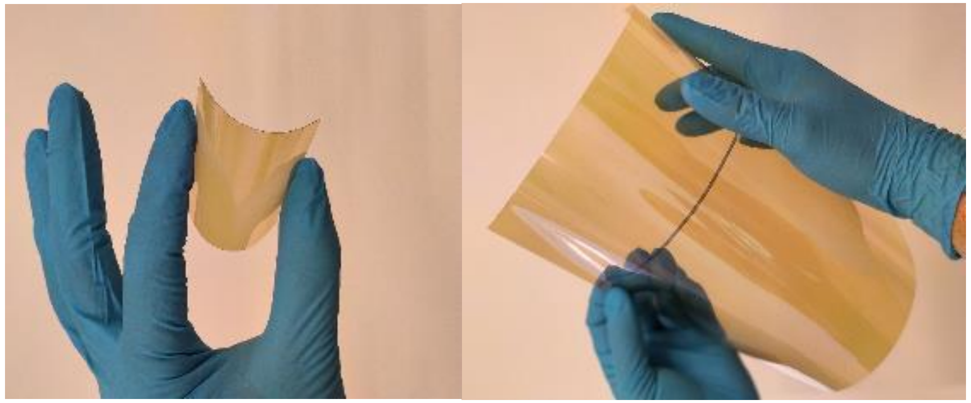
Reactive magnetron sputtering of advanced metal oxide thin films with antibacterial and antiviral properties



$WO_{3-x}/Cu/WO_{3-x}$ multi-structure coatings have been produced by magnetron sputtering technique (pulsed-DC and HiPIMS) on PET substrates.

The coatings show antimicrobial and antiviral effects.

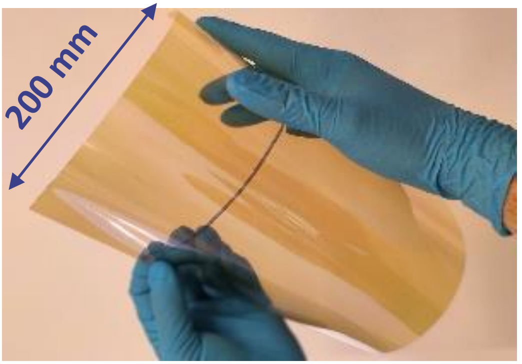


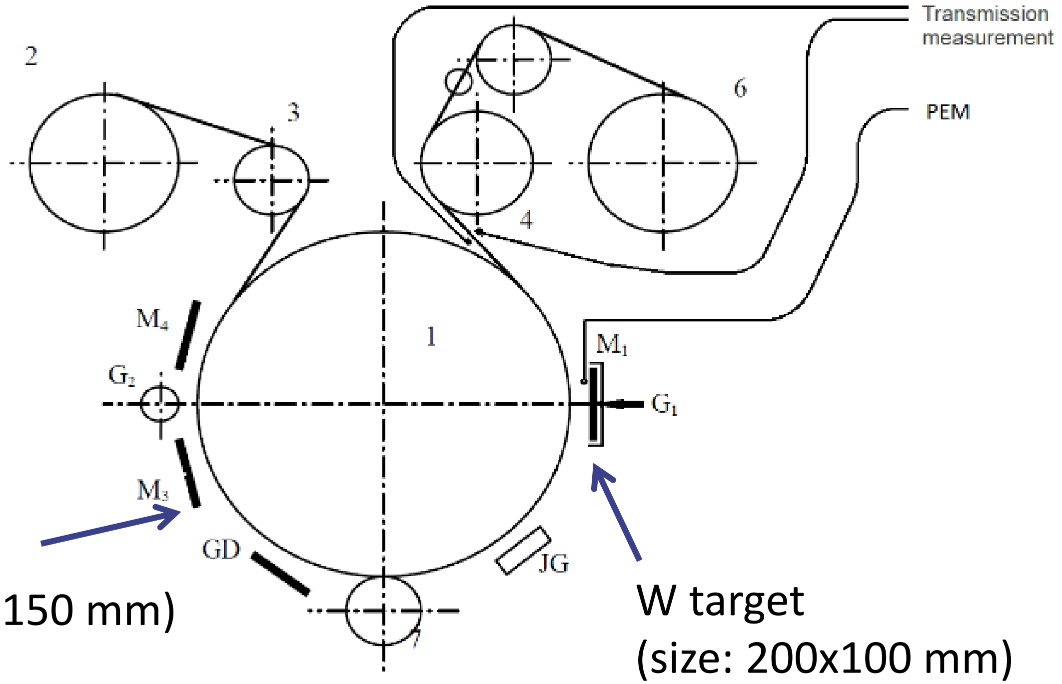


equipment

Multifunctional laboratory coater (roll-to-roll coater).

200 mm wide PET substrate can be coated.



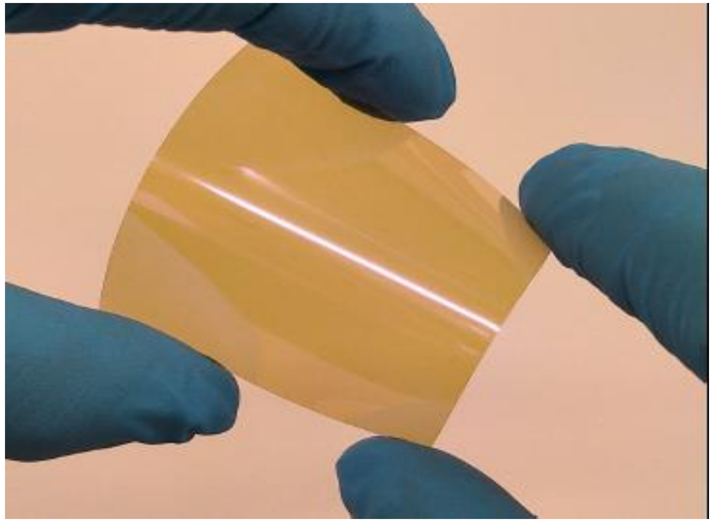


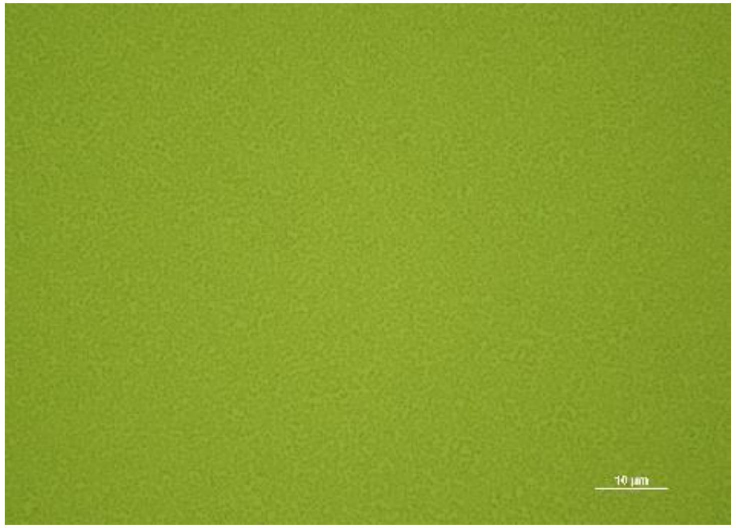
Cu target
(size: 800x150 mm)

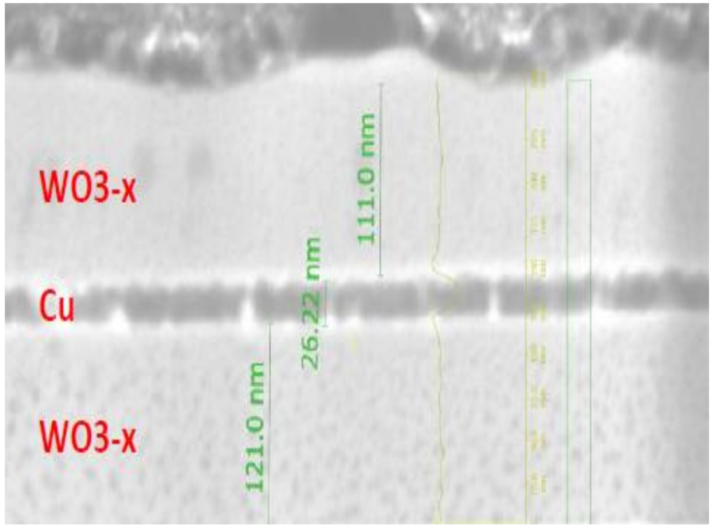
W target
(size: 200x100 mm)

HiPIMS power supply

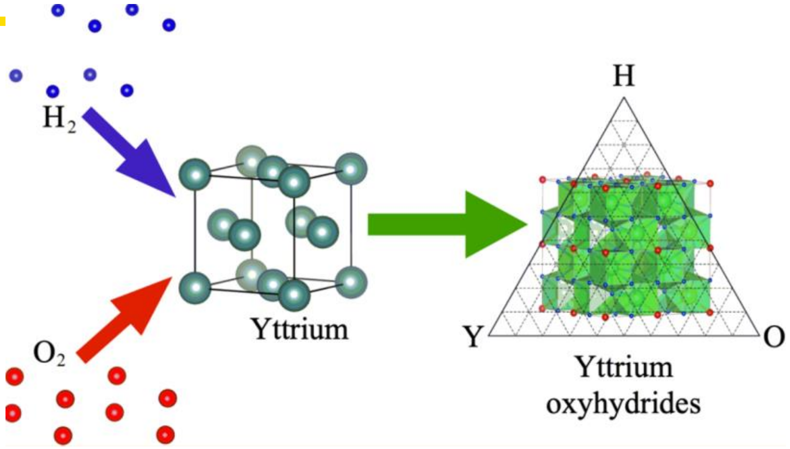
Development of antiviral, antibacterial and yeasticidal $WO_{3-x}/Cu/WO_{3-x}$ coatings deposited by magnetron sputtering







Yttrium SUPERHYDRIDES AND oxy-hydride




nature COMMUNICATIONS

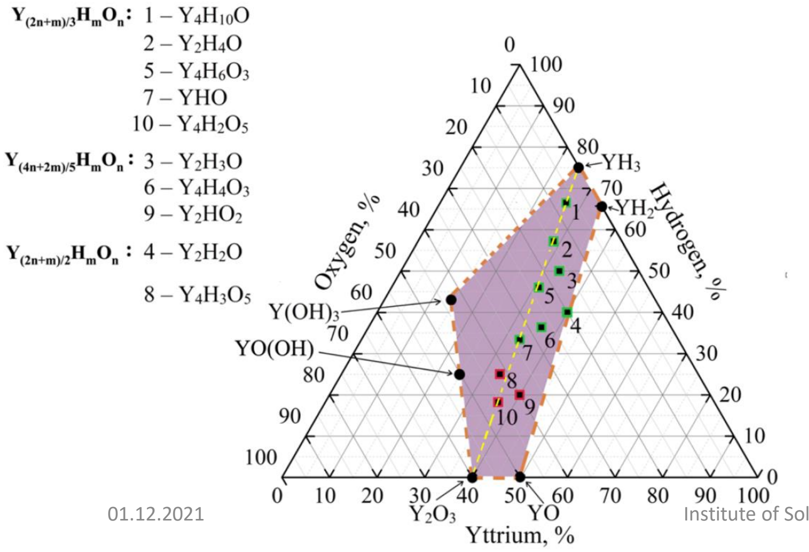
ARTICLE

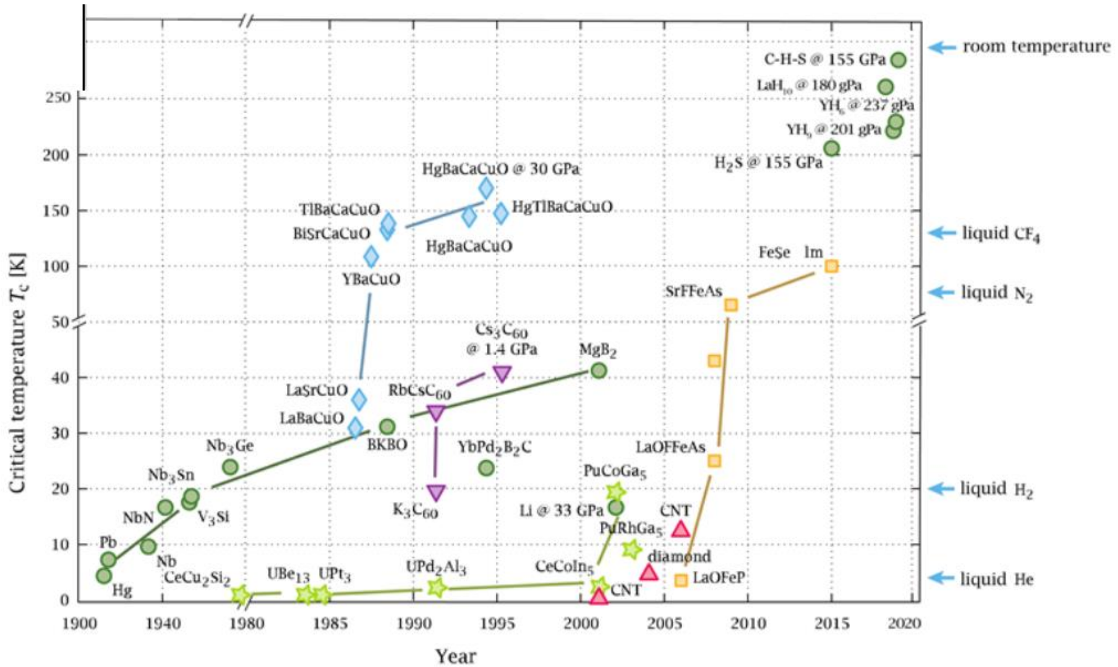
https://doi.org/10.1038/s41467-021-21991-z OPEN

Check for updates

Local electronic structure rearrangements and strong anharmonicity in YH_3 under pressures up to 180 GPa

J. Purans[1,2✉], A. P. Menushenkov[2], S. P. Besedin[3✉], A. A. Ivanov[2], V. S. Minkov[3], I. Pudza[1], A. Kuzmin[1], K. V. Klementiev[4], S. Pascarelli[5,6], O. Mathon[5], A. D. Rosa[5], T. Irifune[7] & M. I. Eremets[3✉]





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Ga_2O_3 and $ZnGa_2O_4$ based thin films: equipment and research at ISSP

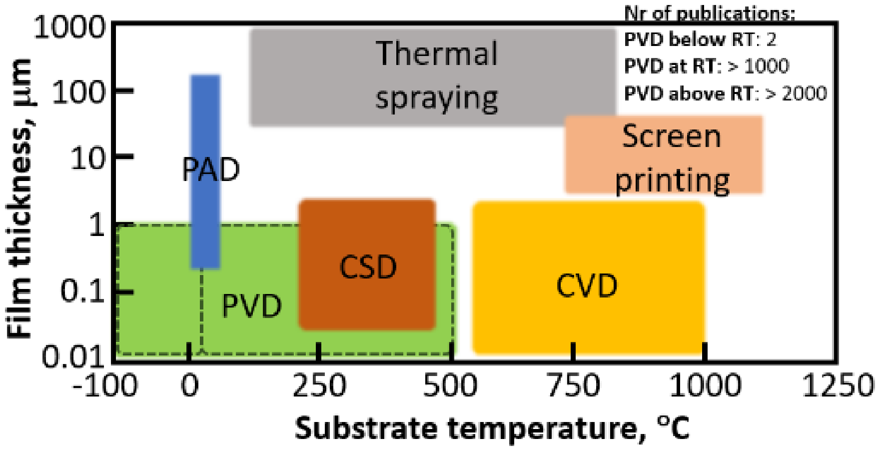
E. Butanovs (PLD, MOCVD), L. Dimitrocenko (MOCVD),

M. Zubkins, A. Azens (Magnetron sputtering)

A. Popov, D. Bocharov, S. Piskunov (DFT),

J. Purans (ERAF & LZP project manager, head of laboratory)

HIPIMS dual (Ga and Zn) magnetron sputtering system: Ga_2O_3 and $ZnGa_2O_4$



Gallium oxide related projects at ISSP:

Regional Development Fund (ERDF) project (537k eur, **01.01.2021 - 30.06.2023**):

Project title:
Functional ultrawide bandgap gallium oxide and zinc gallate thin films and novel deposition technologies

Project partners: SIA AGL Technologies, Dr.pys. **Andris Azens**; SIA BC Corporation Limited, Dr.phys. **Lauris Dimitrocenko**.

The main goals are:

- To develop high rate PVD magnetron sputtering technology for deposition of pure and doped (p-type dopants and RE) amorphous and crystalline gallium oxide Ga_2O_3 thin films and $ZnGa_2O_4$ thin films. The applications in focus are (1) deep UV TCOs/TSOs and (2) efficient inorganic luminescence devices (a-Ga_2O_x:RE).
- To develop MOCVD technology of Ga_2O_3 and $ZnGa_2O_4$ thin films deposition and to establish epitaxial n- and p-type Ga_2O_3 and $ZnGa_2O_4$ thin film growth processes for deep UV optoelectronics and electronics applications.

Gallium oxide related projects at ISSP:

Latvian Council of Science grant (300k eur, **01.01.2021 – 31.12.2023**):

Project title:
Epitaxial Ga_2O_3 thin films as ultrawide bandgap topological transparent electrodes for ultraviolet optoelectronics

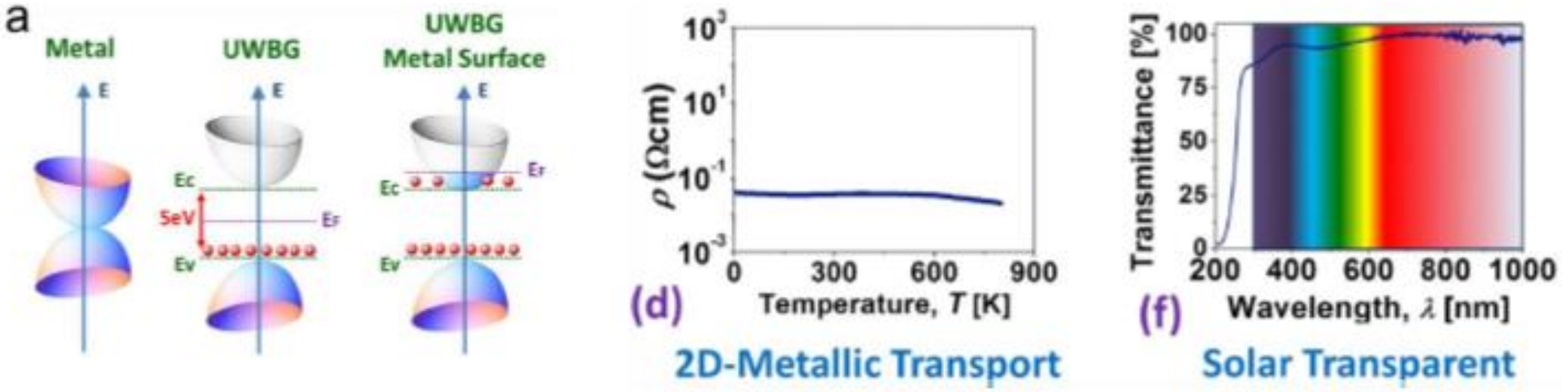
https://www.cfi.lu.lv/en/research/projects/lcsgrants/epitaxial-ga2o3-thin-films-as-ultrawide-bandgap-topological-transparent-electrodes-for-ultraviolet-optoelectronics/

The planned activities include establishment of the MOCVD process for growing epitaxial monocrystalline β–Ga_2O_3 thin films, investigation of as-grown thin film electrical properties together with detailed structural, compositional and optical characterization of the films by traditional laboratory and advanced synchrotron radiation methods with focus on surface properties and possible donor doping, and large-scale theoretical calculations to elucidate the possible surface conductivity mechanisms.

Gallium oxide related projects at ISSP:

Epitaxial Ga_2O_3 thin films as ultrawide bandgap topological transparent electrodes for ultraviolet optoelectronics

«…undoped topological-like conductivity nature of the Ga2O3 film grown on r-plane sapphire. The nominally undoped epitaxial β–Ga2O3 thin films, deposited via pulsed laser deposition (PLD), without any detectable defect have been shown to exhibit unexpectedly low resistivity of 10-2 Ω·cm (equivalent to that of heavily n-type doped Ga2O3)…»



Ga_2O_3 research directions at ISSP:

1. Growth of *n*-type β-Ga_2O_3 thin films

- Growth of *n*-type β-Ga_2O_3 epitaxial film using NO, N_2O, O_2 and H_2O as the oxygen sources.
- Growth of *n*-type β-Ga_2O_3 epitaxial film doped by Si.

2. Growth of *p*-type β-Ga_2O_3 thin films

As no reliable method of *p*-type doping of Ga_2O_3 films has yet been reported, several possible dopants will be tested.

p-type conductivity will be investigated in samples co-doped with Zn and N and doped with Mg.

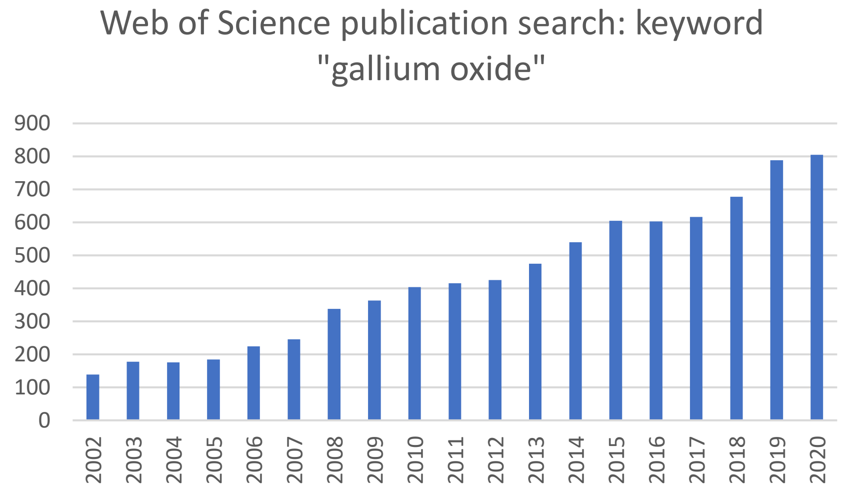
3. Study of undoped Ga_2O_3 film surface conductivity on different orientation sapphire

4. Study of $ZnGa_2O_4$ as a potential ultrawide bangap p-type conductor

5. Amorphous a-Ga_2O_x doped with RE for efficient inorganic luminescence devices

6. Monocrystalline β-Ga_2O_3 thin films for LEDs and HEMT

Gallium oxide thin films:



Ga_2O_3 - a prospective ultrawide bandgap semiconductor

Pearton, S. J., Ren, F., Tadjer, M. & Kim, J. Perspective: Ga2O3 for ultra-high power rectifiers and MOSFETS. *J. Appl. Phys.* **124**, 220901 (2018)

Pearton, S. J. *et al.* A review of Ga2O3 materials, processing, and devices. *Appl. Phys. Rev.* **5**, 011301 (2018)

Teherani, F. H. *et al.* A review of the growth, doping, and applications of Beta-Ga2O3 thin films. in *Oxide-based Materials and Devices IX,* **25** (SPIE, 2018)

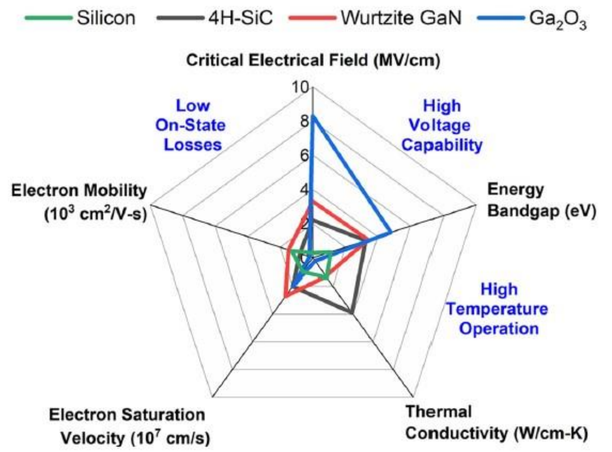


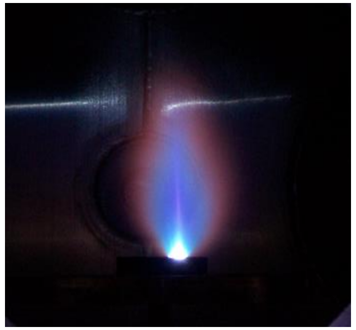
FIG. 1. The pentagon diagram showing the critical material properties important to power semiconductor devices. A larger pentagon is preferred.

TABLE II. Properties of β-Ga_2O_3 relative to other more commonly used semiconductors. We also show some of the common figures-of-merit used to judge the suitability or potential of these materials for various high temperature, high voltage or power switching applications.

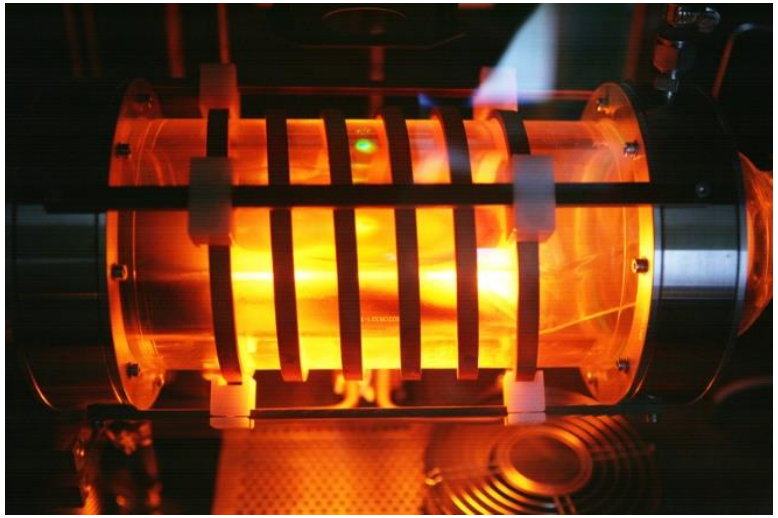
Materials parameters	Si	GaAs	4H-SiC	GaN	Diamond	β-Ga_2O_3	Comments
Bandgap, E_g (eV)	1.1	1.43	3.25	3.4	5.5	4.85	Bandgap of Ga_2O_3 reported in range 4.6–4.9 eV
Dielectric constant, ε	11.8	12.9	9.7	9	5.5	10	
Breakdown field, E_C (MV/cm)	0.3	0.4	2.5	3.3	10	8	Experimental values for Ga_2O_3 have reached ~0.5 times the theoretical maximum
Electron mobility, μ (cm^2/Vs)	1480	8400	1000	1250	2000	300	
Saturation velocity, v_s (10^7 cm/s)	1	1.2	2	2.5	1	1.8-2	1.8 ⟨0 0 1⟩ and ⟨0 1 0⟩, 2.0 ⟨0 1 0⟩
Thermal conductivity λ (W/cm K)	1.5	0.5	4.9	2.3	20	0.1–0.3	0.13 ⟨1 0 0⟩, 0.23 ⟨0 1 0⟩
Figures of merit relative to Si							
Johnson = $E_c^2 \cdot V_s^2/4\pi^2$	1	1.8	278	1089	1110	2844	Power-frequency capability
Baliga = $\varepsilon \cdot \mu \cdot E_c^3$	1	14.7	317	846	24 660	3214	Specific on-resistance in (vertical) drift region
Combined = $\lambda \cdot \varepsilon \cdot \mu \cdot V_s \cdot E_c^2$	1	3.7	248.6	353.8	9331	37	Combined power/frequency/voltage
Baliga high frequency = $\mu \cdot E_c^2$	1	10.1	46.3	100.8	1501	142.2	Measure of switching losses
Keyes = $\lambda \cdot [(c \cdot V_s)/(4\pi \cdot \varepsilon)]^{1/2}$	1	0.3	3.6	1.8	41.5	0.2	Thermal capability for power density/speed
Huang HCAFOM, $\varepsilon\mu^{0.5} E_C^2$	1	5	48	85	619	279	Huang chip area manufacturing FOM

PLD equipment at ISSP:

- KrF (248nm) pulsed excimer laser with laser optics;
- oxide chamber: base pressure 10^{-7} mbar, Ar, O_2, N_2 gases, rotatable target system with 6 targets;
- heatable substrate holder for temperatures up to 900C;
- Around 1x1 cm sample size.



MOCVD equipment at ISSP:

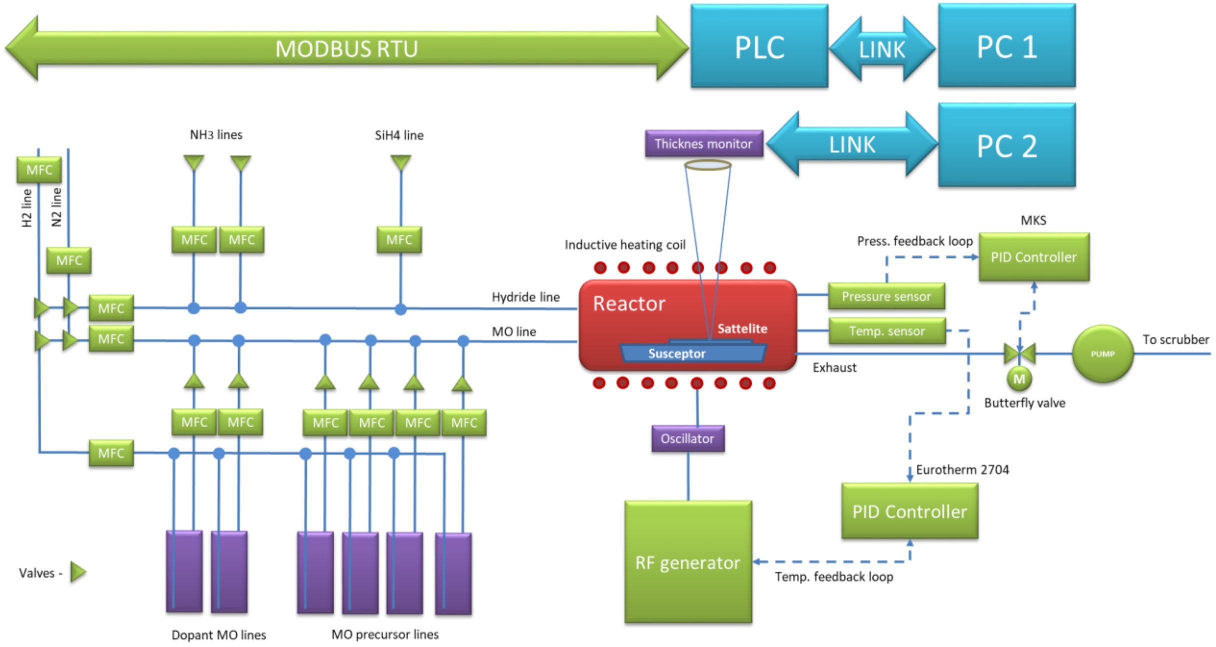


MOCVD equipment at ISSP:

Parameters
- Temperature up to 1200°C
- Pressure 1-1000 mBar
- Single 2’’ wafer load
- In-Situ thickness monitor
- Inductive heating

Available precursors (gas)
- Ammonia
- Silane
- Oxygen (O_2)
- Nitrious oxide (N_2O)
- Nitric oxide (NO)
- Methane (CH_4)

Available precursors (liquid)
- TriMethylGallium (TMGa)
- TriEthylGallium (TEGa)
- 2 x TriMethylAluminium (TMAl)
- DiMethylZinc (DmZn)
- 2 x TriMethylIndium (TMIn)
- Bis(cyclopentadienyl)magnesium (Cp_2Mg)
- Water (H_2O)



Applications
- III-Nitride thin monocrystalline films incl. LED structures
- GaN nanowires growth
- Graphene layers
- Oxide thin films

Carrier gases
- Hydrogen (H_2)
- Nitrogen (N_2)

Ga_2O_3 research collaboration:

1. **Department of Theoretical Physics and Computer Modeling, ISSP (A.Popov, D.Bocharov, S.Piskunov)** https://teor.cfi.lu.lv/

    - Large-scale computer modelling of crystalline a-, c-, r-sapphire/β–Ga_2O_3 heterostructures to predict their atomic composition, electronic band structure and vibrational properties with respect to free-standing equilibrium β–Ga_2O_3 surfaces (LZP project)

    - Computer ab-initio DFT modelling of Ga_2O_3 and $ZnGa_2O_4$ - computer modelling of impurities, atomic, electronic and vibrational properties of materials (ERAF project)

Usseinov, A., Koishybayeva, Zh., Platonenko, A., Akilbekov, A., Purans, J., Pankratov, V., Suchikova, Y. and Popov, A. I.. " Calculations of Oxygen Vacancy in Ga2O3 Crystals" Latvian Journal of Physics and Technical Sciences, vol.58, no.2, 2021, pp.3-10.

Abay Usseinov, Zhanymgul Koishybayeva, Aleksandr Platonenko, Vladimir Pankratov, Yana Suchikova, Abdirash Akilbekov, Maxim Zdorovets, Juris Purans, Anatoli Popov. "Vacancy defects in Ga2O3 - First Principles Calculations of Atomic and Electronic Structure". Submitted for publishing.

2. **ISSP-KTH-RISE (A.Hallen, S.Khartsev, P.Ramvall, Q.Wang)**

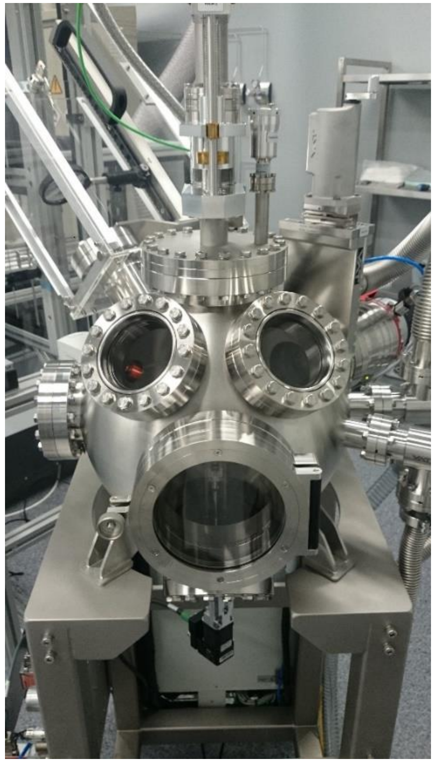
    - PLD deposition of doped Ga_2O_3 films
    - Ga_2O_3-GaN thin film heterostructures for LEDs

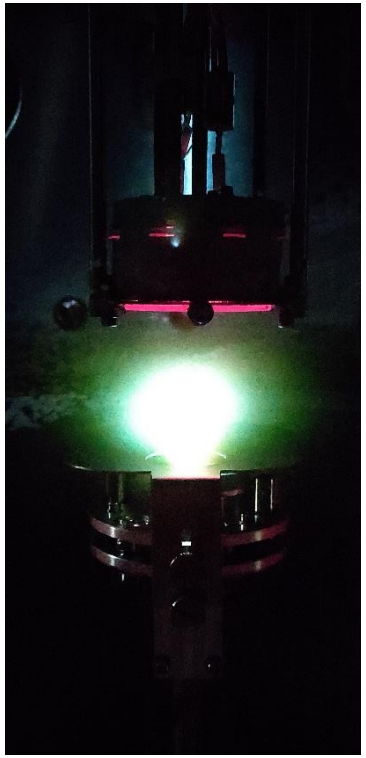
Khartsev, S., Nordell, N., Hammar, M., Purans, J. & Hallén, A. High-Quality Si-Doped β-Ga2O3 Films on Sapphire Fabricated by Pulsed Laser Deposition. Phys. Status Solidi Basic Res. 258, 2–6 (2021)

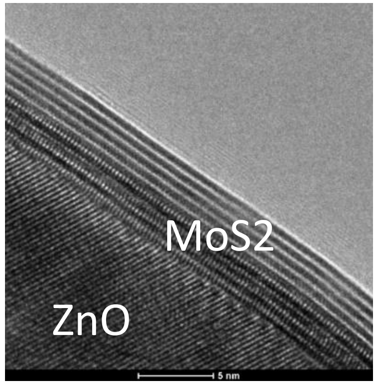
Khartsev, S., Hammar, M., Nordell, N., Zolotarjovs. A, Purans, J. & Hallén, Reverse bias electroluminescence in Er-doped b-Ga2O3 Schottky barrier diodes manufactured by pulsed laser deposition. Submitted for publishing.

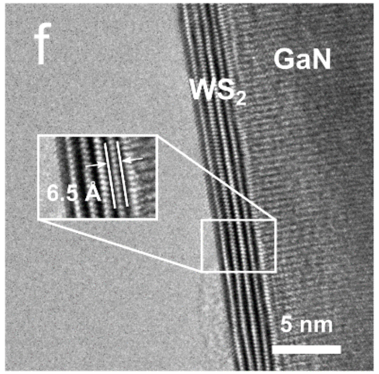
2D and 1D materials

Deposition method:
PLD – Pulsed Laser Deposition
Magnetron Deposition
CVD – Chemical Vapor Deposition
Synthesis in Ampoules





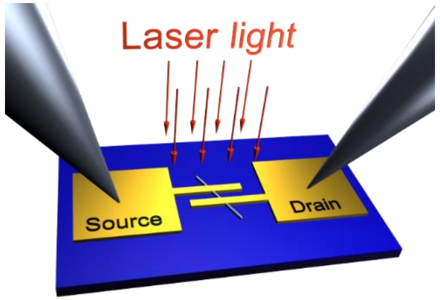


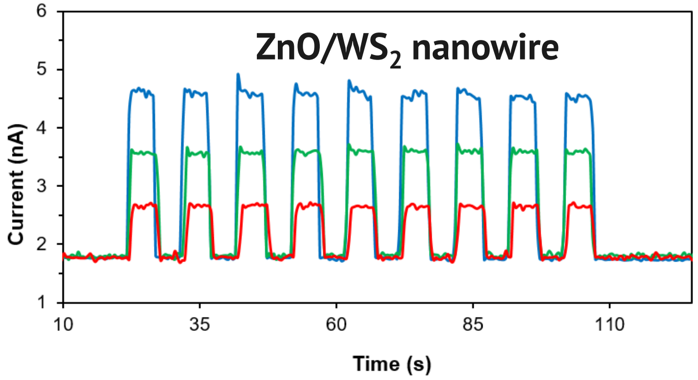


Project: LZP “Core-shell nanowire heterostructures of Charge Density Wave materials for optoelectronic applications”

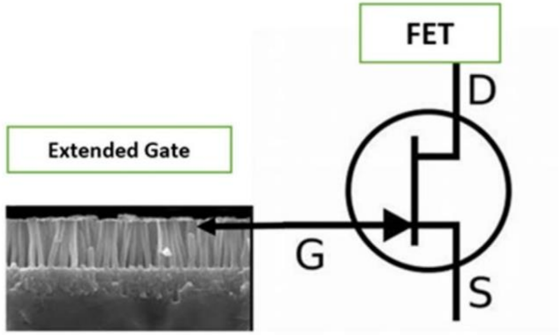
Duration: 2021 - 2023

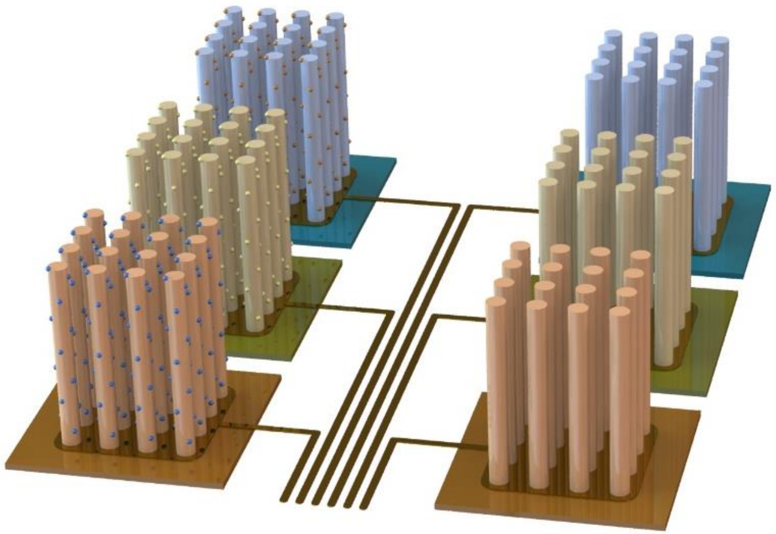
Project description:
In this project, we plan to develop and to investigate new charge density wave (CDW) material hybrid nanowire heterostructures suitable for photodetection in a wide wavelength range. The project idea is based on the combination of CDW material shell and semiconductor nanowire core, resulting in hybrid core-shell nanowires. We plan to investigate layered CDW hybrid systems growth on substrates with a hexagonal crystal structure that are stable in a corrosive sulphur atmosphere, such as GaN, InN, and ZnS, and on materials that can be converted to sulphides, such as ZnO (ZnS). The layered CDW materials to be studied are mainly transition metal chalcogenides (TaS2, VS2, VSe2, TiSe2, etc.). Several synthesis methods will be used and compared to grow the shell of the CDW material (eg pulsating layer deposition, magnetron sputtering, etc.). The electronic and optoelectronic properties of the core-shell nanowires will be studied by integrating them into a single nanowire device, such as a field effect transistor and a phototransistor. The project includes theoretical calculations aimed at studying the structure and properties of the core-shell interface.





2D and 1D materials





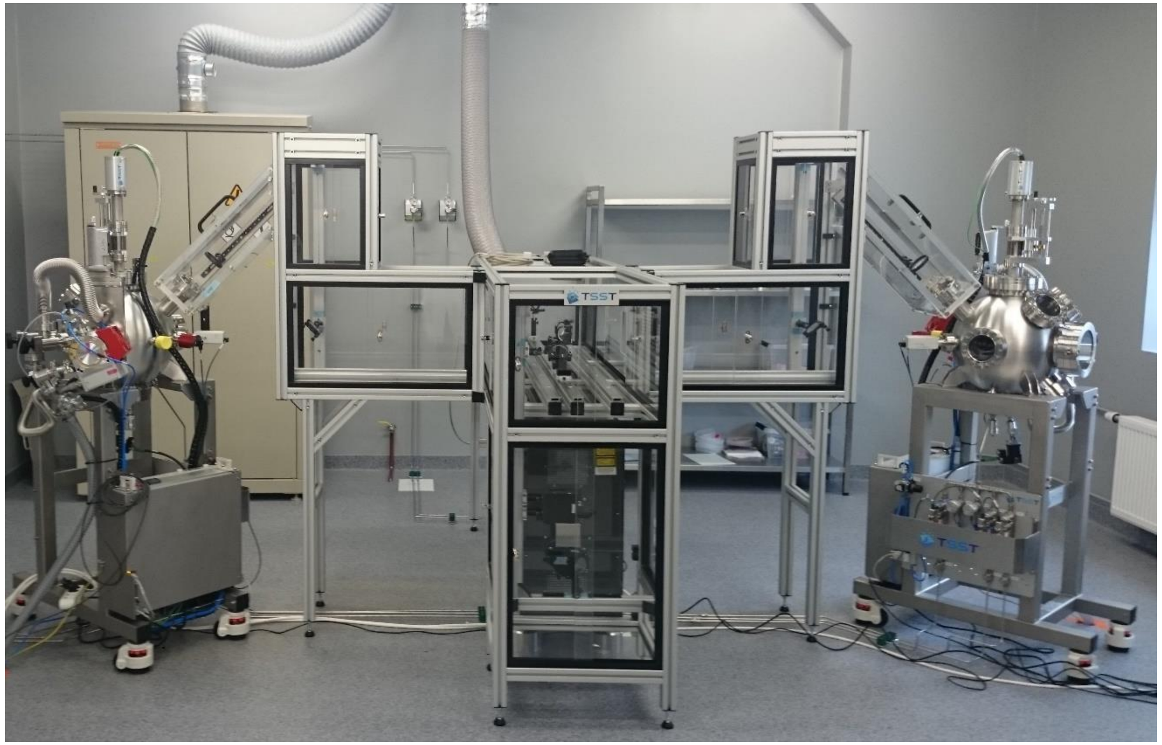
Concept of pure and 2D nanoparticles decorated metal oxide nanowire arrays set for heavy metal ion-sensitive extended gate for field-effect transistor.

Postdoc Project: PORTABLE DIAGNOSTIC DEVICE BASED ON A BIOSENSOR ARRAY OF 2D MATERIAL SENSING ELEMENTS

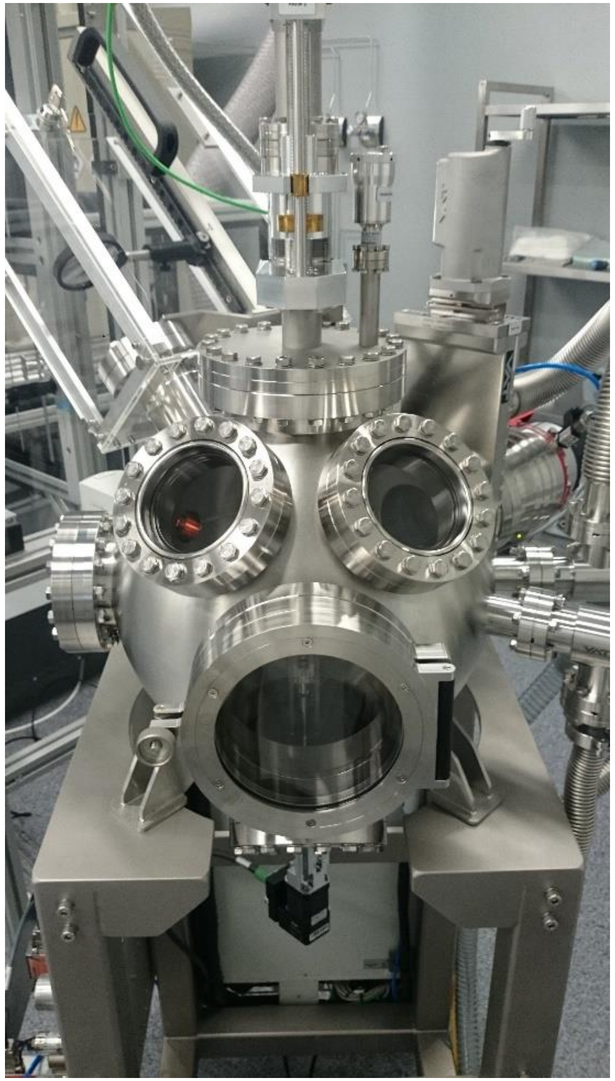
Duration: 2021 - 2023

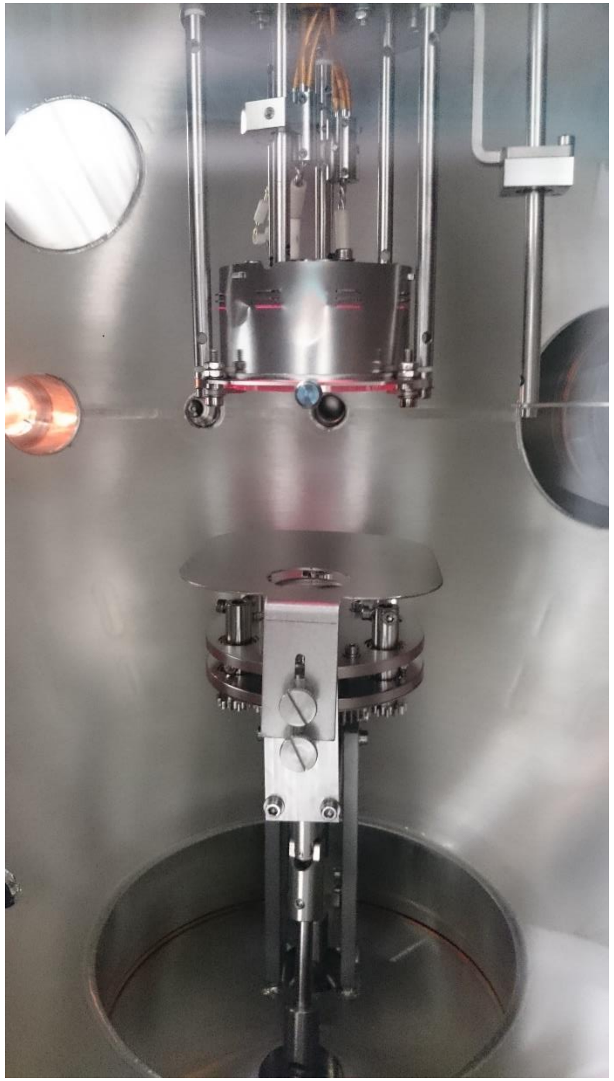
Project description:
Within the framework of this project, various 2D materials will be studied to find the best combinations between: sulfide materials - MoS_2, WS_2, ReS_2, TaS_2, VS_2, TiS_2, SnS_2, CuS; and oxide materials - MoO_3, WO_3, V_2O_5, MnO_2, etc., with the aim of developing sensor elements in the form of a field effect transistor (FET). In addition to the FET configuration, a p-n transition will be created instead of a simple S-D channel based on 2D materials, which can significantly expand the functionality of this type of element. In order to achieve a certain level of sensor selectivity, it is necessary to functionalize the working surface of the obtained elements with certain types of organic and inorganic chemicals (linkers), the level of response of such elements to the chemical reaction on their surfaces will be studied. The elements will be combined in an array, each sensitive element must respond uniquely to each substance of interest. However, instead of seeking to increase the sensitivity and selectivity of an array of individual sensor elements, which may be difficult to achieve, an option with less selective components is possible by creating a so-called 'cross-reactive' sensor array. This type of response processing of individual sensor elements will be performed using machine learning algorithms, obtaining a unique response pattern or "fingerprint". This challenging task will be solved using modern experimental methods, incl. also pulsed laser sputtering (PLD), atomic force microscopy (AFM), scanning electron microscopy (SEM). The multidisciplinary aspects of the project reflect its complex nature, which includes various chemical and physical methods of sensor fabrication, the use of a wide range of experimental methods for sensor testing, and the use of electronics and computer programming for sensor performance analysis.

PLD – Pulsed Laser Deposition

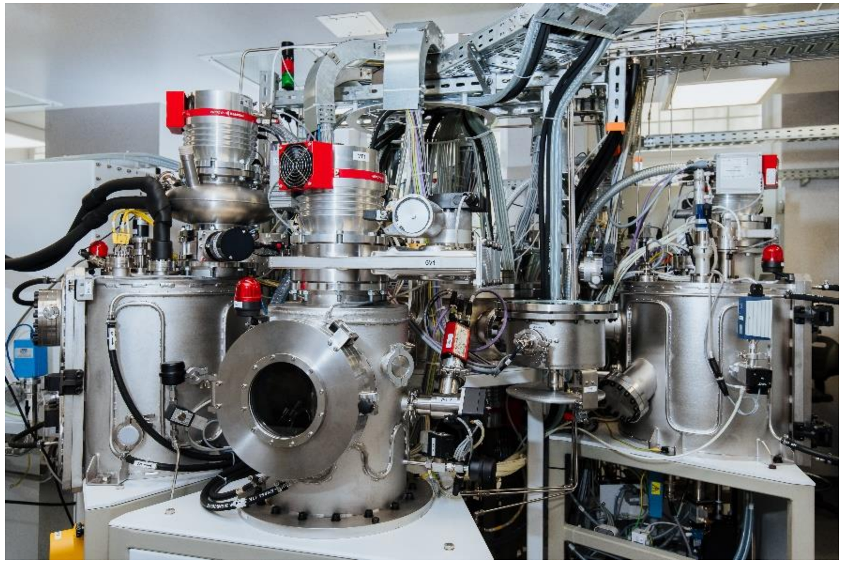


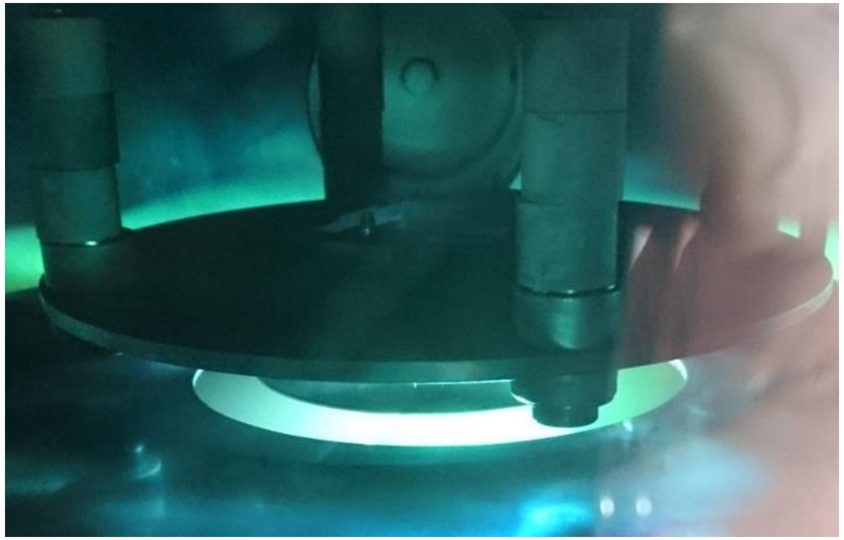
Two chamber PLD system – oxides and sulphides
(900C max, 6 targets in a carousel)

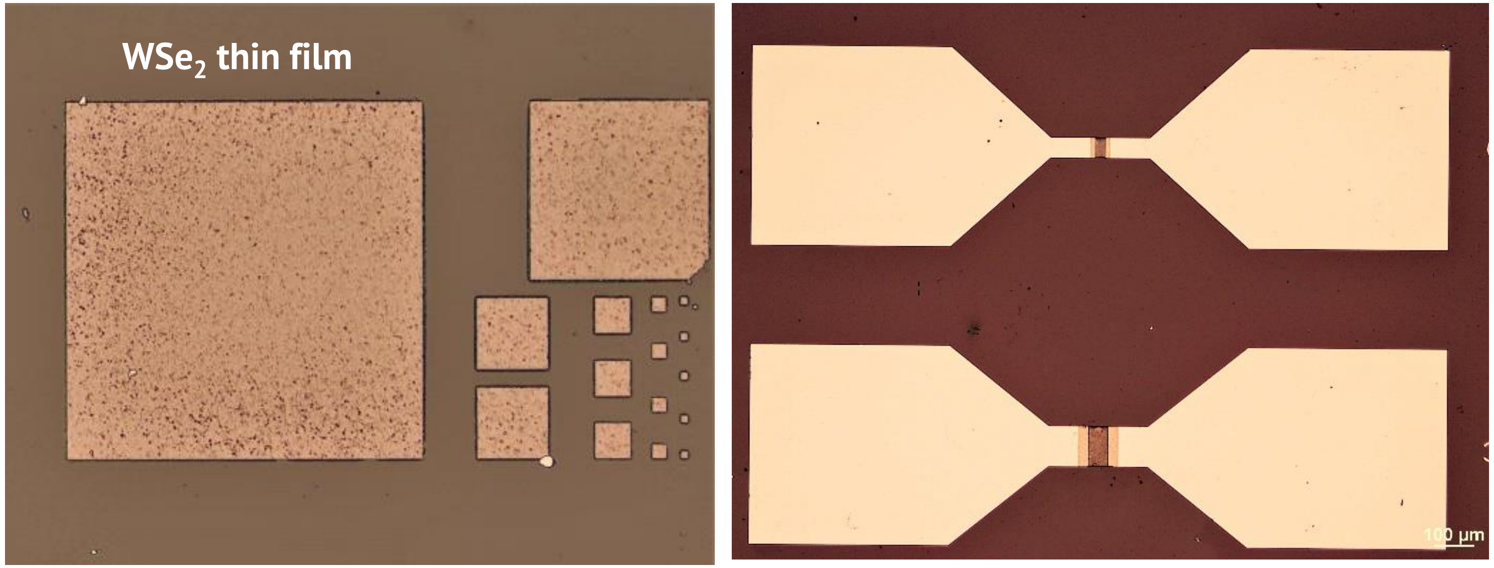


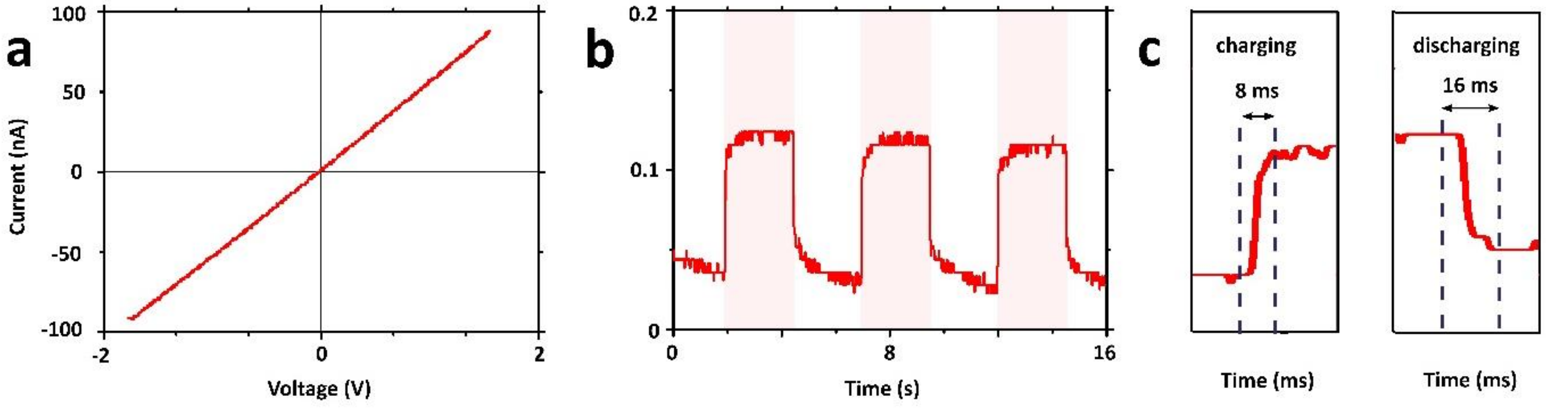


Magnetron deposition (and chalcogenation)







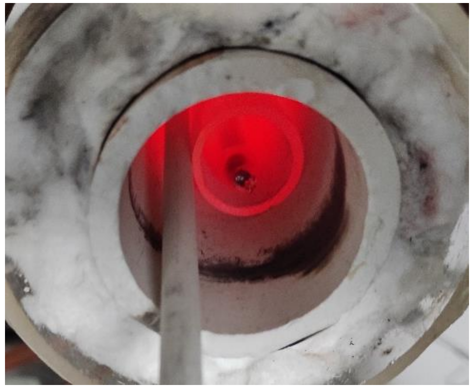


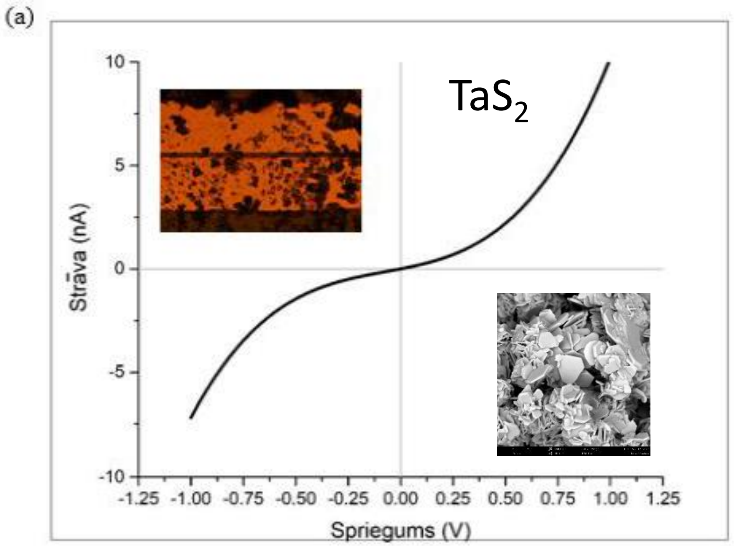
CVD – Chemical Vapor Deposition

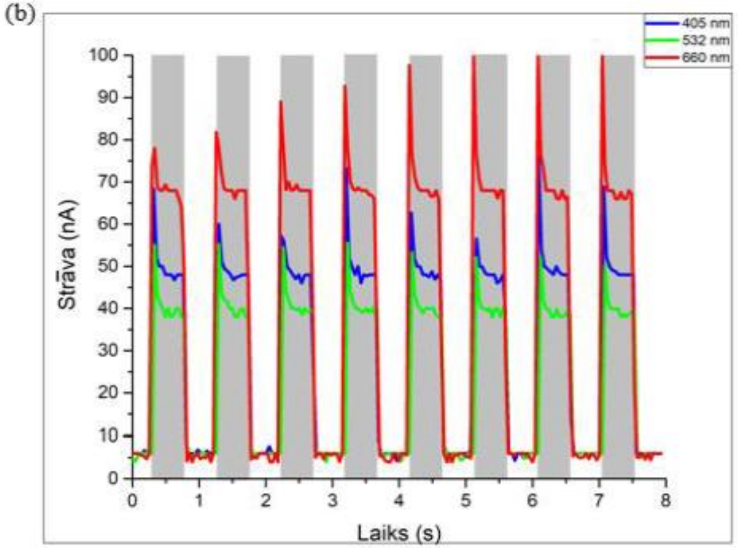
Current situation:
- We use primitive system with quartz tube and without gas flow control. Problems with solid precursors.

Improvements:
- We need programmable furnace and gas flow regulators
- We need low pressure system
- We need “shower-head” type system.

Bulk 2D crystals synthesis in ampoules







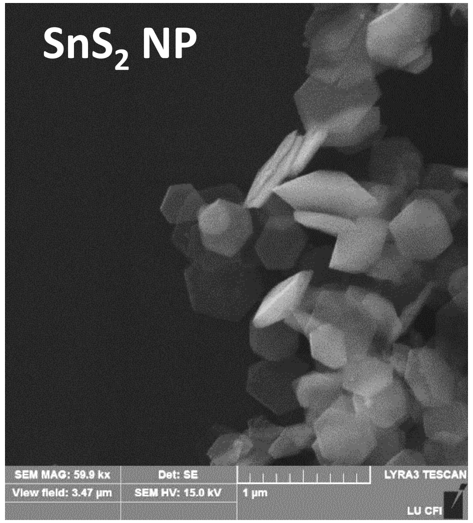
Ink-jet printing

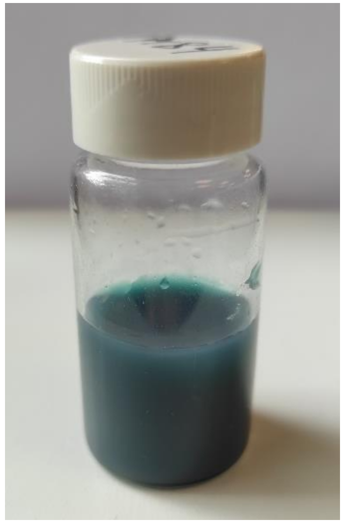
Deposition method:
Ink-jet printing
Spray deposition

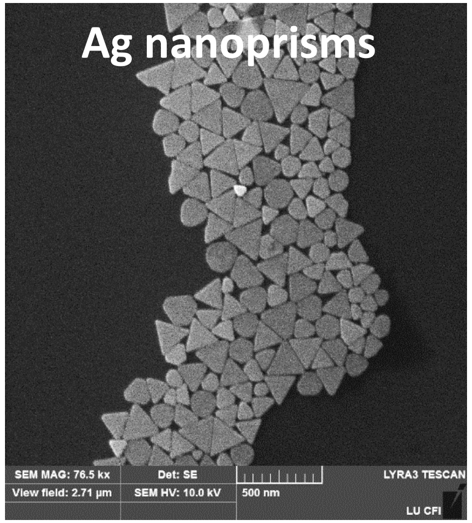
Project: ERAF "Functional ink-jet printing of wireless energy systems"

Duration: 2021 - 2023

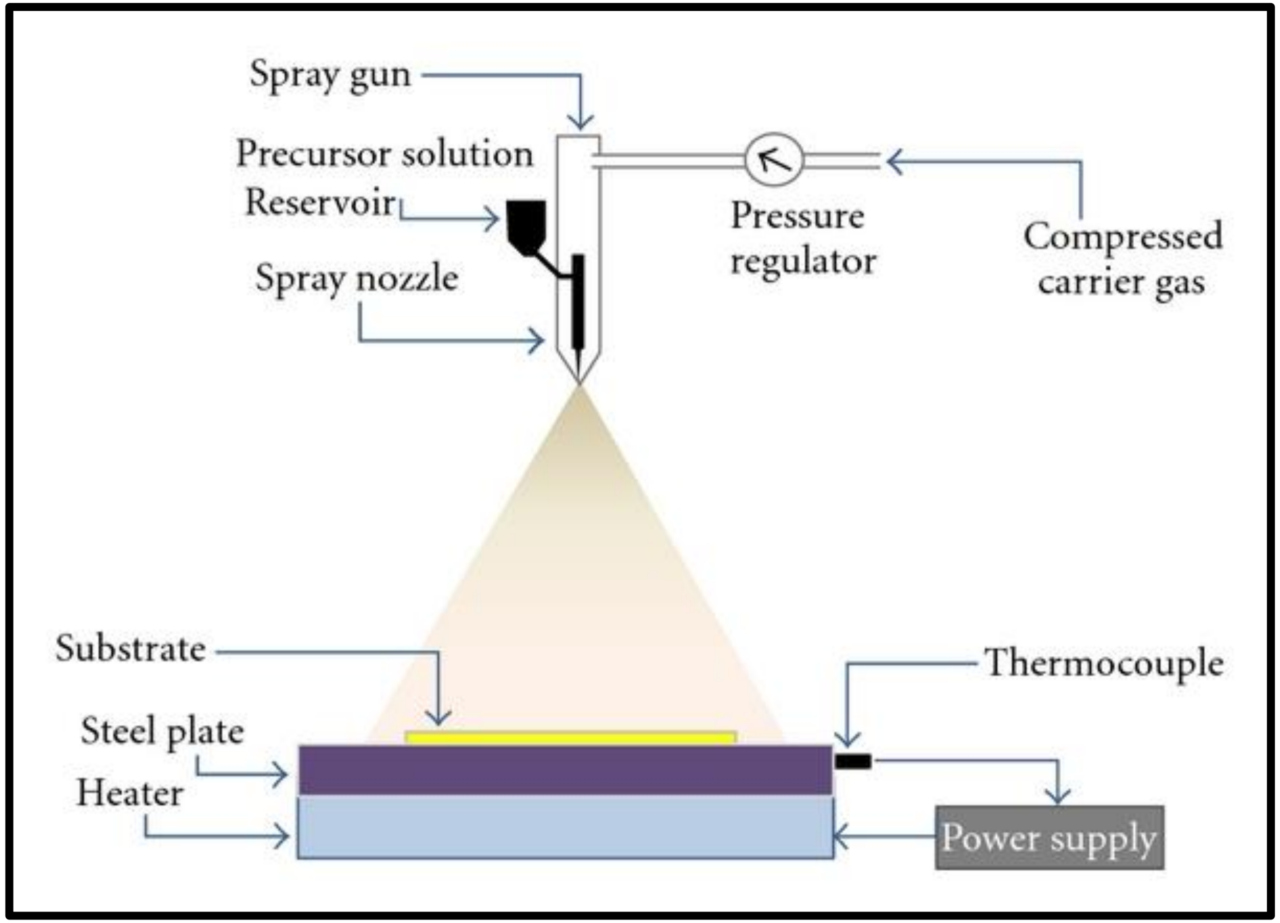
Project description:
Functional ink-jet printing is a promising new technology, cheap and environmentally friendly, and creates a new paradigm in digital manufacturing where electronic devices and circuits can be printed on demand.
The main goal of this project is a development and demonstration of the ink-jet technology that will be able to print wearable and flexible functional electronic devices, including the inductive antenna, capable of capturing electrical energy in the kilohertz range and feeding printed electroluminescent light-emitting devices implemented as 2D drawings.
The main result of the project is the development of the ink-jet printed prototype of a light-emitting device coupled with a wireless energy-receiving antenna.







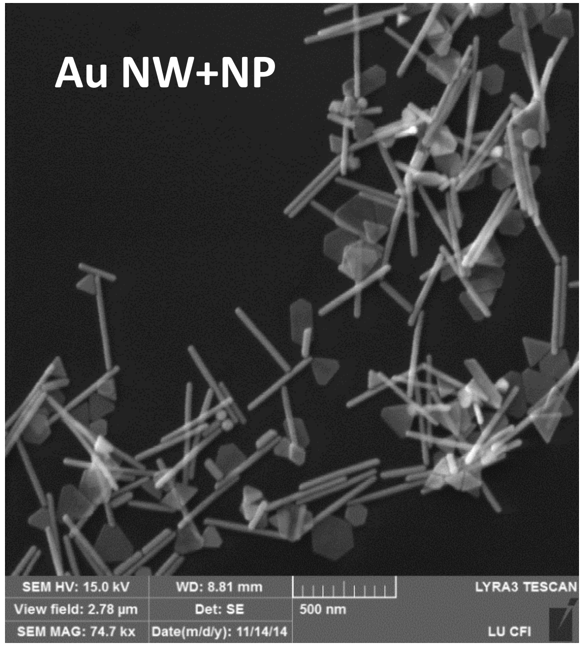
Spray deposition



Hermetic box

Spray deposition method can be used:

- For large areas;
- Metal nanowires or micron-size particles.



To be ordered or constructed…

Publications in this field:

Polyakov et al, Unexpected epitaxial growth of a few WS2 Layers on 1100 facets of ZnO nanowires, **2016**, *Journal of Physical Chemistry C*, 120(38), pp. 21451-21459

Butanovs et al, Synthesis and characterization of ZnO/ZnS/MoS2 core-shell nanowires, **2017**, *Journal of Crystal Growth*, 459, pp. 100-104

Butanovs et al, Towards metal chalcogenide nanowire-based colour-sensitive photodetectors, **2018**, *Optical Materials*, 75, pp. 501-507

Polyakov et al, Fast-Response Single-Nanowire Photodetector Based on ZnO/WS2 Core/Shell Heterostructures, **2018**, *ACS Applied Materials and Interfaces*, 10(16), pp. 13869-13876

Butanovs et al, Growth and characterization of PbI2-decorated ZnO nanowires for photodetection applications, **2020**, *Journal of Alloys and Compounds*, 825,154095

Butanovs et al, Synthesis and characterization of GaN/ReS2, ZnS/ReS2 and ZnO/ReS2 core/shell nanowire heterostructures, **2021**, *Applied Surface Science*, 536,147841

Butanovs et al, Nanoscale X-ray detectors based on individual CdS, SnO2 and ZnO nanowires, **2021**, *Nuclear Instruments and Methods in Physics Research*, 1014,165736

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https://forms.gle/Rd7bBvNkyLKjYrCd7