SOLID21
VP5 Plasmatic technologies

VP5 leader
Zdeněk Hubička

FZU Fyzikální ústav Akademie věd České republiky

The project Solid state physics for the 21st century – SOLID21
CZ.02.1.01/0.0/0.0/16_019/0000760 is co-funded by the European Union.

EVROPSKÁ UNIE
Evropské strukturální a investiční fondy
Operační program Výzkum, vývoj a vzdělávání

MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

Research program Plasmatic Technologies (RP 5)
head Zdeněk Hubička

RP5 is composed of six Research activities (RA):

RA1- R&D of advanced low temperature plasma systems for thin film polycrystalline materials (Z. Hubička)

RA2 - Plasma diagnostics, optimization of plasma deposition systems, and monitoring of deposition processes (M. Čada)

RA3 - Plasma methods of preparation of thin metallic and intermetallic layers (J. Lančok)

RA4 - Thin-film chemical sensors (M. Novotný)

RA5 – Optical materials-plasmon structures (J. Bulíř)

RA6 – Structures exhibiting a combination of ferromagnetic properties (M. Tjunina)

Research program 1
R&D of advanced low temperature plasma systems for thin film polycrystalline materials

RP leader

Zdeněk Hubička

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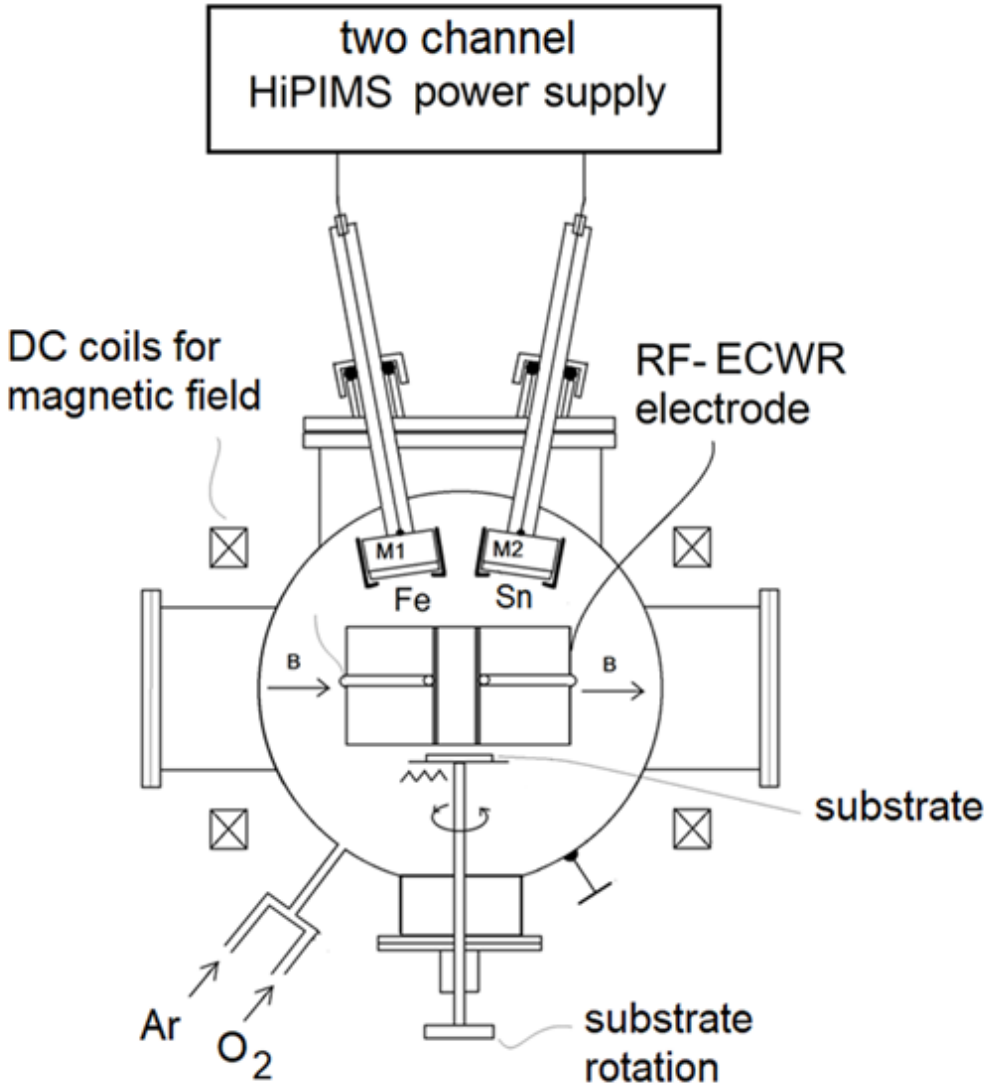
- semiconductor oxides (doped, ternary) deposited by reactive pulsed HiPIMS plasma systems are investigated for solar water splitting and hydrogen production

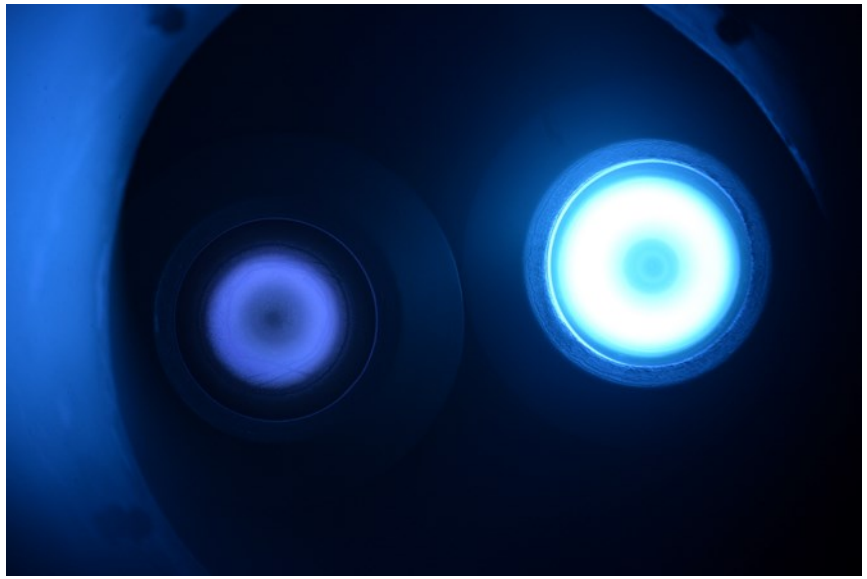
- ZnO semiconductor thin films deposited by plasma systems for fast photon detectors cooperation with Institute of Laser Engineering in Osaka university Japan (Marilou Catadal Raduban, Nobuhiko Sarukura, Kohei Yamanoi)

- unipolar and bipolar pulsed linear hollow cathode sputtering plasma jet was developed and sold as prototype to IQS group, s.r.o. as a deposition source implemented in large industrial roll to roll coater

- new plasma machines for pulsed reactive sputtering of sulphides and selenides was already finished. Polycrystalline LuS_2, MoS_2 semiconductor thin films were deposited for photonic applications

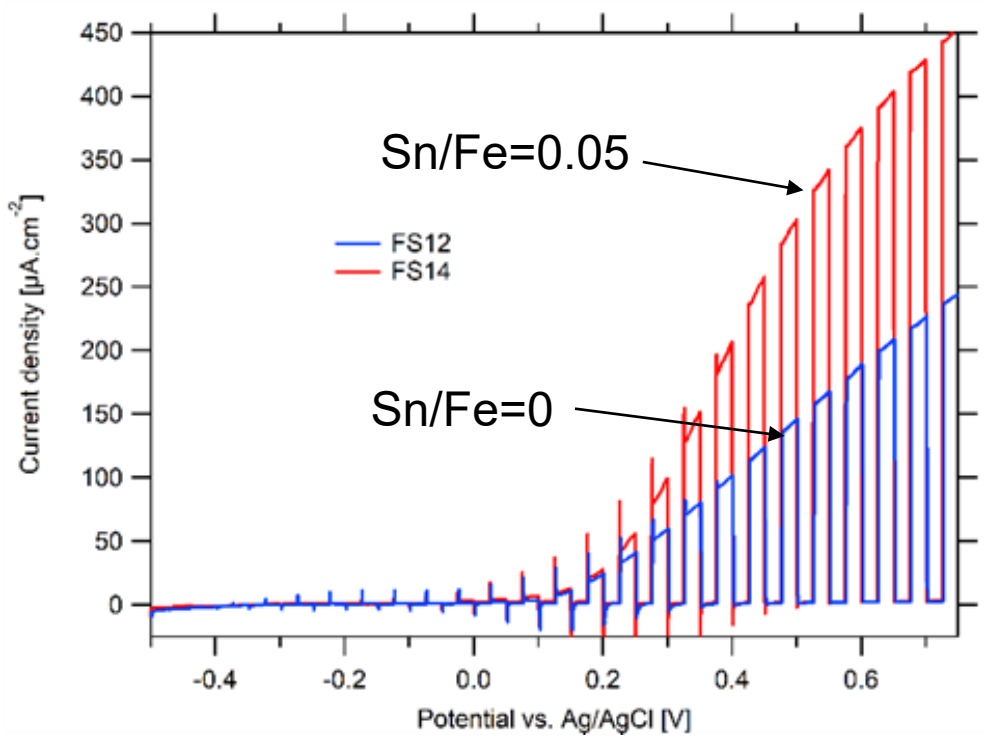
Deposition of Fe_2O_3:Sn semiconducting (n-type) thin films by reactive pulsed r-HiPIMS + ECWR co-sputtering from Fe and Sn target. (to be published with VSCHT and J. Heyrovsky institute of Physical Chemistry CAS)

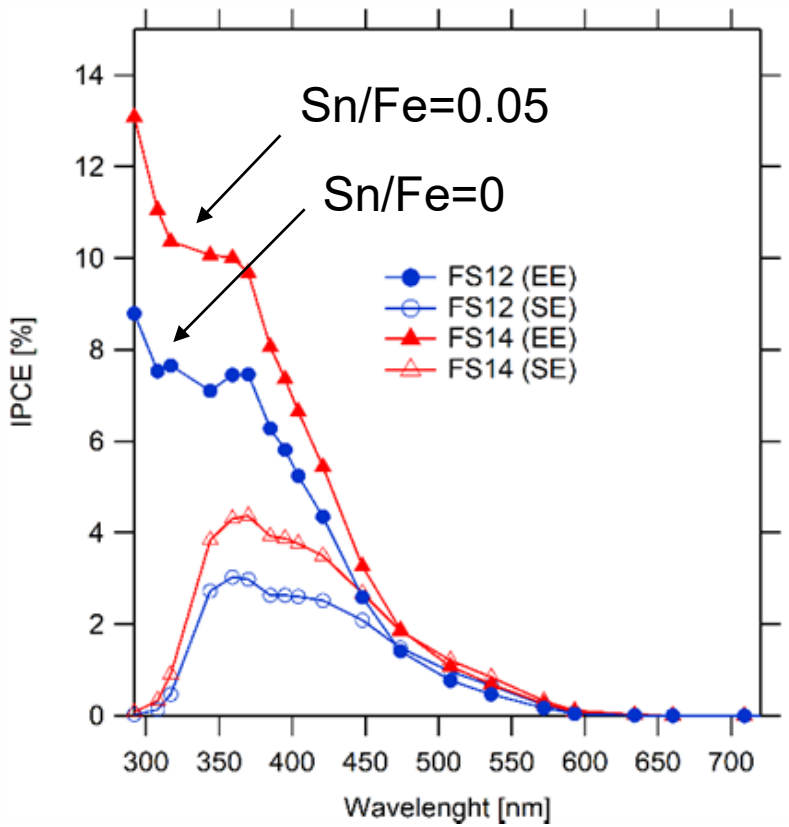




Deposition of Fe_2O_3:Sn semiconducting (n-type) thin films by reactive pulsed r-HiPIMS + ECWR co-sputtering from Fe and Sn target

PEC measurements (photoanode)





LSV, chopped-light 5 s dark/ 5 s light, scan rate 5 mV/s, Light source UV diode, intensity 100 W/m^2, electrolyte/electrode illumination, electrolyte: 0.1M NaOH of samples FS12 and FS14 deposited on FTO electrode.

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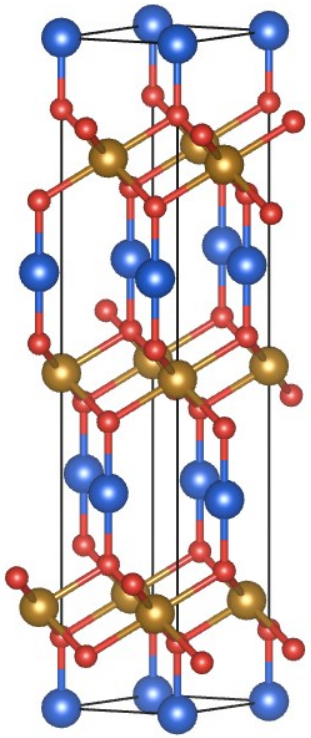
Photocathode p-type semiconductor $CuFeO_2$ with delafossite structure

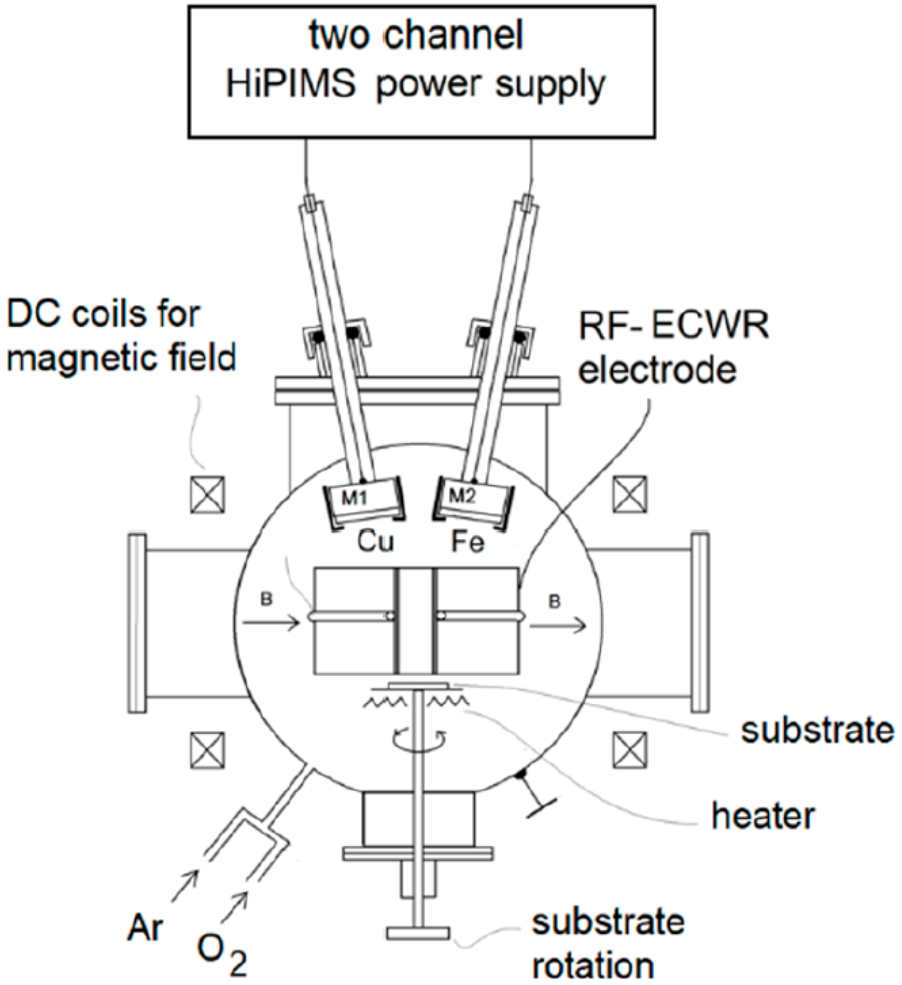
- cooperation with University of Greifswald

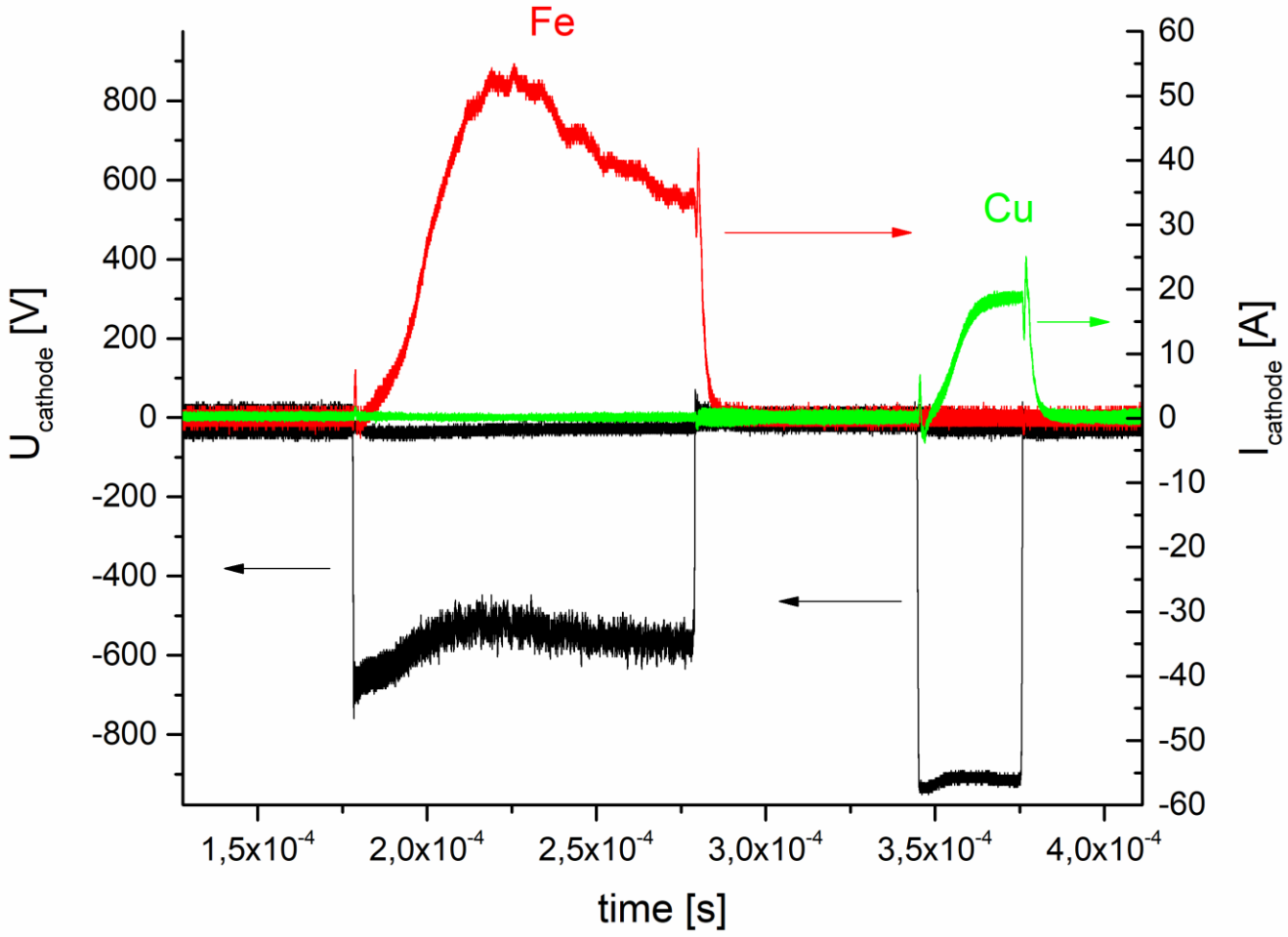
- exceptional stability in basic aqueous electrolyte
- favorable band gap E_g = 1.47 eV
- earth-abundant component (Cu, Fe, O)
- disadvantage - small photocurrents (needs improvement)



HiPIMS or HiPIMS+ECWR with dual magnetron for alloy and multicomponent thin films $Cu_{1+y}FeO_x$

(semiconducting films: $Cu_{1+y}FeO_x$)



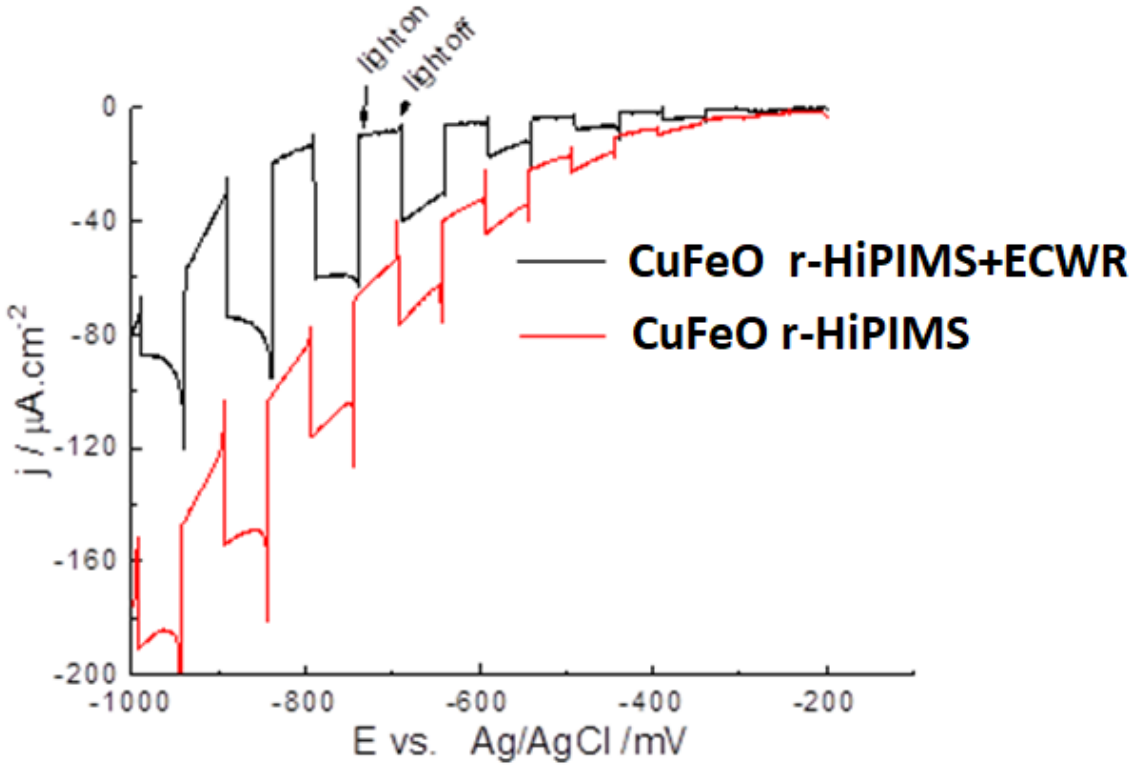


Akademie věd České republiky

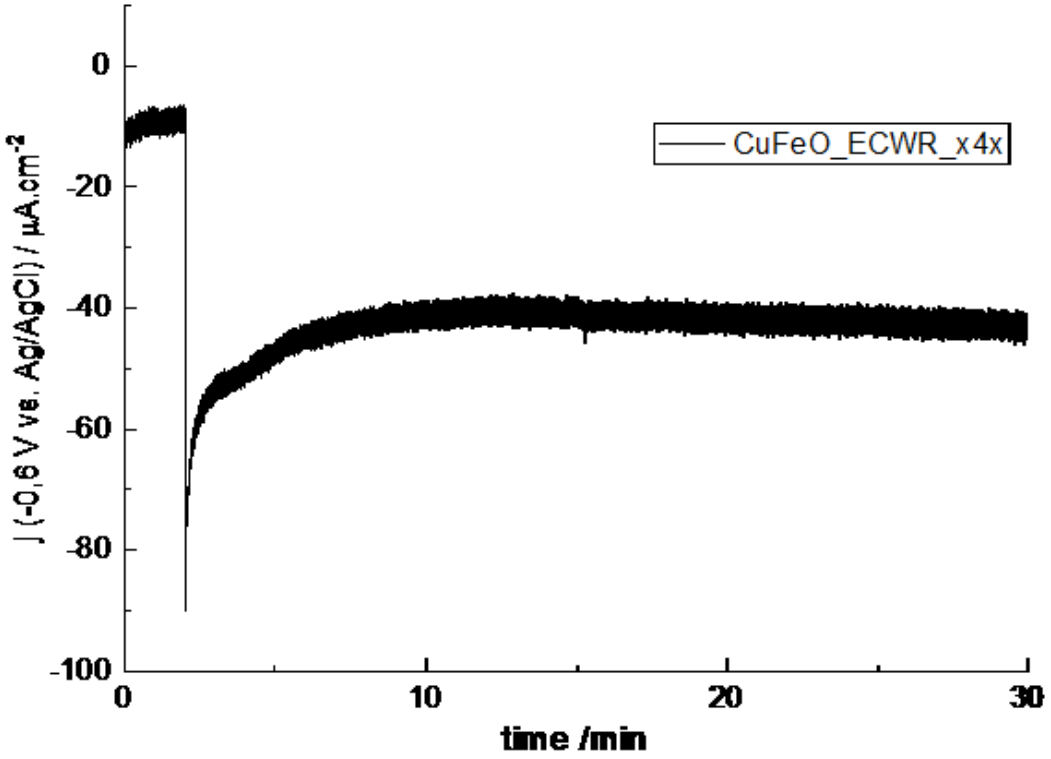
Z. Hubička, M, Zlámal, J. Olejníček, D. Tvarog, M. Čada, J. Krýsa, Coatings 10 (2020) 232.

Plasma diagnostics by RF planar probe during the deposition process

Deposition of $CuFeO_2$ with Cu and Fe target in $Ar+O_2$ gas mixture (*A. Písaříková, et. al. to be published*)



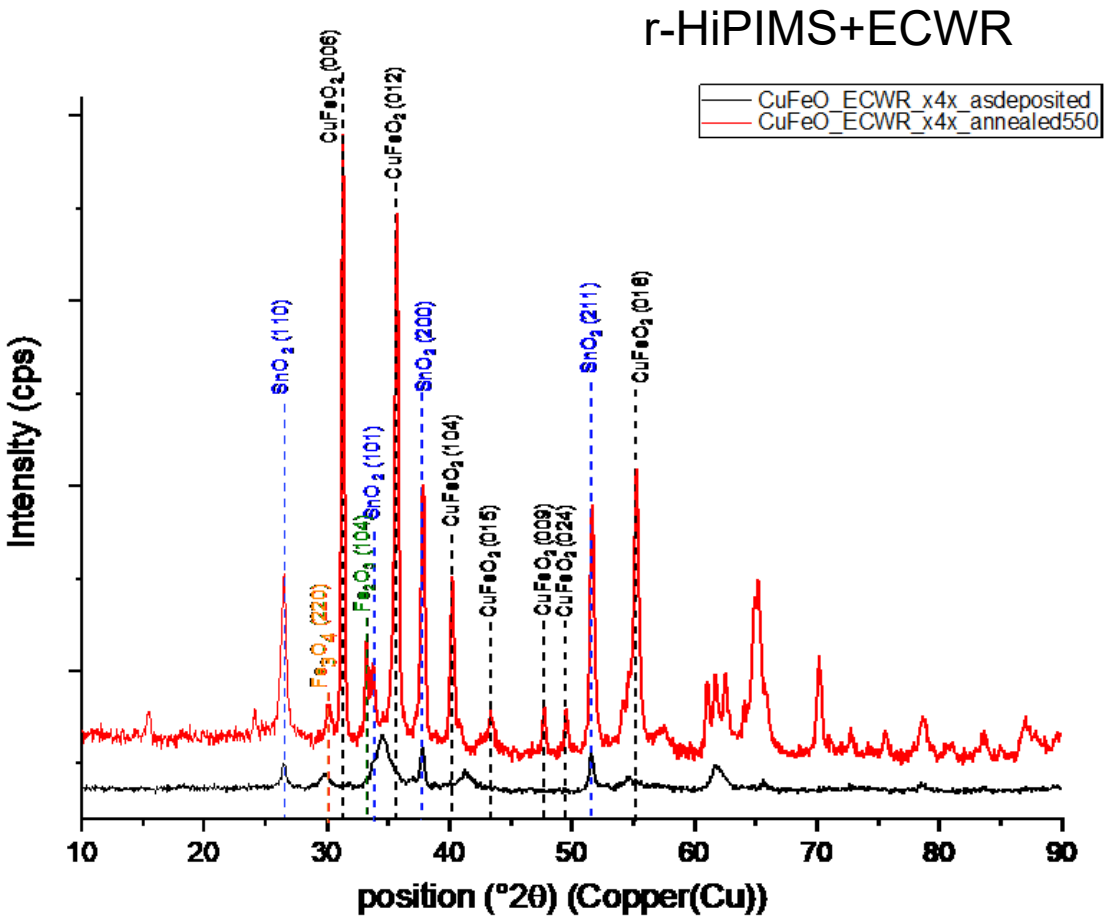
Copped polarization curves of CuFeO2 prepared by r-HiPIMS, r-HiPIMS+ECWR, annealed at 550°C, in 1 mol/l NaOH



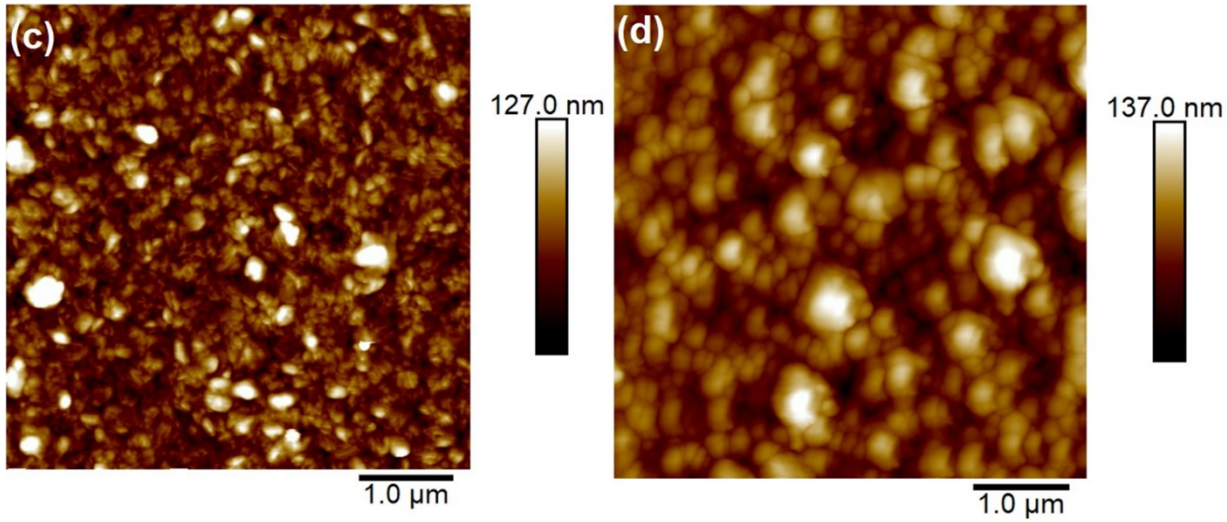
Chronoamperometry of sample CuFeO_ECWR_x4x, annealed at 550 °C in argon, measured at -0.4 V vs. Ag/AgCl, 1 mol/l NaOH

Plasma diagnostics by RF planar probe during the deposition process

Deposition of $CuFeO_2$ with Cu and Fe target in $Ar+O_2$ gas mixture (*A. Písaříková, et. al. to be published*)



X-ray diffractograms of as-deposited (black) and annealed (red) samples deposited by r-HiPIMS+ECWR on FTO glass



Surface morphology of $CuFeO_2$ of as-deposited and annealed samples. (c), (d) as-deposited and annealed films of CuFeO2 prepared by r-HiPIMS + ECWR, respectively.

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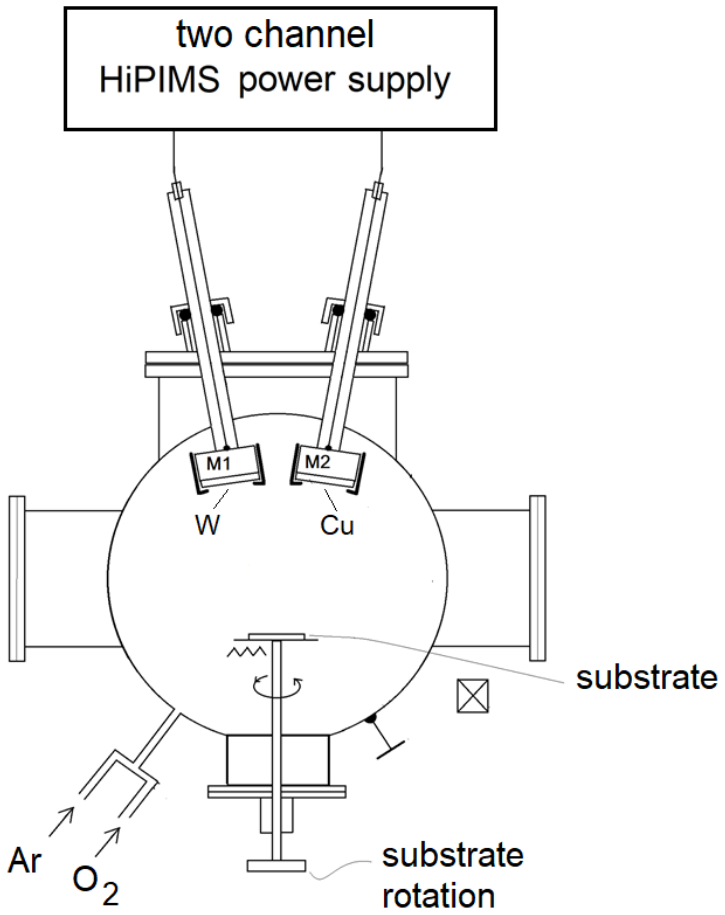
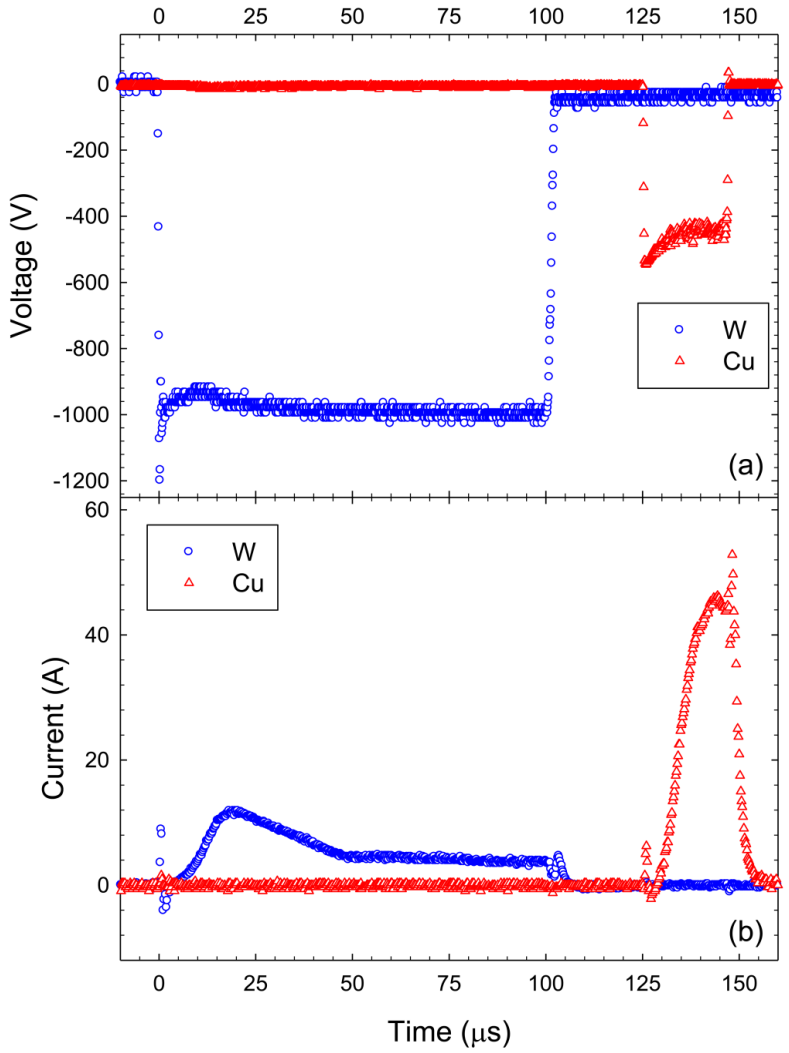
Deposition of tungsten copper oxide (WCu_xO_y) films by reactive high power impulse magnetron co-sputtering (W and Cu targets in $Ar+O_2$ gas mixture).





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A. Hrubantova, R. Hippler, H. Wulff, M. Cada, O. Gedeon, P. Jiricek, J. Houdkova, J. Olejnicek, N. Nepomniashchaia, C. A. Helm, and Z. Hubicka, Copper tungsten oxide (CuxWOy) thin films for optical and photoelectrochemical applications deposited by reactive high power impulse magnetron co-sputtering, Cite as: J. Appl. Phys. 132, 215301 (2022).

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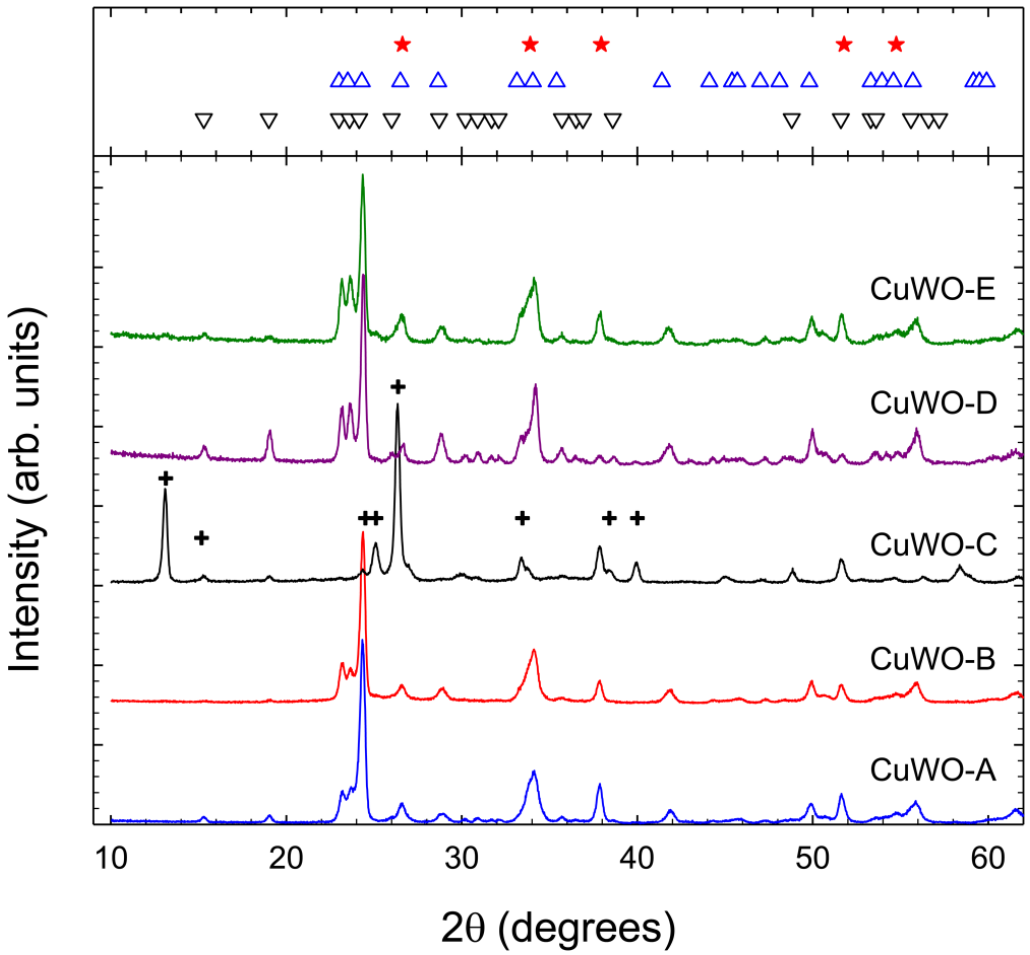

TABLE. Main crystallographic phases of annealed films on microscope glass (MG) and FTO-coated glass as obtained from the GIXRD measurements.

Sample	MG	FTO
CuWO-A	$Na_2W_2O_7$	WO_3 + $CuWO_4$ (10%)
CuWO-B	$Na_2W_4O_{13}$ + $Na_2W_2O_7$ (15%)	WO_3
CuWO-C	$CuWO_4$	Cu_2WO_4
CuWO-D	WO_3 + $CuWO_4$ (50%)	WO_3 + $CuWO_4$ (25%)
CuWO-E	$Na_2W_2O_7$ + $Na_2W_4O_{13}$ (46%) + $CuWO_4$ (8%)	WO_3 + $CuWO_4$ (10%)

GIXRD diffractogram of annealed Cu_xWO_y films deposited by HiPIMS on FTO-coated glass substrates. Reflections from the assumed monoclinic Cu_2WO_4 (+), monoclinic WO_3 (Δ), $CuWO_4$ (∇), and FTO (*) are indicated.

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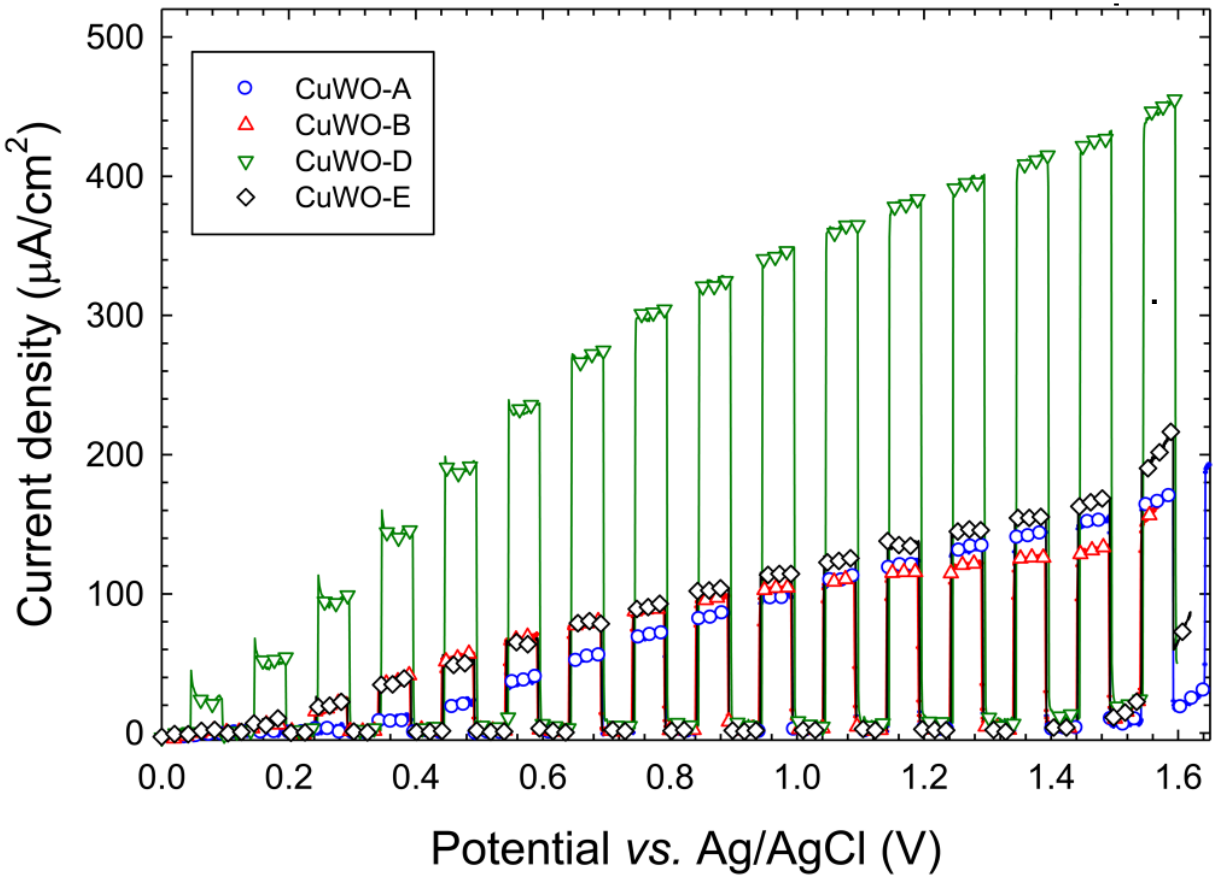

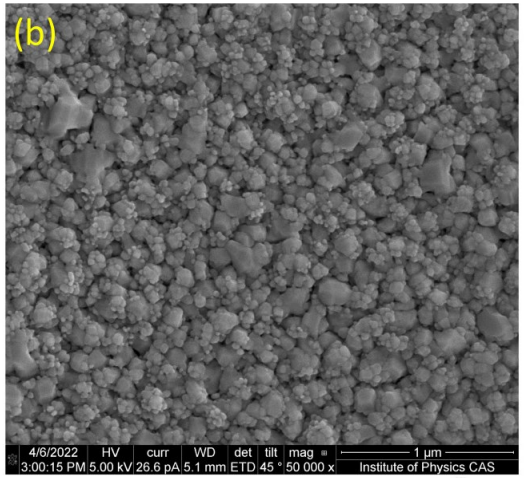

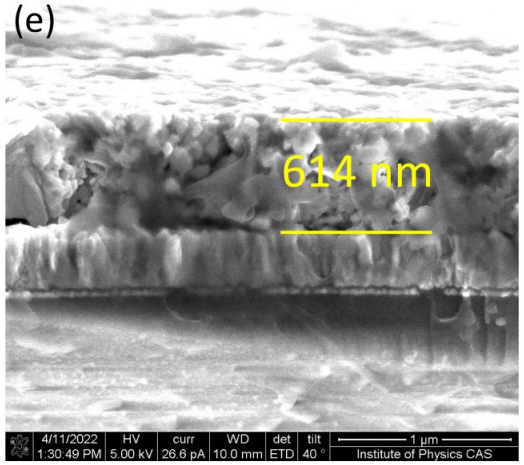

SEM
CuWO-D (FTO)
WO_3 + $CuWO_4$ 25%

Current density of annealed Cu_xWO_y on FTO) as a function of applied voltage under simulated solar light irradiation with an intensity of 0.62 sun. Scan rate 10 mV/s, electrolyte 0.1 mol/l Na_2SO_4, periodically illuminated 5 s dark/5 s light.

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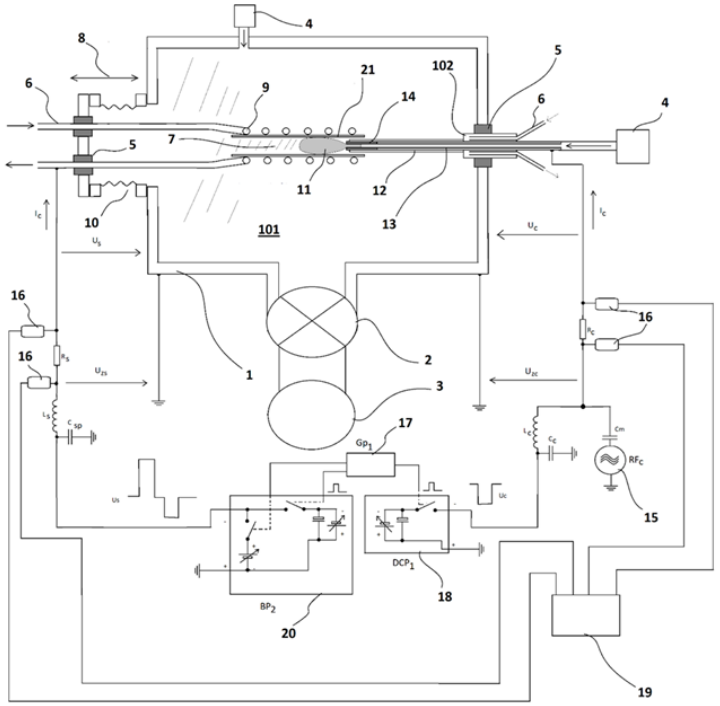
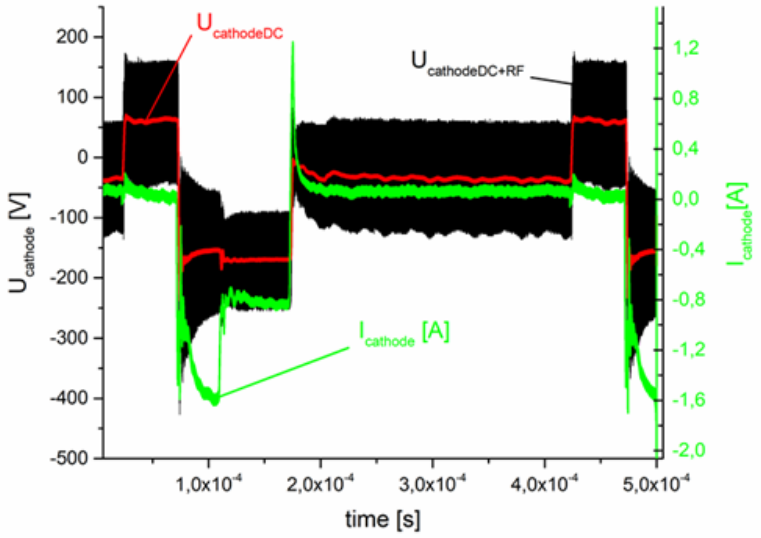
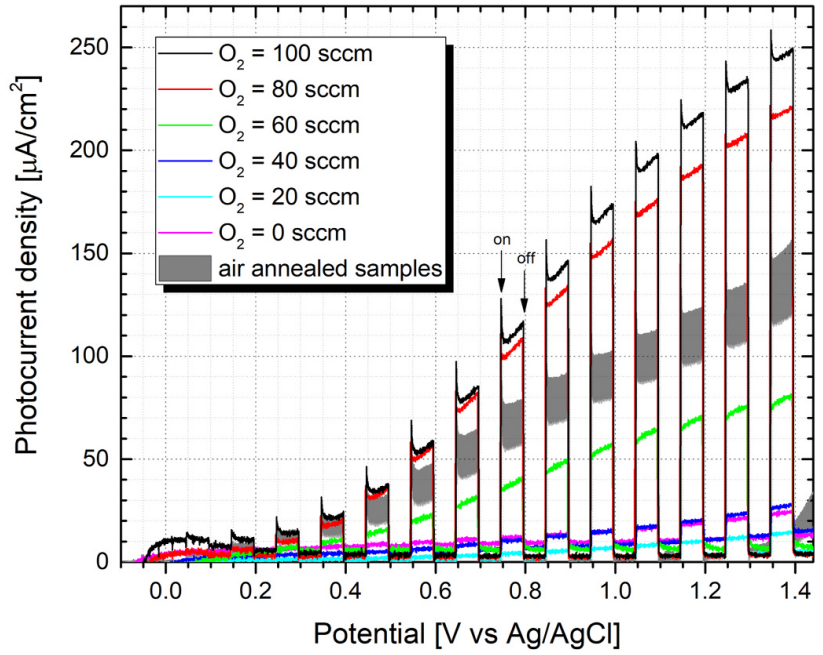
VP5 international patent (deposition of catalytic films in tubes)

Team of VP5 developed new hollow cathode pulsed deposition plasma jet method for deposition of thin films

Z. Hubička, M. Čada, P. Kšírová, M. Klinger, A method of generating low temperature plasma, a method of coating the inner surface of hollow electrically conductive or ferromagnetic tubes and the equipment for doing this, PV-2018-206307842, PCT/CZ2019/050019, WO 2019/210891 A1, EU patent EP3788181A1



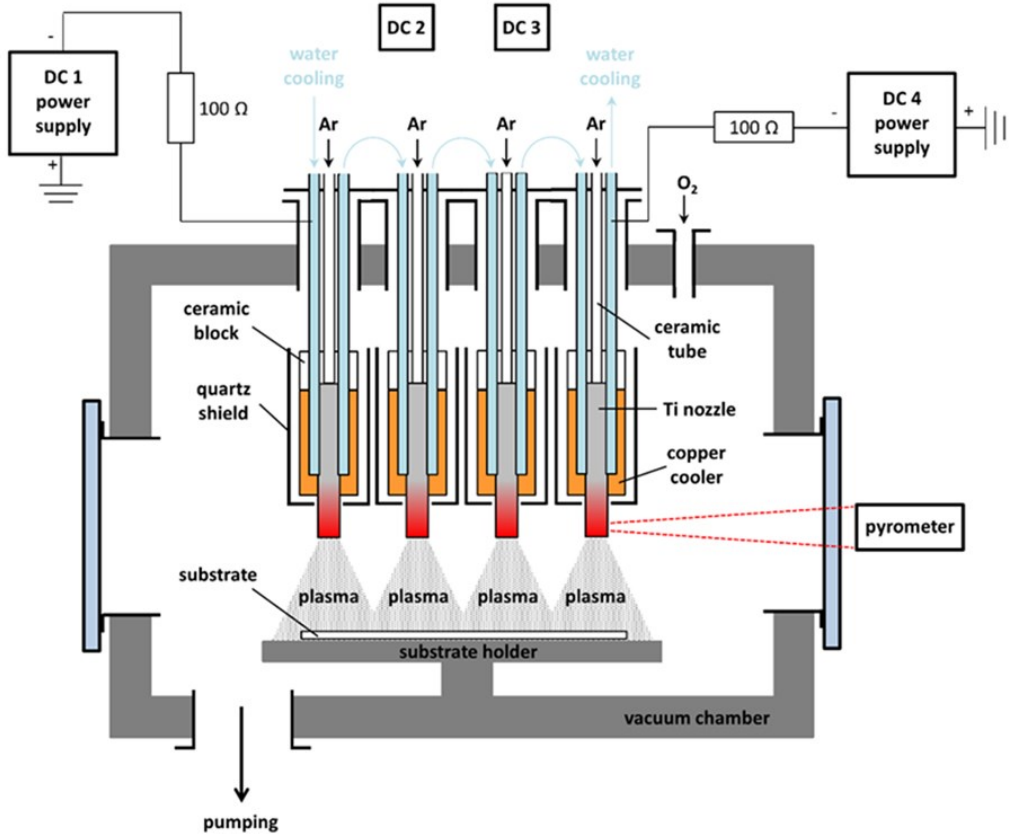


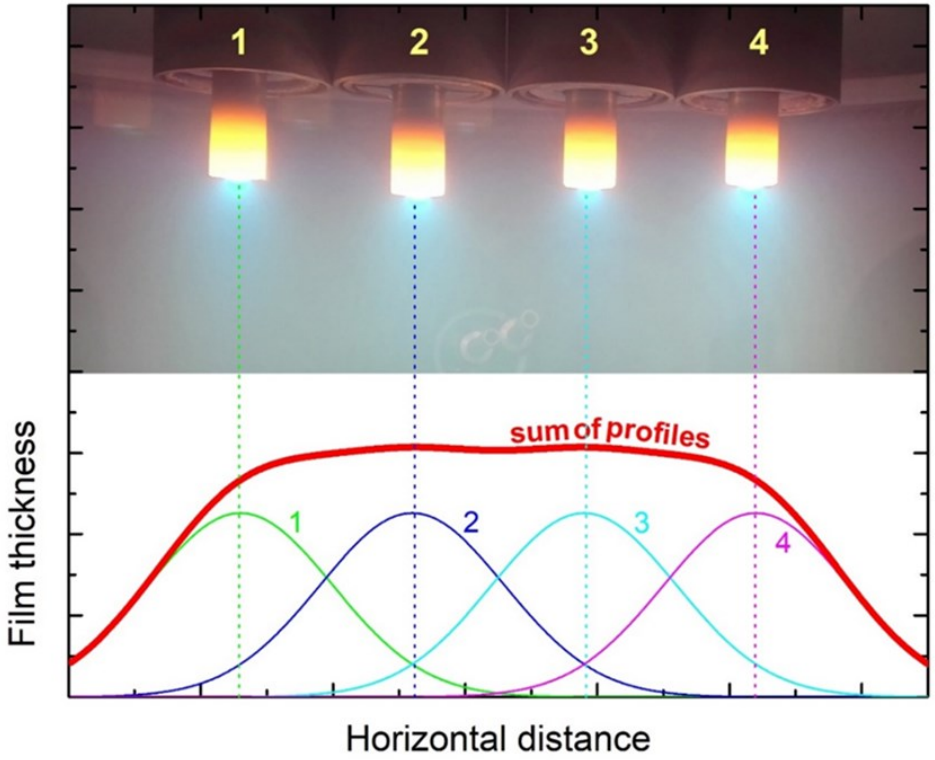


2) J.Olejníček, A.Hrubantová, L.Volfová, M.Dvořáková, M.Kohout, D.Tvarog, O.Gedeon, H.Wulff, R.Hippler, Z.Hubička, WO_3 and WO_{3-x} thin films prepared by DC hollow cathode discharge, Vacuum 195 (2022), 110679.

Cooperation between IQ structures, s.r.o. - FZU AVČR, v.v.i.
- thin film optical security elements for bank notes

High rate deposition of homogeneous oxide semiconductor films by pulse multi-nozzle system of hot hollow cathodes
- the system was already sold as a prototype to IQS group, s.r.o. as a deposition source for implementation in large industrial roll to roll coater





Reactive pulse sputtering system for sulphides and selenides was installed and finished

- polycrystalline LuS_2 semiconductor films were deposited for RP3
- MoS_2 semiconductor thin films were deposited for photonic applications with HiLASE
- the bilayer structure WO_3/WS_2 is being prepared for sensory application

SOLID21
Research program 2

RP leader

Martin Čada

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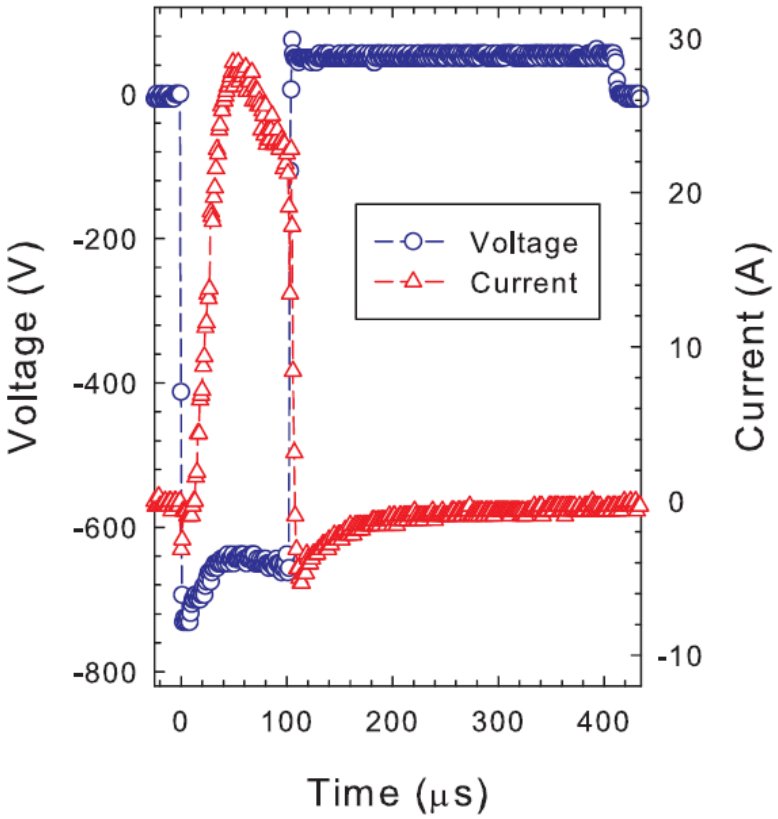
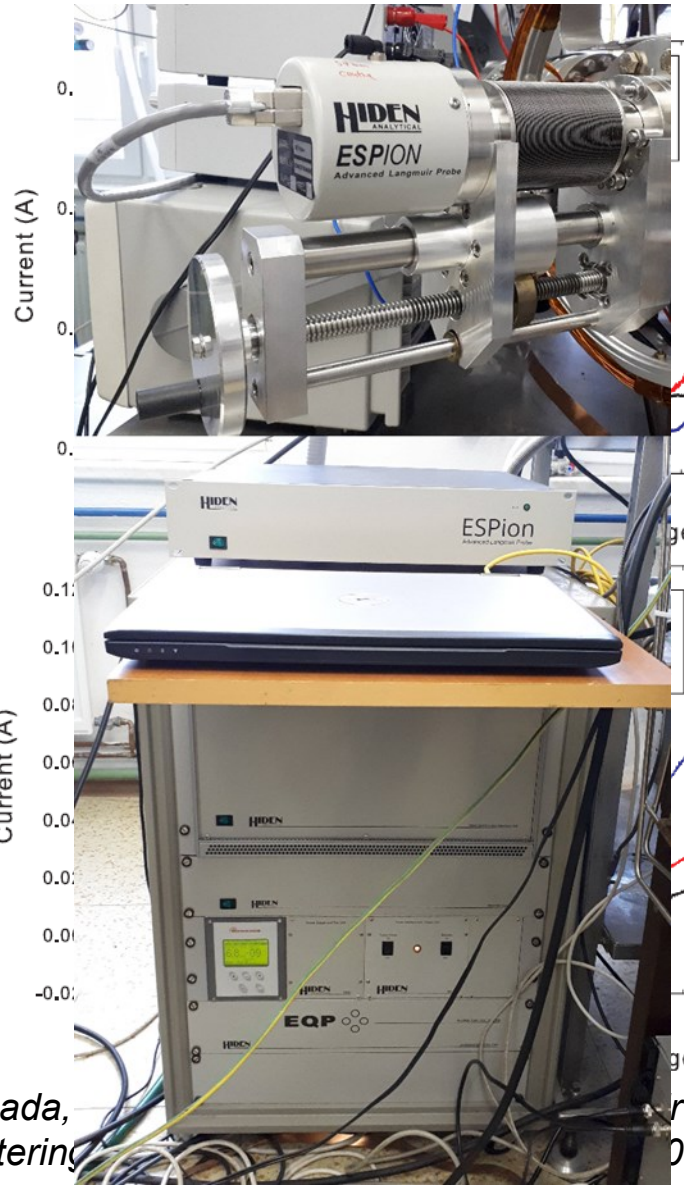
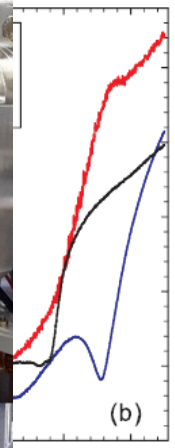
VP5 - plasma diagnostic of reactive r-HiPIMS and bipolar r-HiPIMS plasma

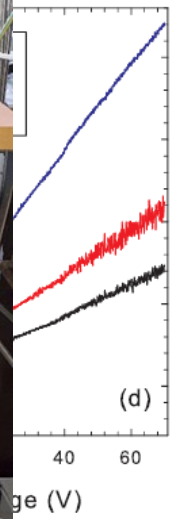
bipolar HiPIMS

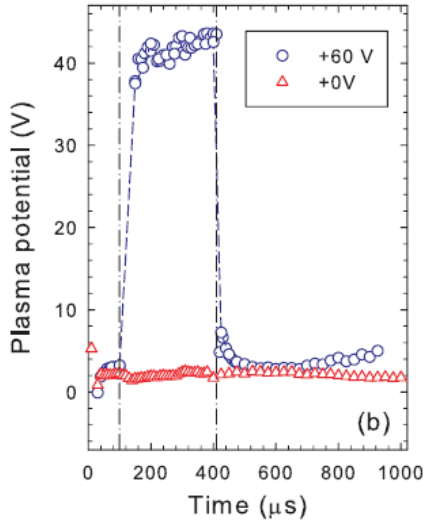
- time resolved Langmuir probe masurements of bipolar HiPIMS plasma during positive pulse

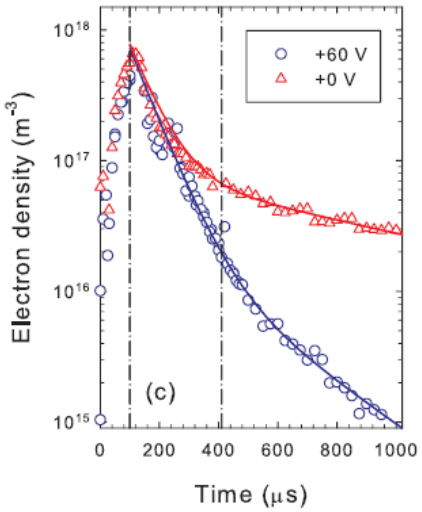












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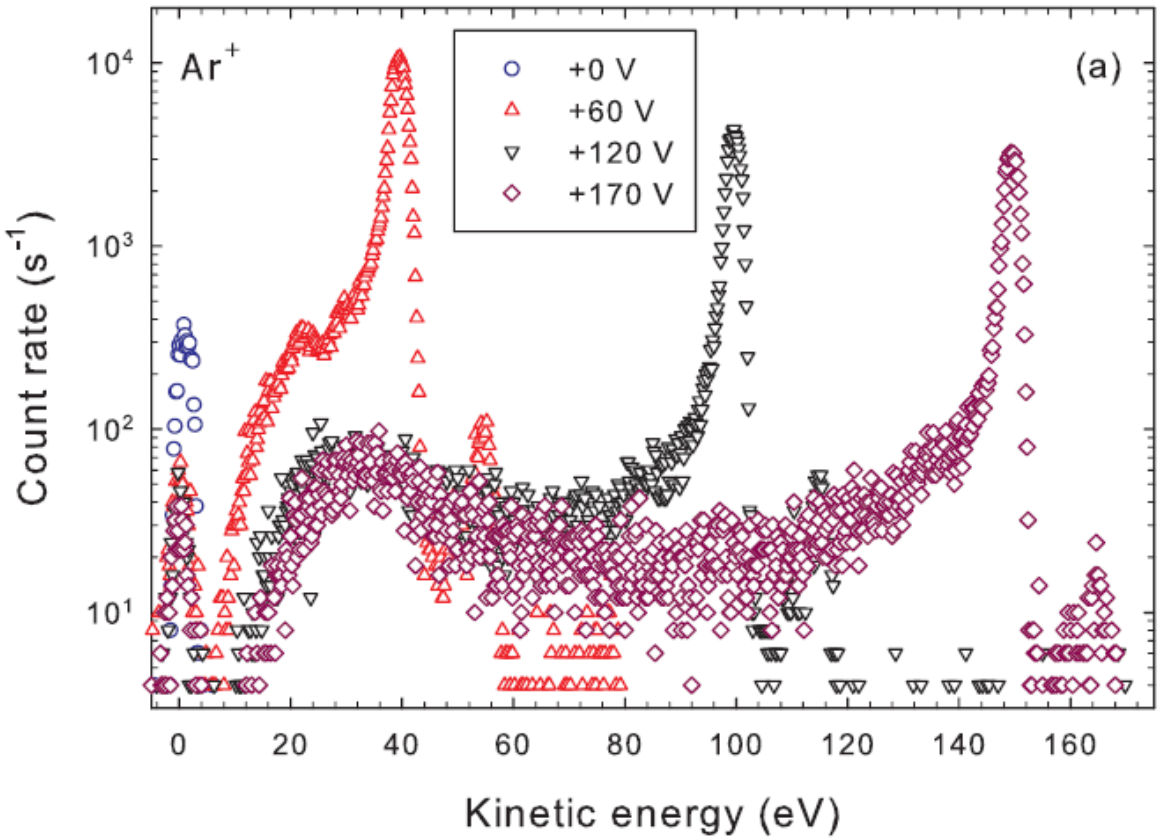
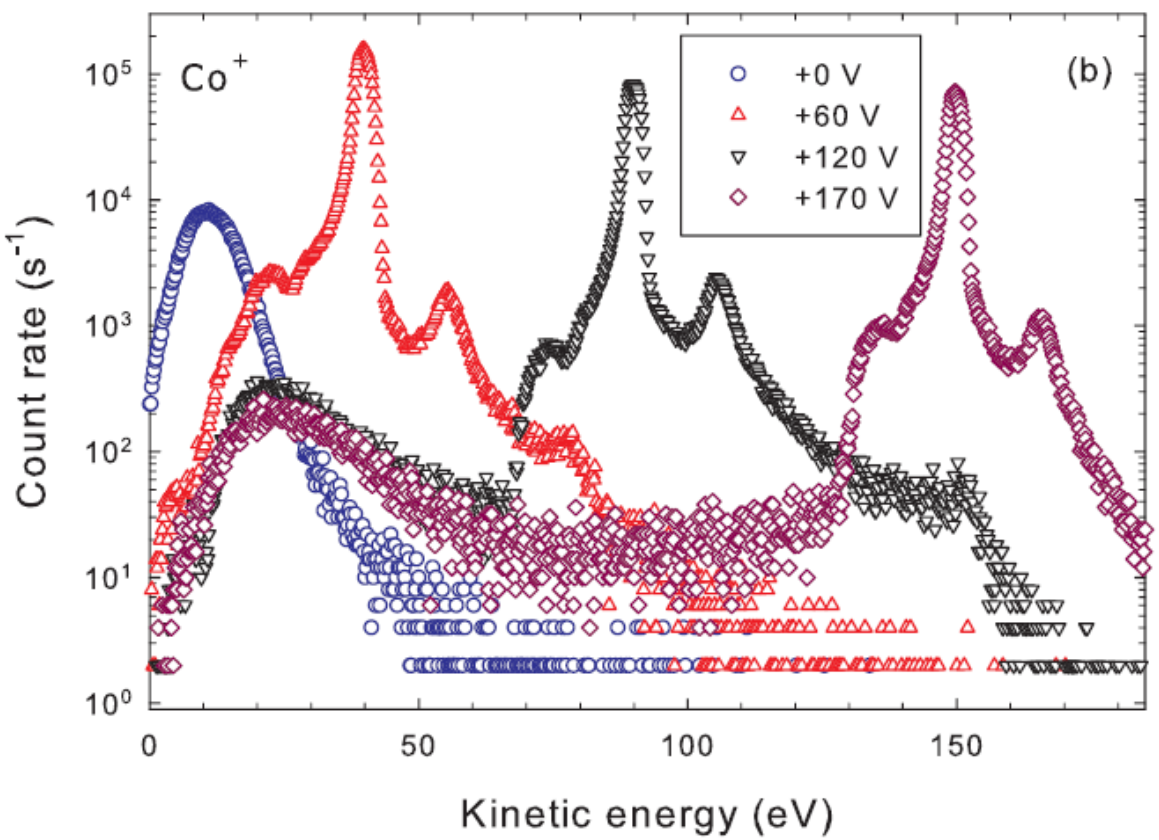
R. Hippler, M. Čada, ... r probe diagnostics of a bipolar high power impulse magnetron sputtering ... 020) 064101.

-ion mass spectrometry with energetic resolution for different values of positive pulse

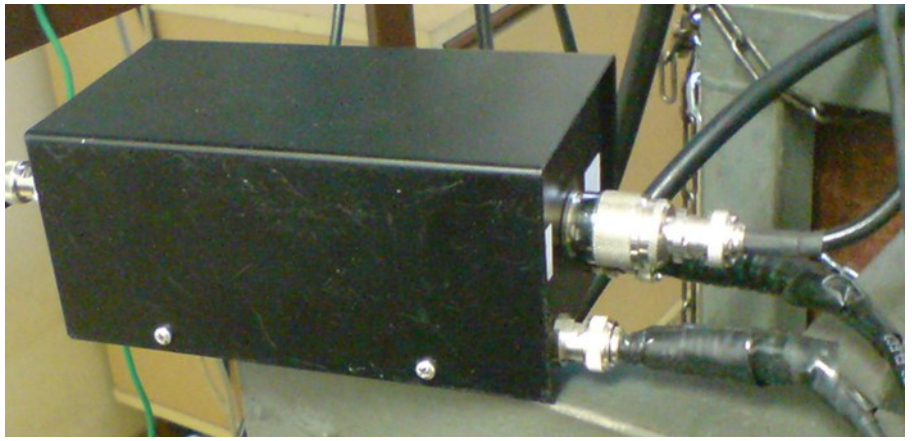


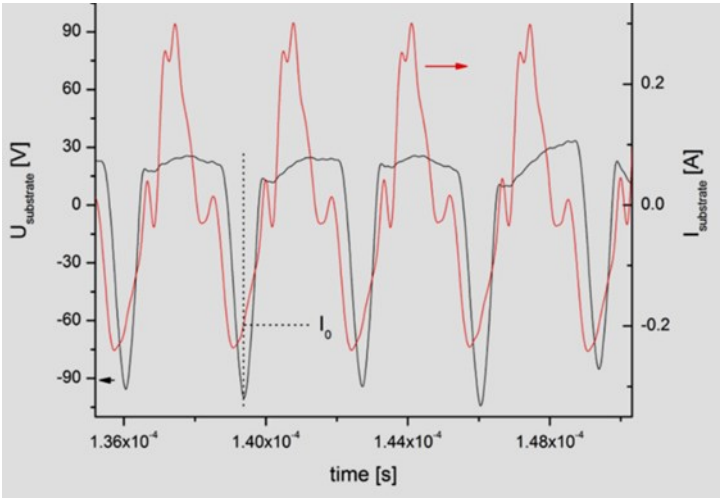


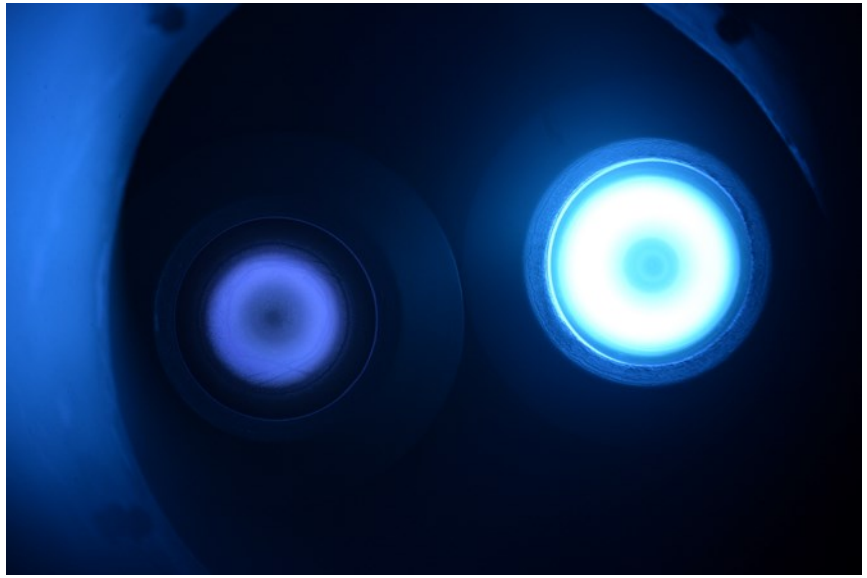
R. Hippler, M. Čada, Z. Hubička, Time-resolved Langmuir probe diagnostics of a bipolar high power impulse magnetron sputtering discharge, Appl. Phys. Lett. 116 (2020) 064101.

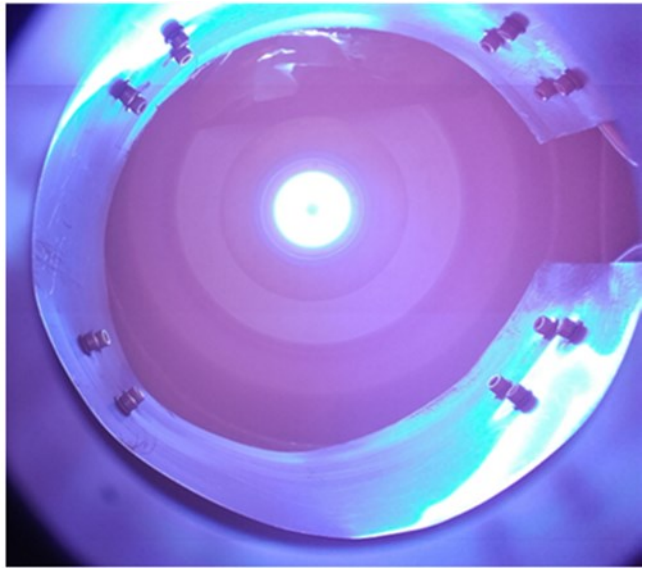
HiPIMS or HiPIMS+ECWR with dual magnetron for alloy and multicomponent thin films

RF planar probe









Akademie věd České republiky

Plasma diagnostics by RF planar probe during the deposition process

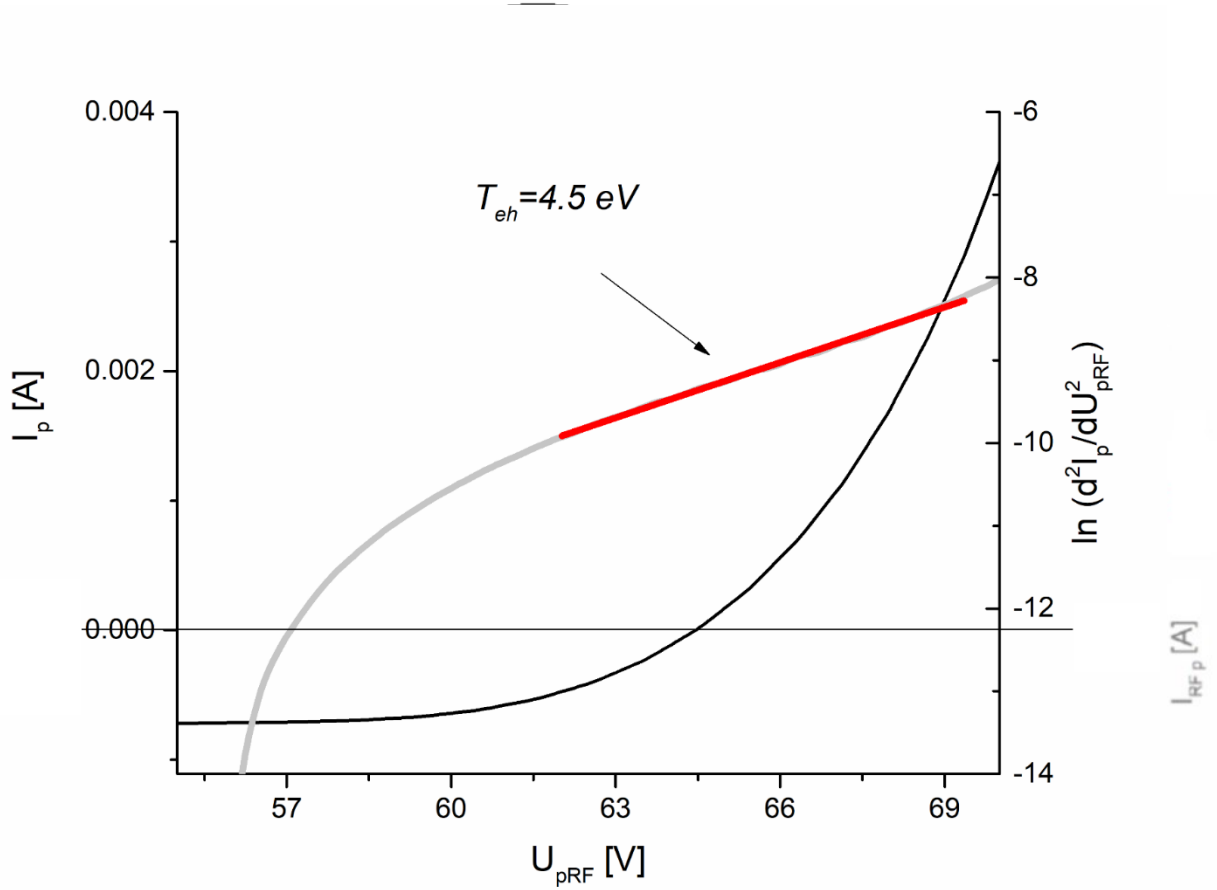
$f_p << f_{ion}$ we can use analytical model

$$i_{ionflux} = e \times n_i \times \sqrt{\frac{k_B T_e}{M_i}} \times 0.6$$

$$I_p(t) = I_{RFp}(t) - C_p(U_{RFp}) \frac{dU_{RFp}}{dt}(t)$$

(1) $\frac{dU_{RFp}}{dt} > 0 \qquad I_{RFp} = I_{SA}(U_{RFp}) = I_p(U_{RFp}) + C_p(U_{RFp}) \frac{dU_{RFpA}}{dt}(U_{RFp})$

(2) $\frac{dU_{RFp}}{dt} < 0 \qquad I_{RFp} = I_{SB}(U_{RFp}) = I_p(U_{RFp}) + C_p(U_{RFp}) \frac{dU_{RFpB}}{dt}(U_{RFp})$



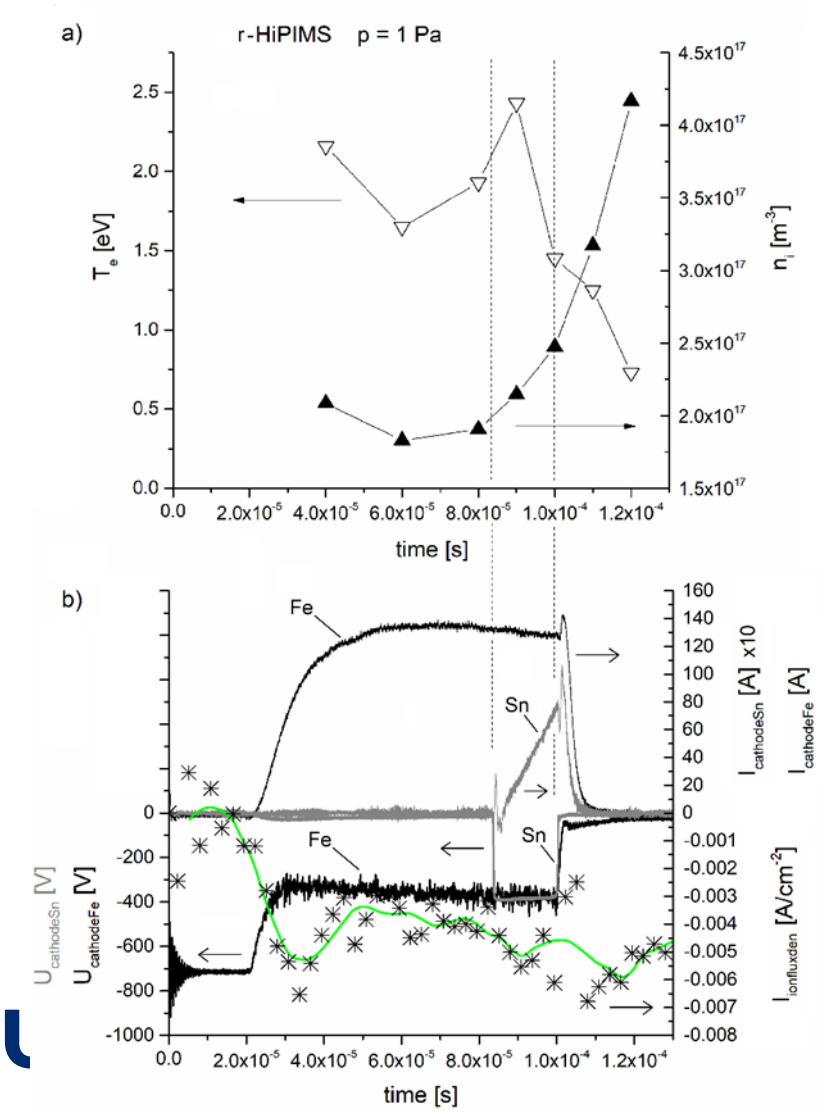
Sezemský, P.; Straňák, V.; Kratochvíl, J.; Čada, M.; Hippler, R.; Hrabovský, M.; Hubicka, Z. Modified high frequency probe approach for diagnostics of highly reactive plasma. *Plasma Sources Sci. Technol.* **2019**, *28*, 115009, doi:10.1088/1361-6595/ab506c.

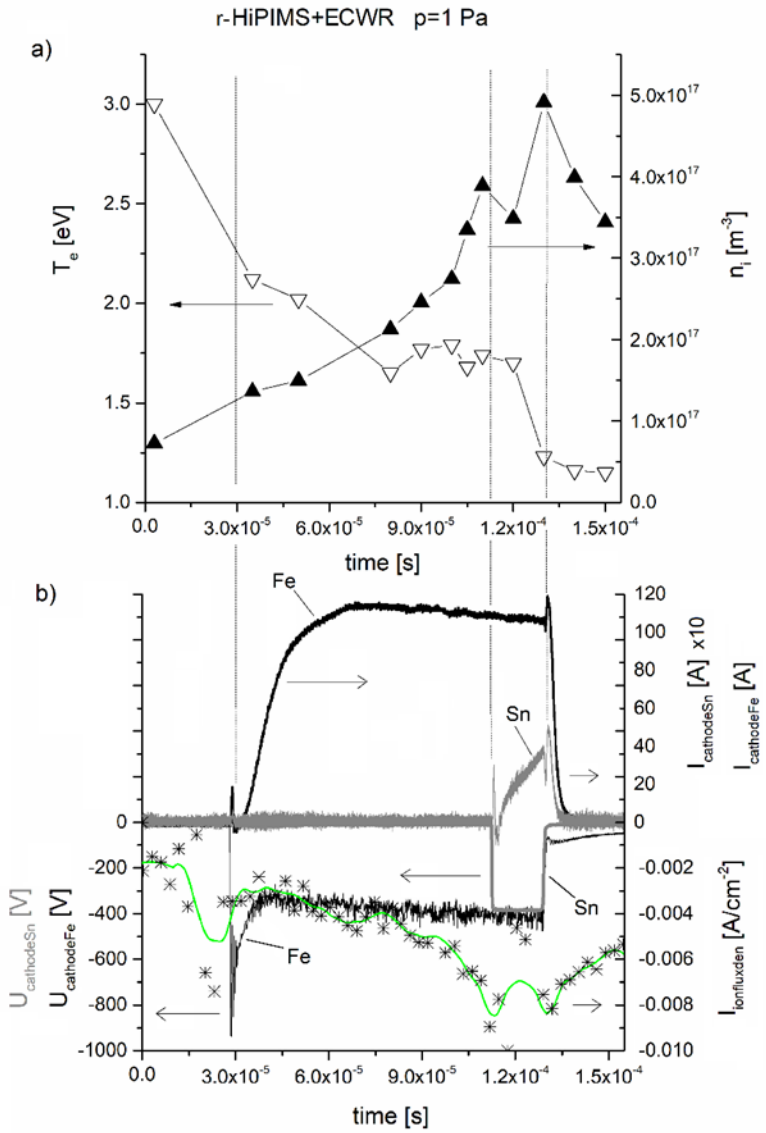
FZU Fyzikální ústav Akademie věd České republiky

Z. Hubička, M, Zlámal, J. Olejníček, D. Tvarog, M. Čada, J. Krýsa, Coatings 10 (2020) 232.

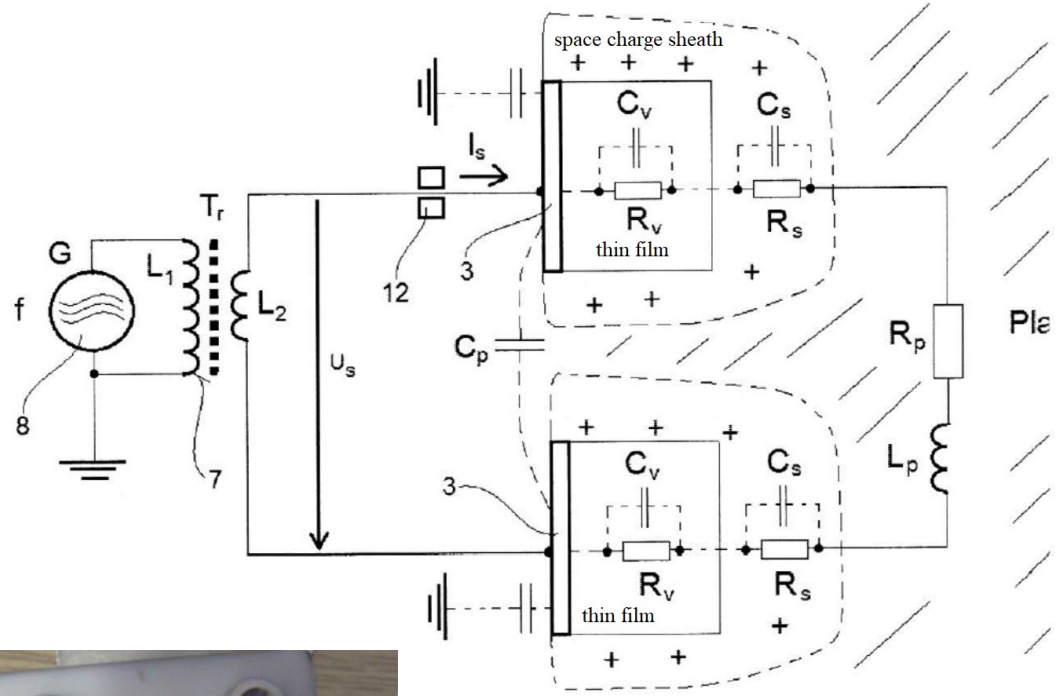
RF probe diagnostics at plasma deposition of Fe_2O_3:Sn semiconducting (n-type) thin films

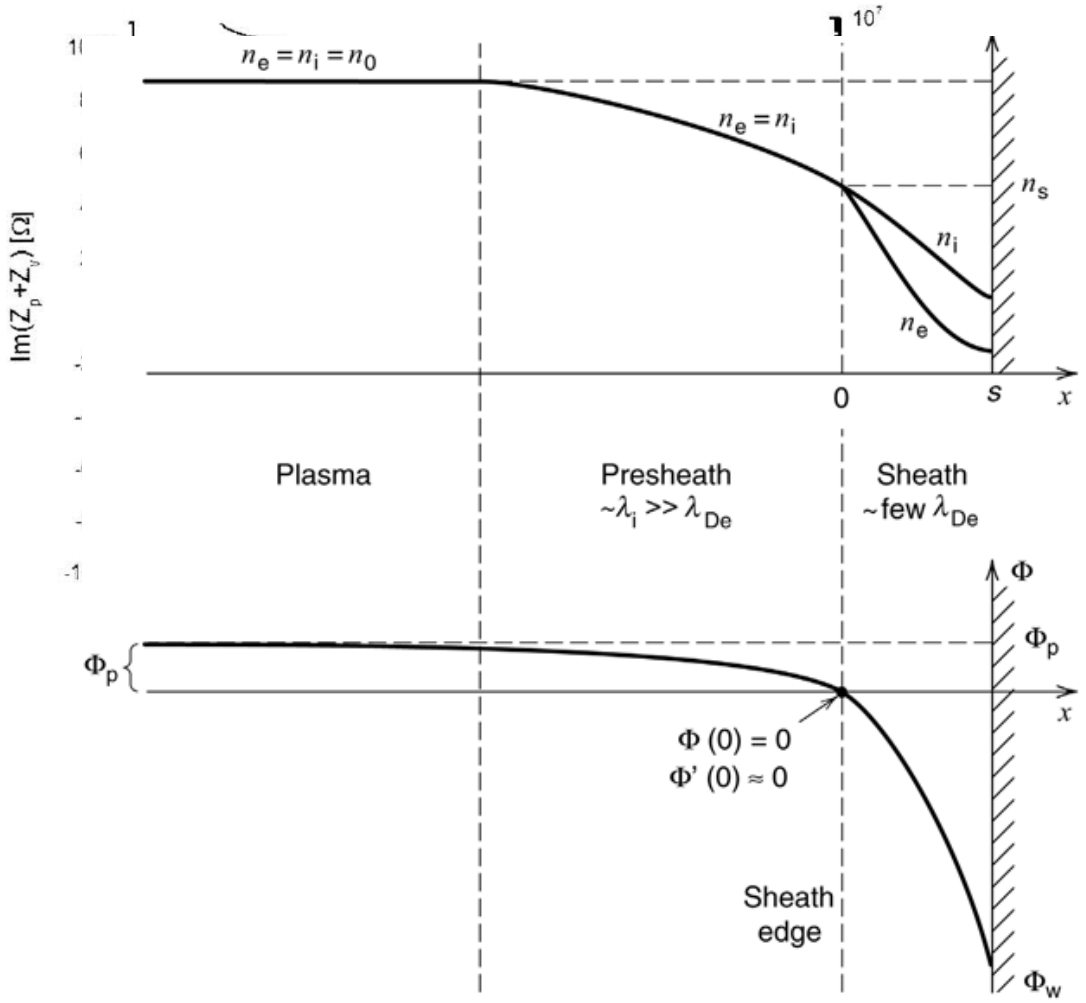
- plasma parameters measured by RF probe in r-HiPIMS and r-HiPIMS+ECWR during deposition





Impedance spectroscopy of system plasma-semiconductor film

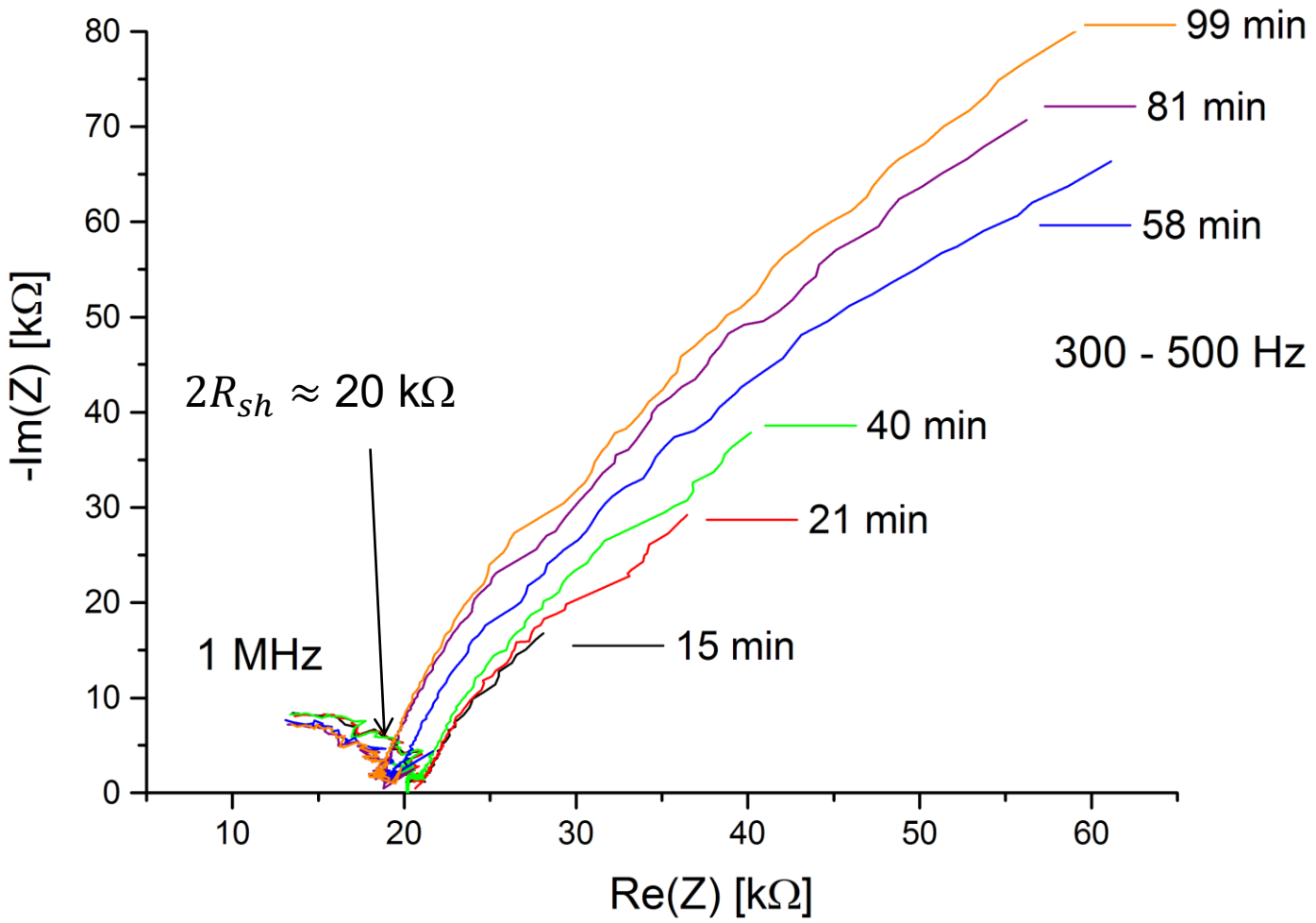




Qualitative behavior of sheath and presheath in contact with a wall.

FZU Fyzikální ústav Akademie věd České republiky

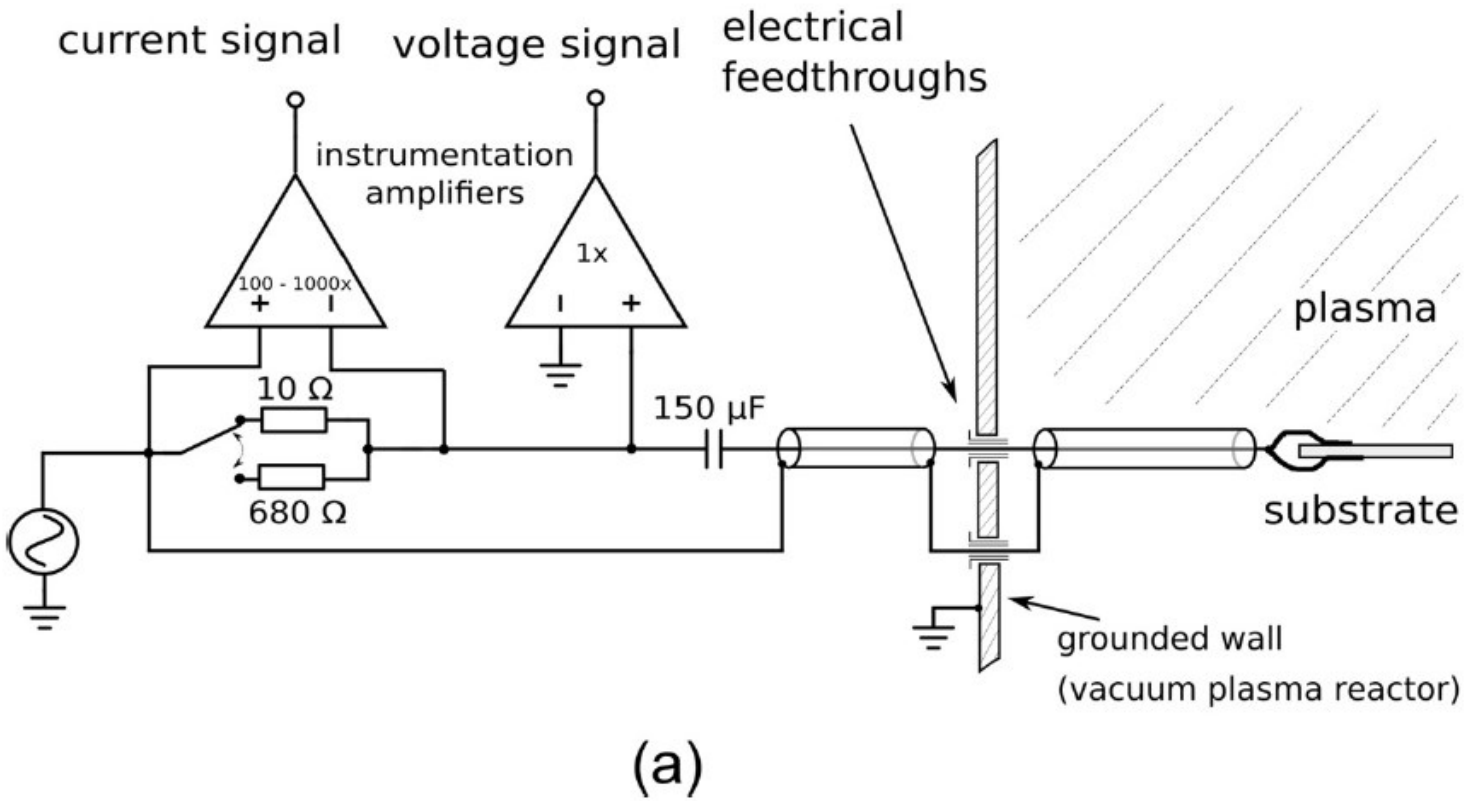
Measurement of impedance spectra during the deposition of TiO_2 by reactive sputtering process



Each frequency dependence (300 values of frequencies equidistant in logarithmic scale) was measured 45 second

FZU Fyzikální ústav Akademie věd České republiky

In-situ impedance spectroscopy of a plasma-semiconductor thin film system during reactive sputter deposition



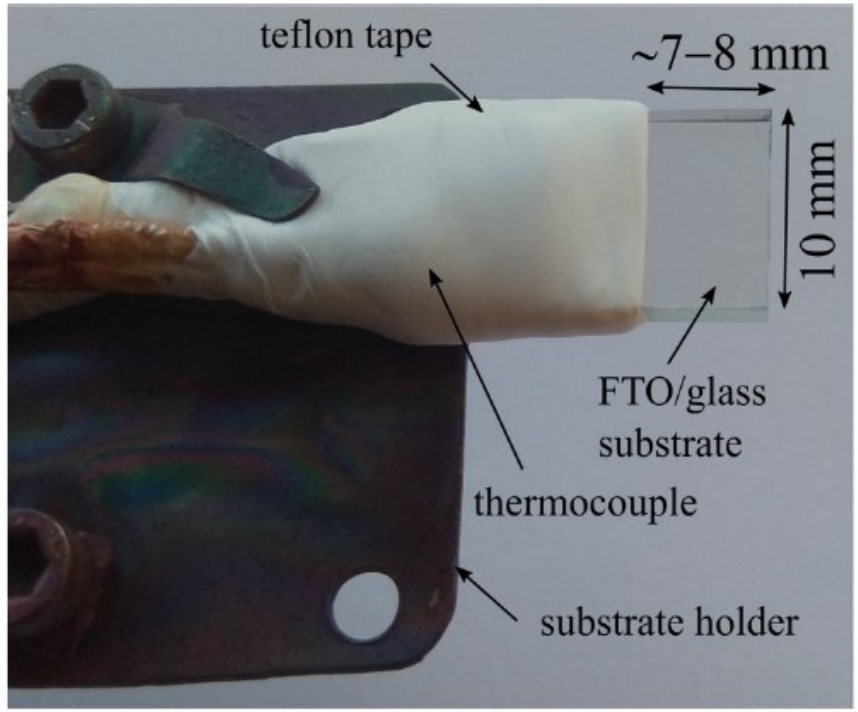


FIG. 3. (a) Measuring circuit together with the connection to the probe/substrate. (b) Photo of the substrate and substrate holder prior to the deposition.

FZU Fyzikální ústav Akademie věd České republiky

M. Zanáška, P. Kudrna, M. Čada, M. Tichý, and Z. Hubička, In-situ impedance spectroscopy of a plasmasemiconductor thin film system during reactive sputter depositionJ. Appl. Phys. 126, 023301 (2019); doi: 10.1063/1.5102163.

J. Morozumi, T. Goya, T. Kuyama, K. Eriguchi, K. Urabe, In situ electrical monitoring of SiO2/Si structures in low-temperature plasma using impedance spectroscopy, Japanese Journal of Applied Physics 62, SI1010 (2023).

In-situ impedance spectroscopy of a plasma-semiconductor thin film system during reactive sputter deposition

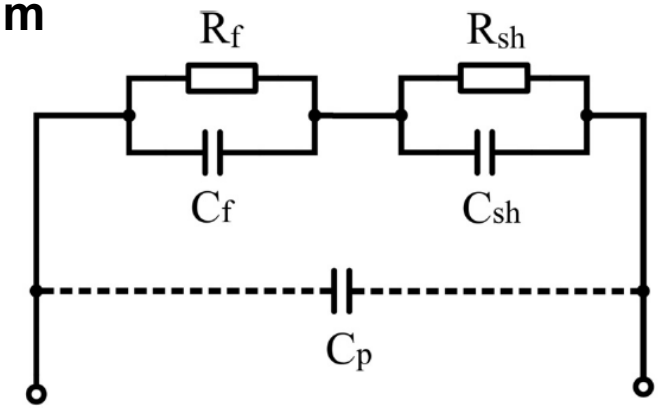
$$Z_f = Z - Z_s = Z - \frac{1}{1/R_s + i\omega C_s}$$

$$\frac{1}{Z_f} = \frac{1}{R_f} + i\omega C_f$$

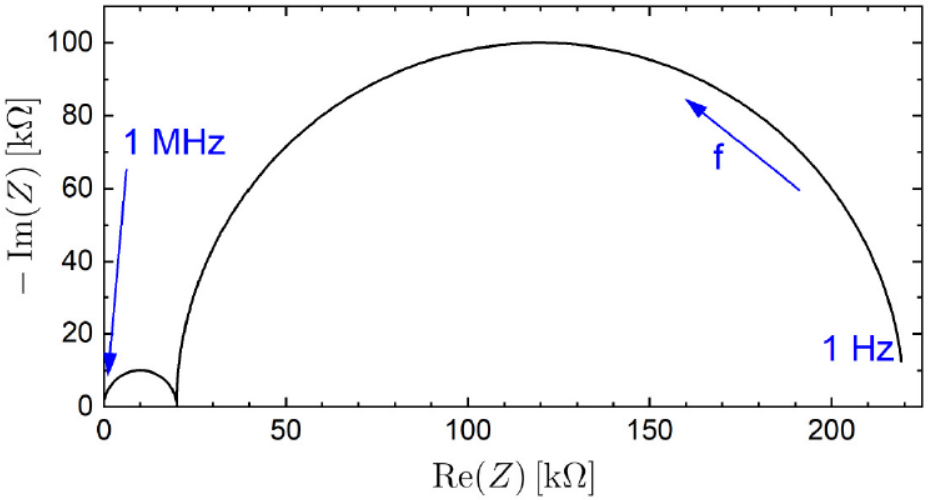
$$\varepsilon_r = \varepsilon_r' - i\varepsilon_r'' = \varepsilon_r' - \frac{i\sigma}{\omega\varepsilon_0},$$

$$C_f = \frac{\varepsilon_0 \varepsilon_r' A}{d}, \qquad R_f = \frac{d}{A\sigma},$$

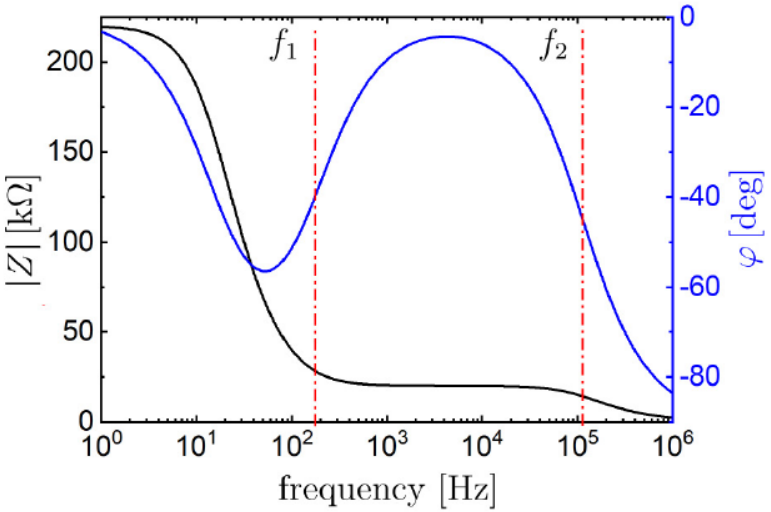
$$\tan\delta = \frac{\varepsilon_r''}{\varepsilon_r'} = \frac{1}{\omega R_f C_f}.$$



Simple equivalent circuit describing the impedance of the deposited thin film and the surrounding plasma sheath together with the parasitic capacitance C_p. R_s and C_s represent the sheath, R_f and C_f represent the deposited film.



(a)



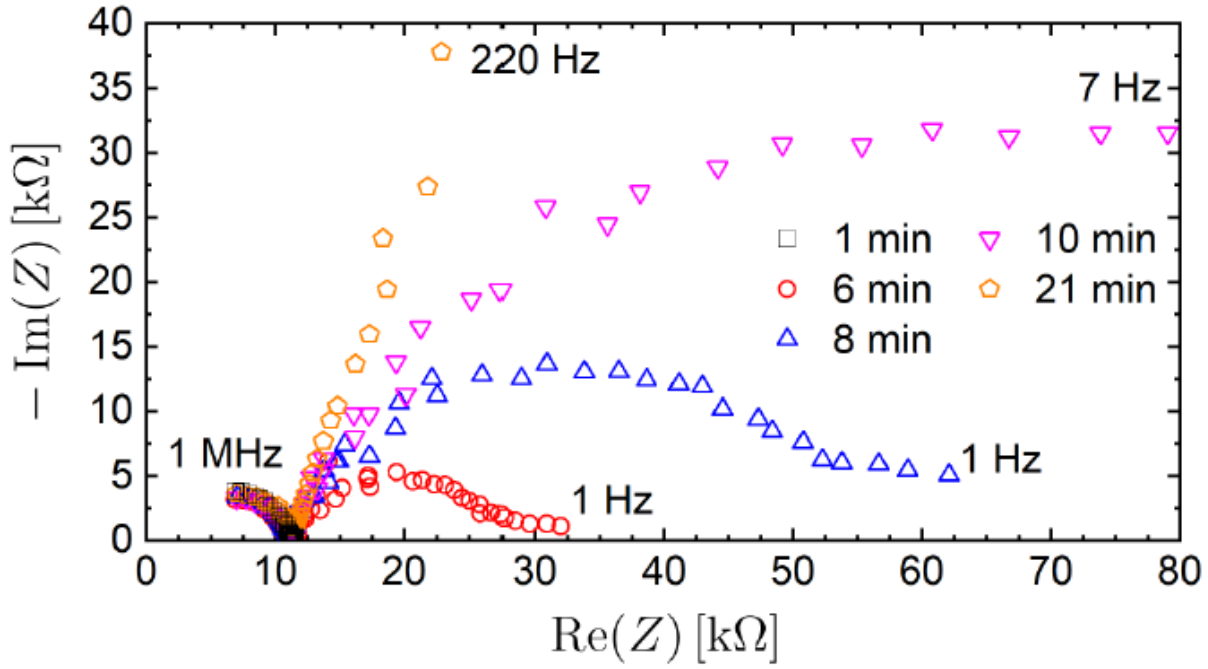
(b)

(a) Nyquist plot and (b) Bode plot of the equivalent circuit depicted in Fig. 1, in the range from 1 Hz to 1 MHz for parameters: $R_s = 20\,k\Omega$, $C_s = 30\,pF$, $C_p = 40\,pF$, $R_f = 200\,k\Omega$, and $C_f = 50\,nF$. At these conditions, the effect of the parasitic capacitance is almost identical to the sheath capacitance, i.e., with changed parameters C_s and C_p such that $C_s + C_p = 70\,pF$, the difference in the spectrum is negligible. Note that the y axis in the Nyquist plot represents the negative imaginary part of the impedance.

M. Zanáška, P. Kudrna, M. Čada, M. Tichý, and Z. Hubička, J. Appl. Phys. 126, 023301 (2019); doi: 10.1063/1.5102163

In-situ impedance spectroscopy of a plasma-semiconductor thin film system during reactive sputter deposition

Results of time evolution of impedance spectra of Fe_2O_3 thin films during the growth process



Nyquist plot of the impedance during the deposition of Fe_2O_3 (#1). The effect of the parasitic capacitance and capacitance of the blocking capacitor has been subtracted. For clarity, we show only the spectra from the first 21 min of the deposition.

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M. Zanáška, P. Kudrna, M. Čada, M. Tichý, and Z. Hubička, J. Appl. Phys. 126, 023301 (2019); doi: 10.1063/1.5102163

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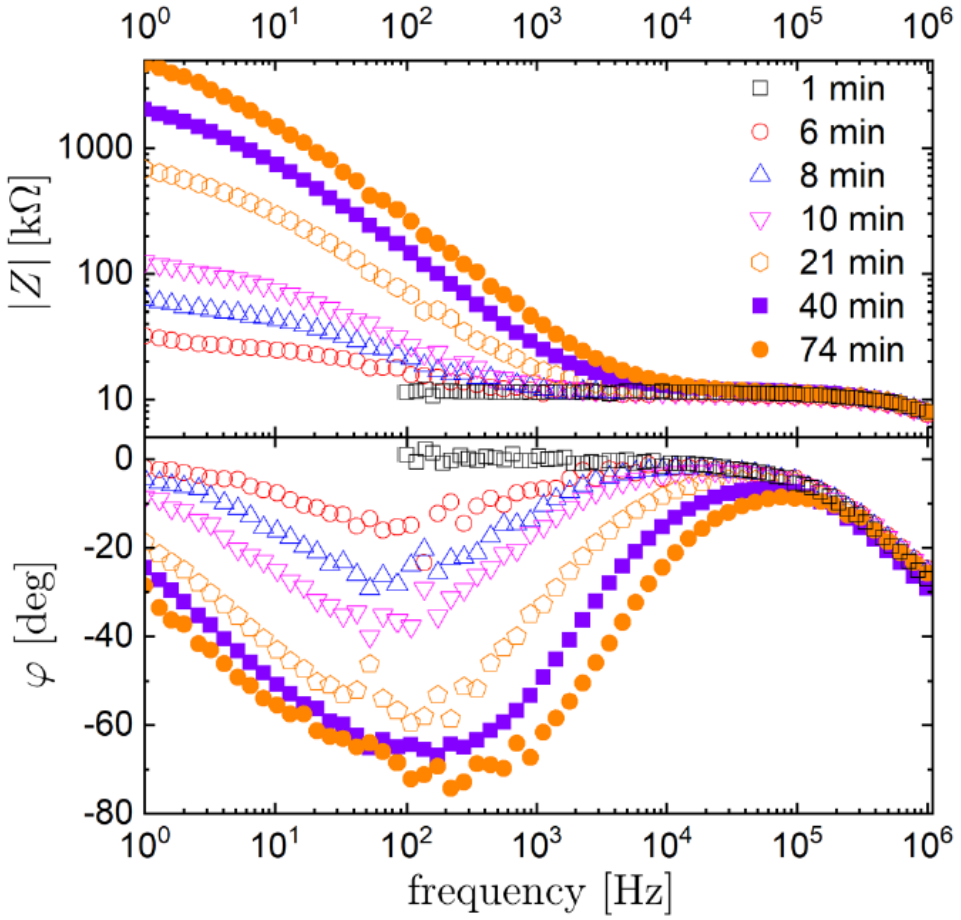

Bode plot of impedance spectra measured during the deposition of the Fe_2O_3 film (#1).

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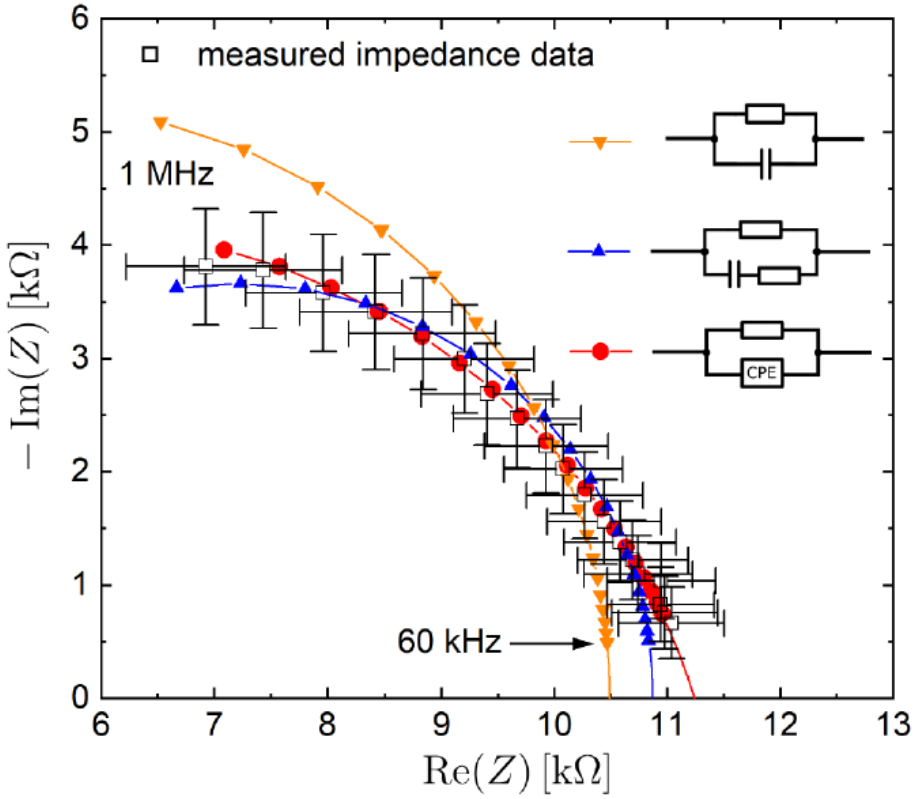
M. Zanáška, P. Kudrna, M. Čada, M. Tichý, and Z. Hubička, J. Appl. Phys. 126, 023301 (2019); doi: 10.1063/1.5102163

In-situ impedance spectroscopy of a plasma-semiconductor thin film system during reactive sputter deposition

Fitting of impedance spectra of Fe_2O_3 thin films with different circuits models



Nyquist plot of impedance spectrum after 1 min of the deposition of the Fe_2O_3 film (#1) and fits of three different models evaluated in the range 60 kHz–1 MHz. The points of the measured data and points at the fitted curves correspond to the same frequencies and indicate the frequency range of the fits. The fitted parameters of the third (red) model [and using Eq. (13)]: $R_s \approx 11.2\,\mathrm{k\Omega}$, $C_s \approx 9\,\mathrm{pF}$, $n \approx 0.8$.

$$Z_{CPE} = Q^{-1}(i\omega)^{-n}$$

$$0 \leq n \leq 1$$

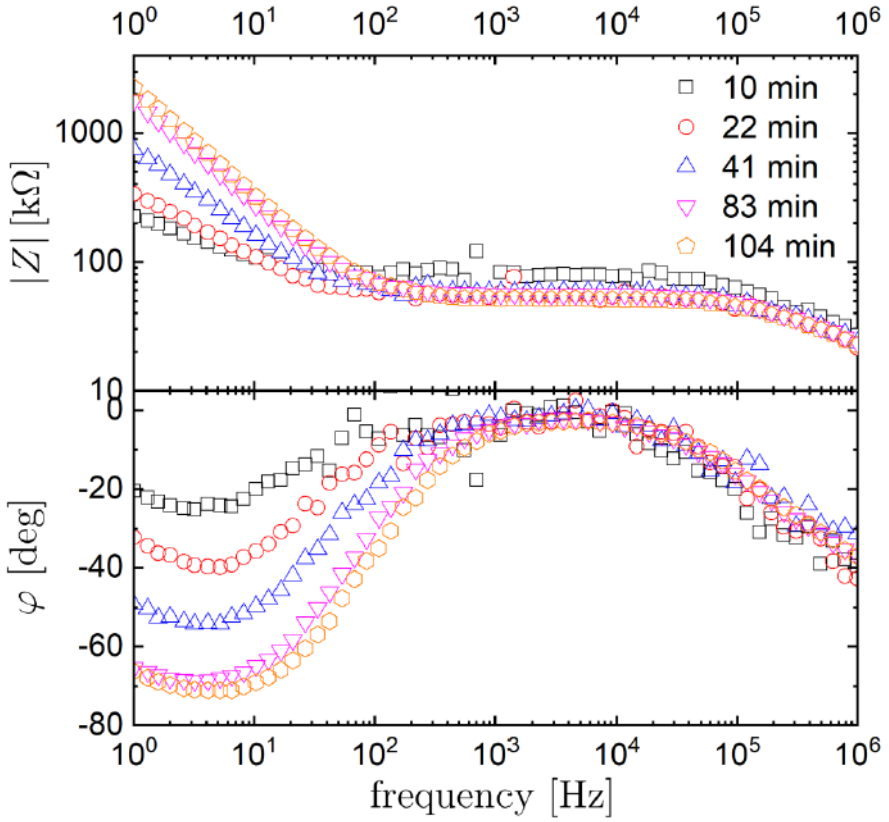
$$C = (QR^{1-n})^{1/n}$$

FZ

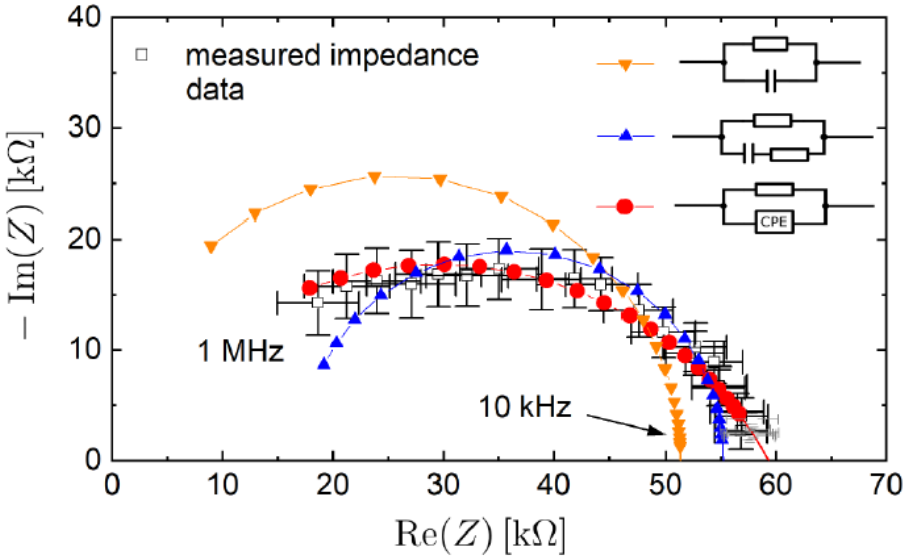
M. Zanáška, P. Kudrna, M. Čada, M. Tichý, and Z. Hubička, J. Appl. Phys. 126, 023301 (2019); doi: 10.1063/1.5102163

In-situ impedance spectroscopy of a plasma-semiconductor thin film system during reactive sputter deposition

Results of time evolution of impedance spectra of TiO_2 thin films during the growth process



Bode plot of impedance spectra measured during the deposition of the TiO_2 film (#3).



Nyquist plot of impedance spectrum during the deposition of TiO_2 (#3) and fits of three different models evaluated in the range 10 kHz–1 MHz. The points of the measured data and points at the fitted curves correspond to the same frequencies and indicate the frequency range of the fits. The fitted parameters of the third (red) model [and using Eq. (13)]: $R_s \approx 59.4\,k\Omega$, $C_s \approx 7\,pF$, $n \approx 0.7$.

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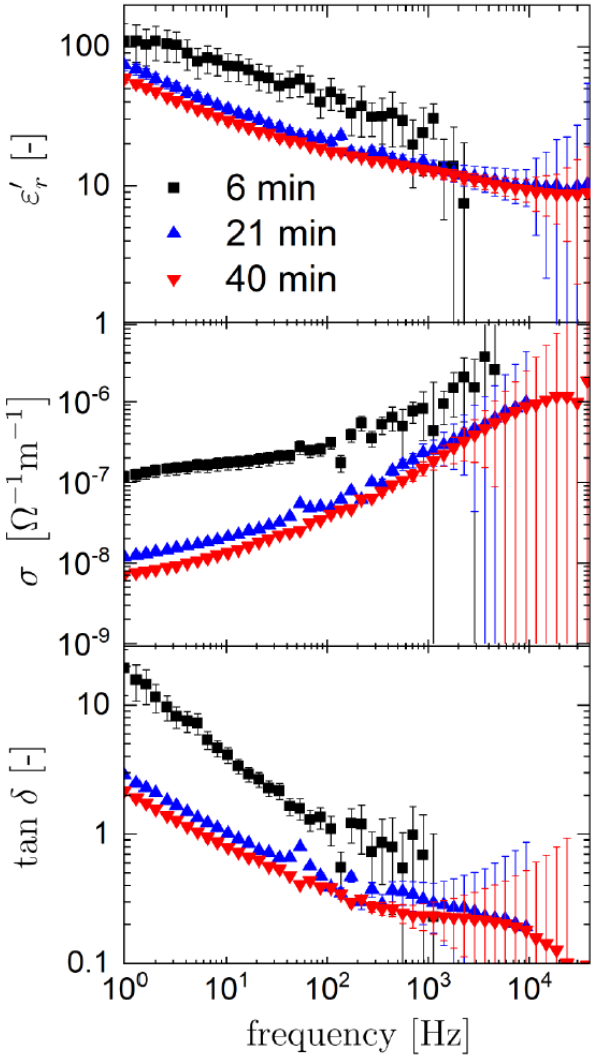
M. Zanáška, P. Kudrna, M. Čada, M. Tichý, and Z. Hubička, J. Appl. Phys. 126, 023301 (2019); doi: 10.1063/1.5102163

Dielectric properties of the deposited films (Fe_2O_3)

thickness measured in time by QCM



Frequency dependence of the real part of the dielectric constant, conductivity, and dielectric loss of the deposited Fe_2O_3 (#1) film for three instants during the deposition. These data were retrieved from the impedance spectra shown in Figs. 4 and 5.

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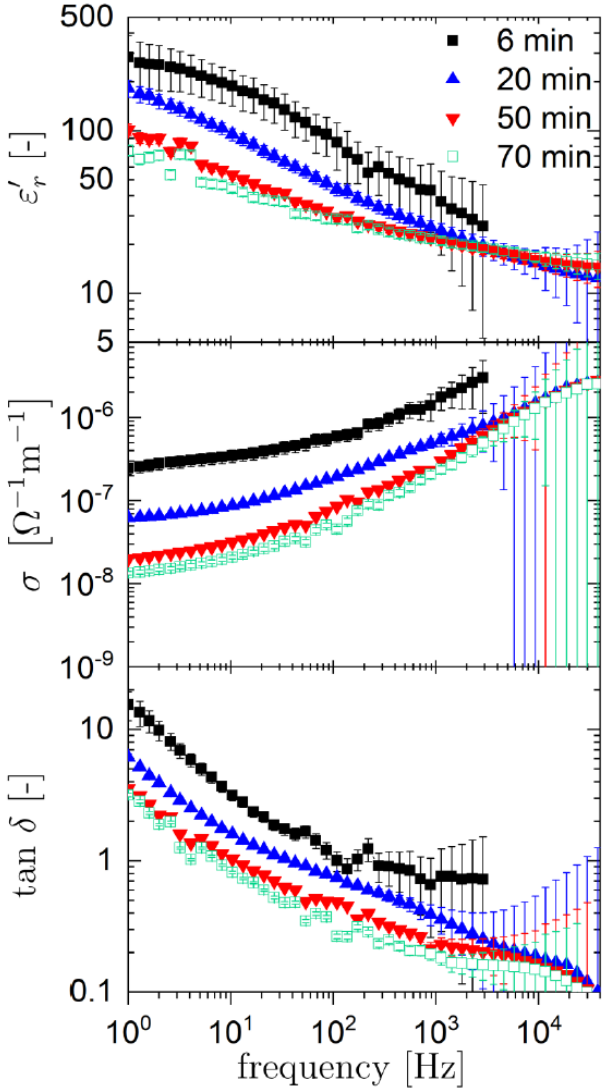
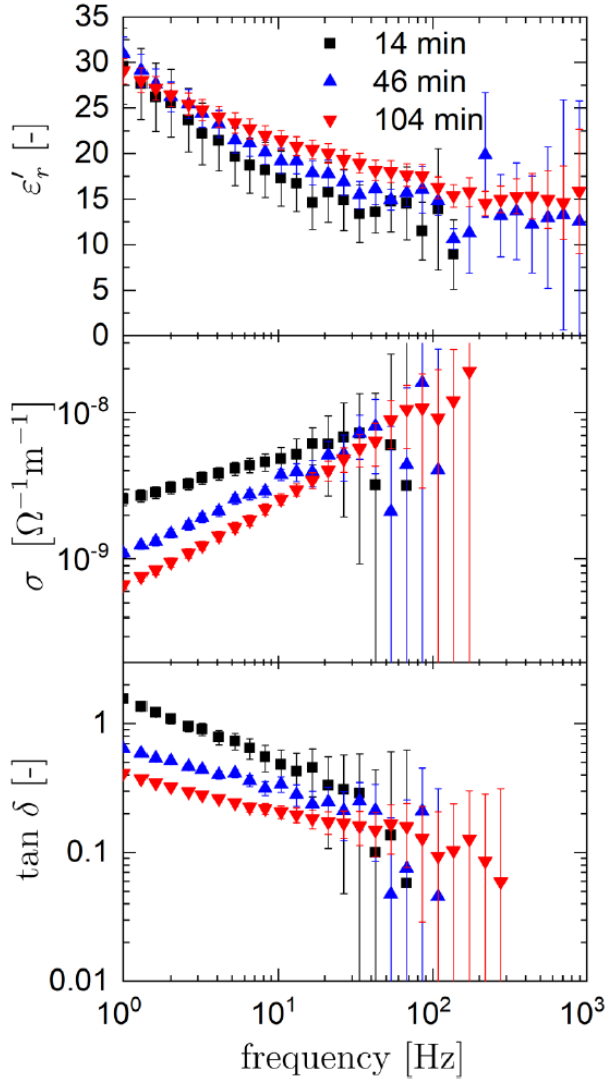
M. Zanáška, P. Kudrna, M. Čada, M. Tichý, and Z. Hubička, J. Appl. Phys. 126, 023301 (2019); doi: 10.1063/1.5102163

Dielectric properties of the deposited films (TiO_2)

thickness measured in time by QCM



Frequency dependence of the real part of the dielectric constant, conductivity, and dielectric loss of the deposited TiO_2 (#2) film for four instants during the deposition.



Frequency dependence of the real part of the dielectric constant, conductivity, and dielectric loss of the deposited TiO_2 film (#3) for three instants during the deposition.

M. Zanáška, P. Kudrna, M. Čada, M. Tichý, and Z. Hubička, J. Appl. Phys. 126, 023301 (2019)

RF probe + impedance spectroscopy + QCM ionmeter ⟶ international cooperation

- Dr. Daniel Lundin and professor Henrik Pedersen, University of Linkoping Sweden

Plasma assisted CVD metal deposition - plasma diagnostics by RF probe

- Professor Tiberiu Minea, Paris-Sud University, France

plasma diagnostics of HiPIMS plasma by ionmeter and RF probe (Ph.D student Anna Kapran)

- Dr. Daniel Lundin Ionautics

RF probe and plasma impedance spectroscopy of reactive HiPIMS deposition process

New international projects from RA1 and RA2:

- International scientific project between Institute of Physics CAS and Osaka University Japan focused on the research of thin film optical detectors

- M-ERA.NET project with EU partners (research institutions, industrial companies)

Smart industrial synthesis of transparent protective oxide thin films through plasma process control

- Horizon EU project with EU partners (research institutions, industrial companies)

Dr. Daniel Lundin and professor Henrik Pedersen, University of Linkoping Sweden

“New plasma sources for CVD and ALD” (search for suitable call)

SOLID21
RA 3: Heusler alloys with outstanding magnetic and magnetooptic propertiestitle

Ján Lančok

FZU Fyzikální ústav Akademie věd České republiky

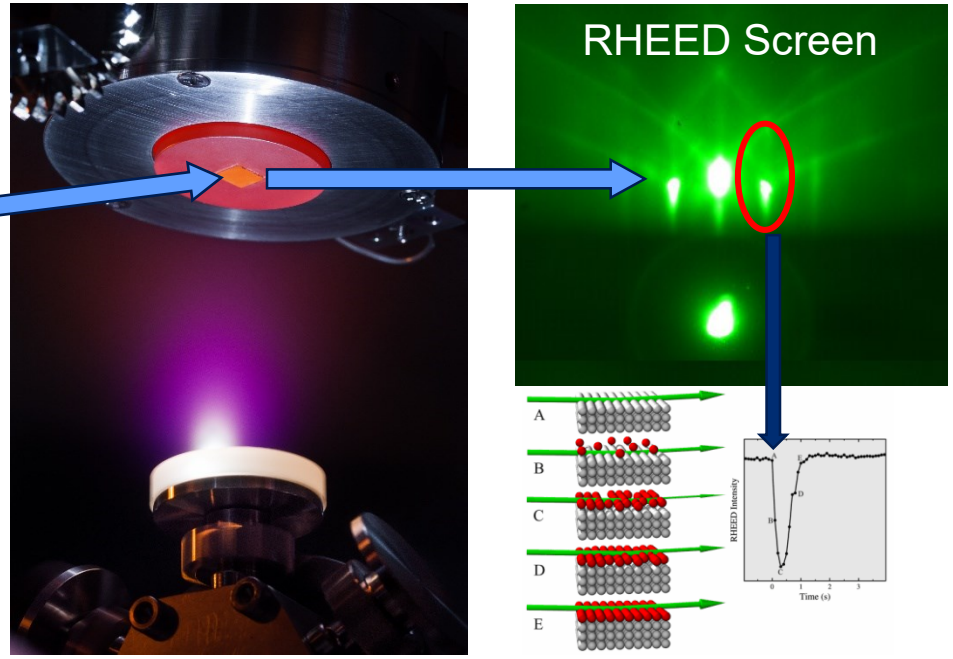
The project Solid state physics for the 21st century – SOLID21
CZ.02.1.01/0.0/0.0/16_019/0000760 is co-funded by the European Union.

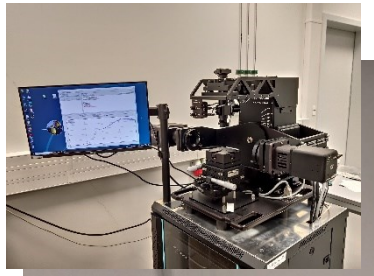
EVROPSKÁ UNIE
Evropské strukturální a investiční fondy
Operační program Výzkum, vývoj a vzdělávání

MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

VP5-RA3-6

Pulsed Laser Deposition system with high pressure RHEED - Laser-MBE equipped with: in-situ ellipsometr, heating up to 1100°C, transfer under UHV for NanoESCA and STM





- Growing of high quality ferroelectric thin films such as $SrTiO_3$, $BaTiO_3$
- Multitferroic system based on heterostructures MnO-NiO RA6 - (VP2)
- Heuller alloys Co_2TiSn for magnetooptics, Rh_2MnSb for spintronics RA3 - (VP1)
- Crystalline garnets and oxides doped with rare earth (VP3)

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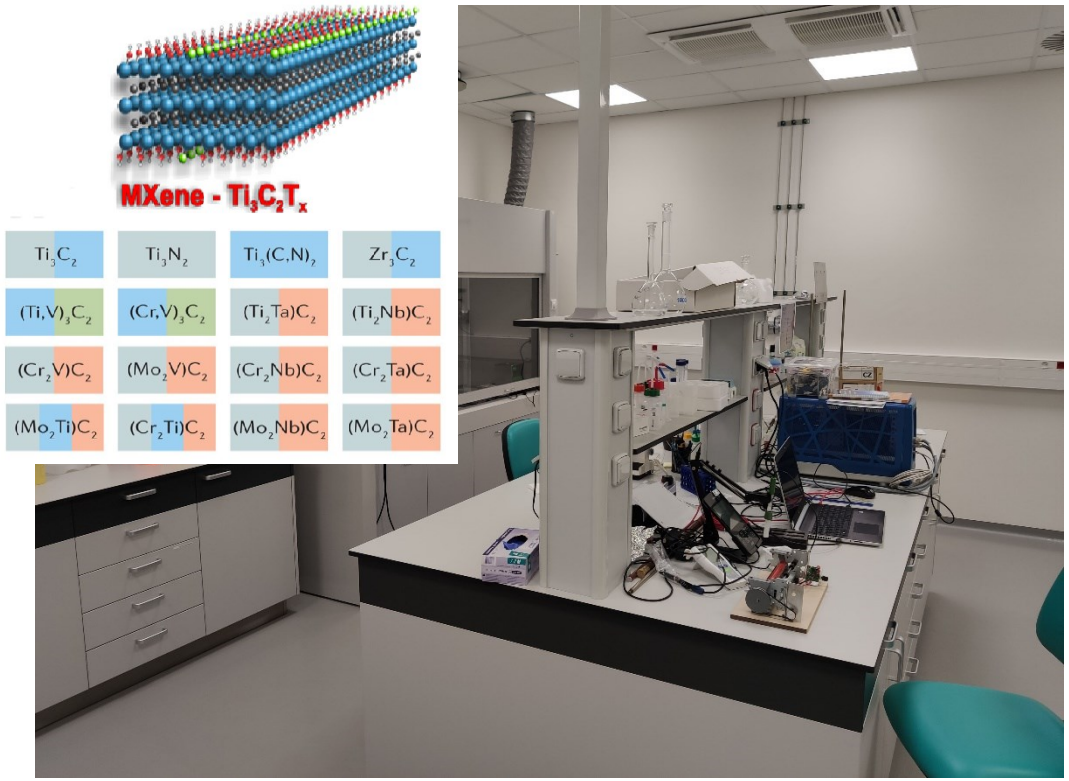
Evropské strukturální a investiční fondy
Operační program Výzkum, vývoj a vzdělávání

MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

The project Solid state physics for the 21st century – SOLID21 CZ.02.1.01/0.0/0.0/16_019/0000760 is co-funded by the European Union.

Laboratory for Mxene – 2D materials



Recently the great attention of the material community was paid on the family of 2D transition metal carbides, carbonitrides and nitrides (collectively referred to as MXenes).

$$\mathbf{M}_{n+1}\mathbf{X}_n\mathrm{T}_x\ (n=1–3)$$

M represents an early transition metal (such as Sc, Ti, Zr, Hf, V, Nb, Ta, Cr, Mo and so on),
X is carbon and/or nitrogen and
T_x stands for the surface terminations (for example, hydroxyl, oxygen or fluorine).

Publications

Plasmon coupling inside 2D-like TiB_2 flakes for water splitting half reactions enhancement in acidic and alkaline conditions	Zabelina, A., Miliutina, E., Zabelin, D., (...), Švorčík, V., Lyutakov, O.	2023	Chemical Engineering Journal 454,140441
Chiral Plasmonic Response of 2D $Ti_3C_2T_x$ Flakes: Realization and Applications *Open Access*	Olshtrem, A., Panov, I., Chertopalov, S., (...), Vana, J., Lyutakov, O.	2023	Advanced Functional Materials
Covalent functionalization of Ti_3C_2T MXene flakes with Gd-DTPA complex for stable and biocompatible MRI contrast agent	Neubertova, V., Guselnikova, O., Yamauchi, Y., (...), Chertopalov, S., Lyutakov, O.	2022	Chemical Engineering Journal 446,136939
Design of hybrid Au grating/TiO_2 structure for NIR enhanced photo-electrochemical water splitting	Zabelin, D., Zabelina, A., Miliutina, E., (...), Svorcik, V., Lyutakov, O.	2022	Chemical Engineering Journal 443,136440
Plasmon-assisted MXene grafting: Tuning of surface termination and stability enhancement *Open Access*	Olshtrem, A., Chertopalov, S., Guselnikova, O., (...), Svorcik, V., Lyutakov, O.	2021	2D Materials 8(4),045037
Surface plasmon-polariton triggering of $Ti_3C_2T_{:X}$ MXene catalytic activity for hydrogen evolution reaction enhancement	Zabelina, A., Zabelin, D., Miliutina, E., (...), Chertopalov, S., Lyutakov, O.	2021	Journal of Materials Chemistry A 9(33), pp. 17770-17779

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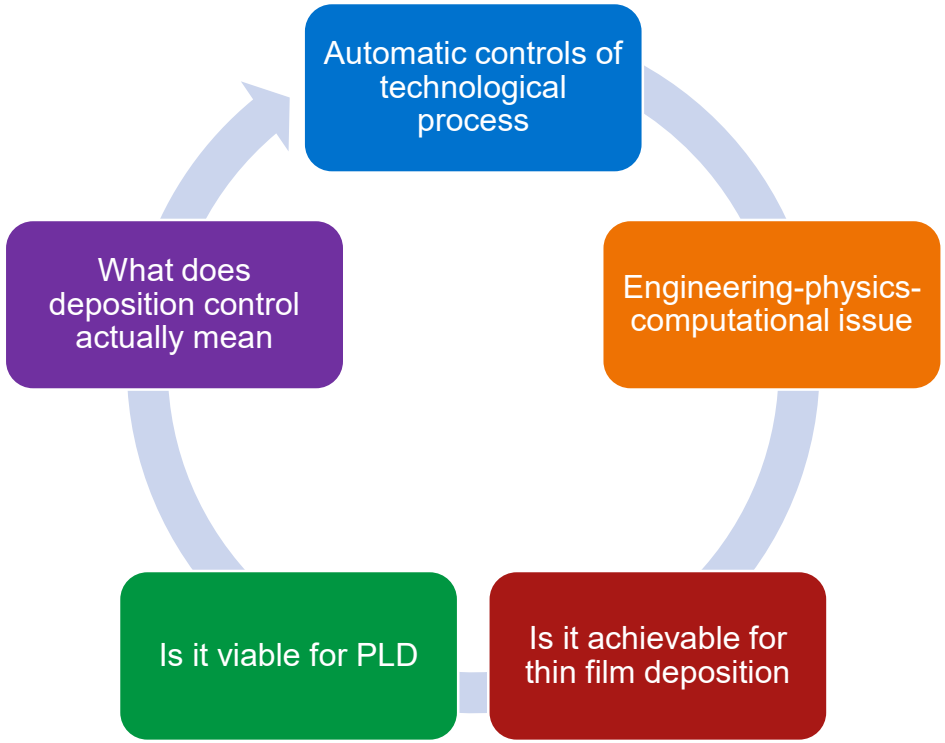
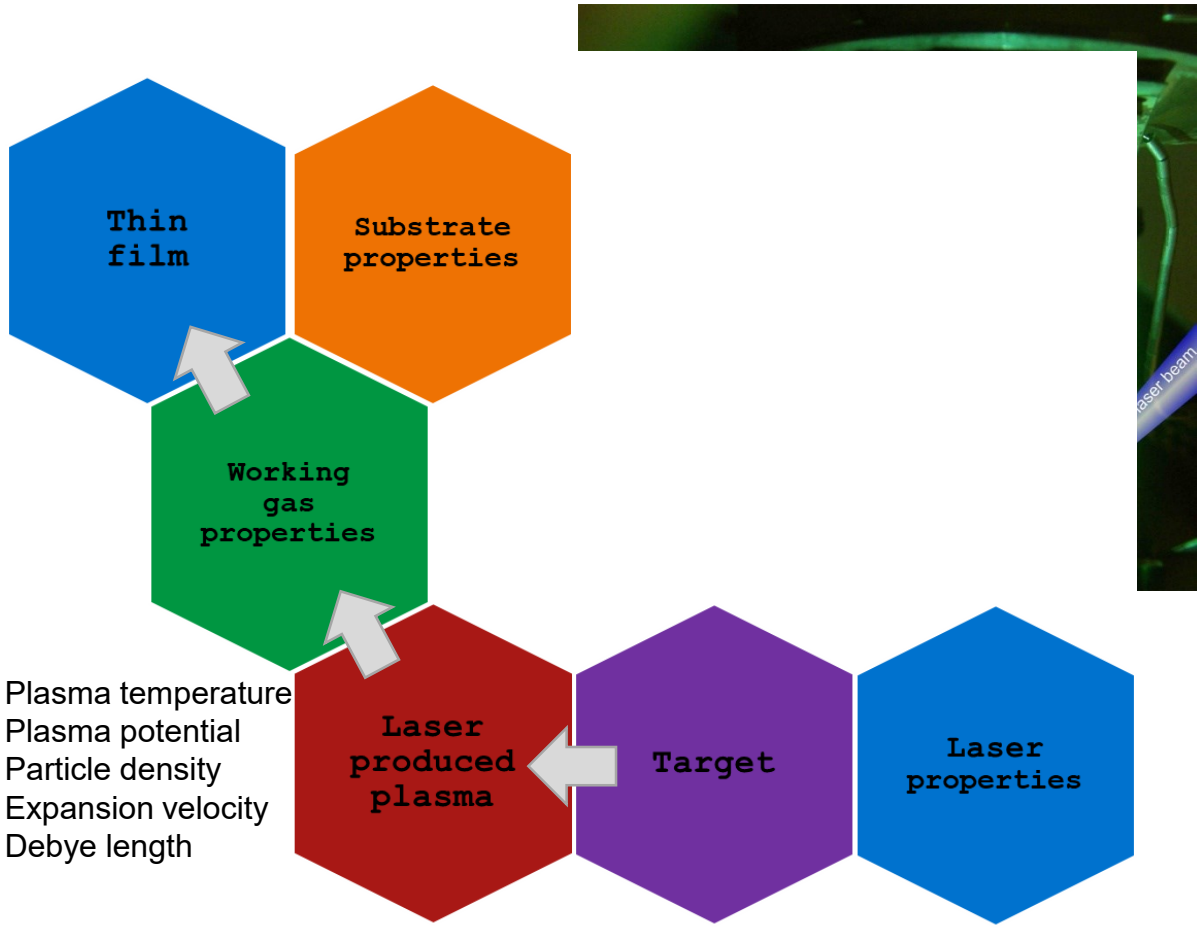
In-situ plasma diagnostics during PLD Toward the PLD automatiszation



Industry 4.0 is **the digital transformation of manufacturing and related industries and value creation processes.**

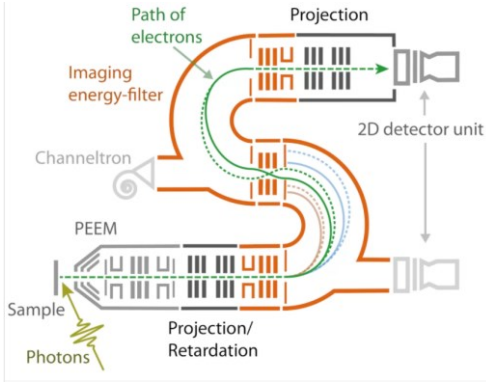
Langmuir probe method in its angular and time-resolved setup, combined with Optical em. Sp.

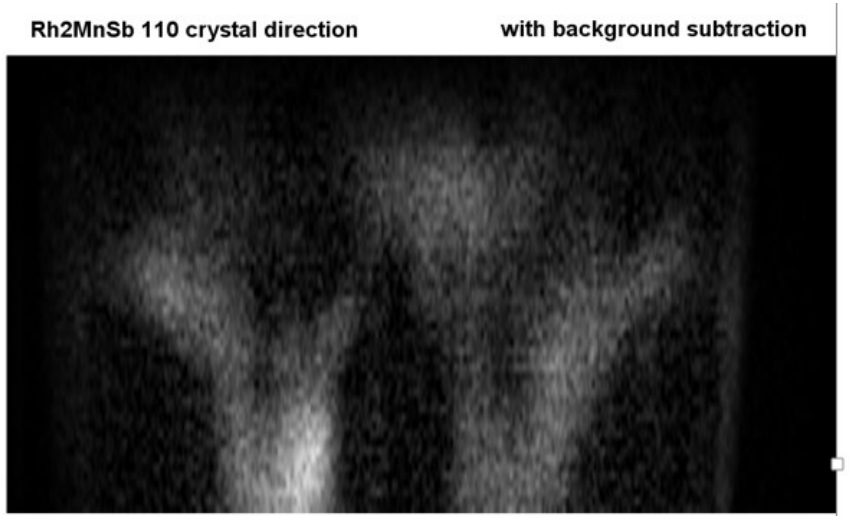


S.A. Irimiciuc et. al.

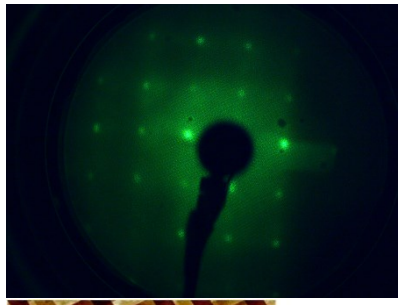
- Plasma Processes and Polymers e (2022) 2100102(1)-2100102(14).
- Vacuum 193 (2021) 110528(1)-110528(10)
- Coatings 11 (2021) 762(1)-762(17)
- Materials 14 (2021) 7336(1)-7336(13)

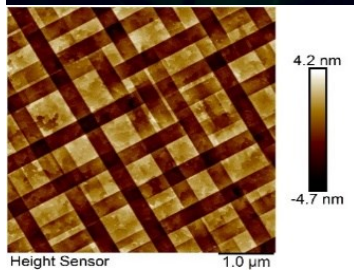
RA 3: Heusler alloys and thin metalic fim –VP1



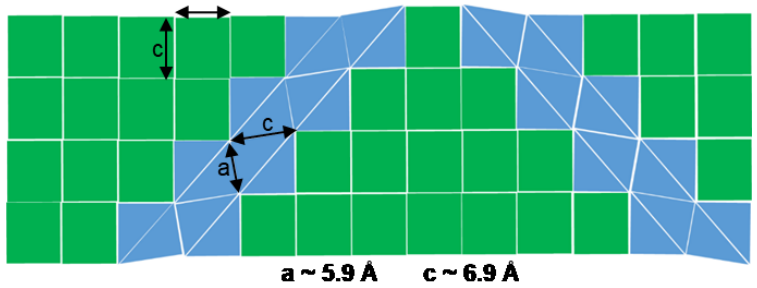


- **UHV deposition chamber for magnetron sputtering**
- **UHV suitcase for transport to under UHV conditions to NanoESCA – XPS, ARPES**

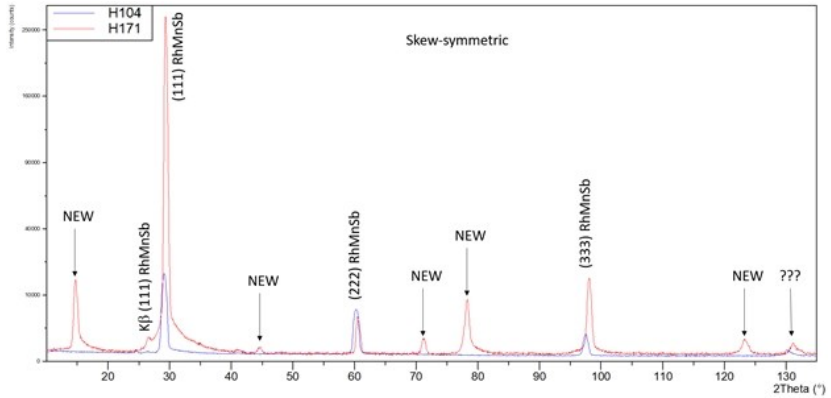




Rh_2MnSb, RhMnSb, Co_2TiSn



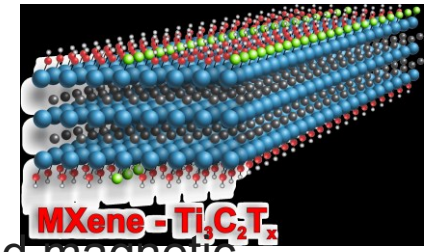
- Superstructural ordering of Heusler alloys PRB 105 (2022) 184106



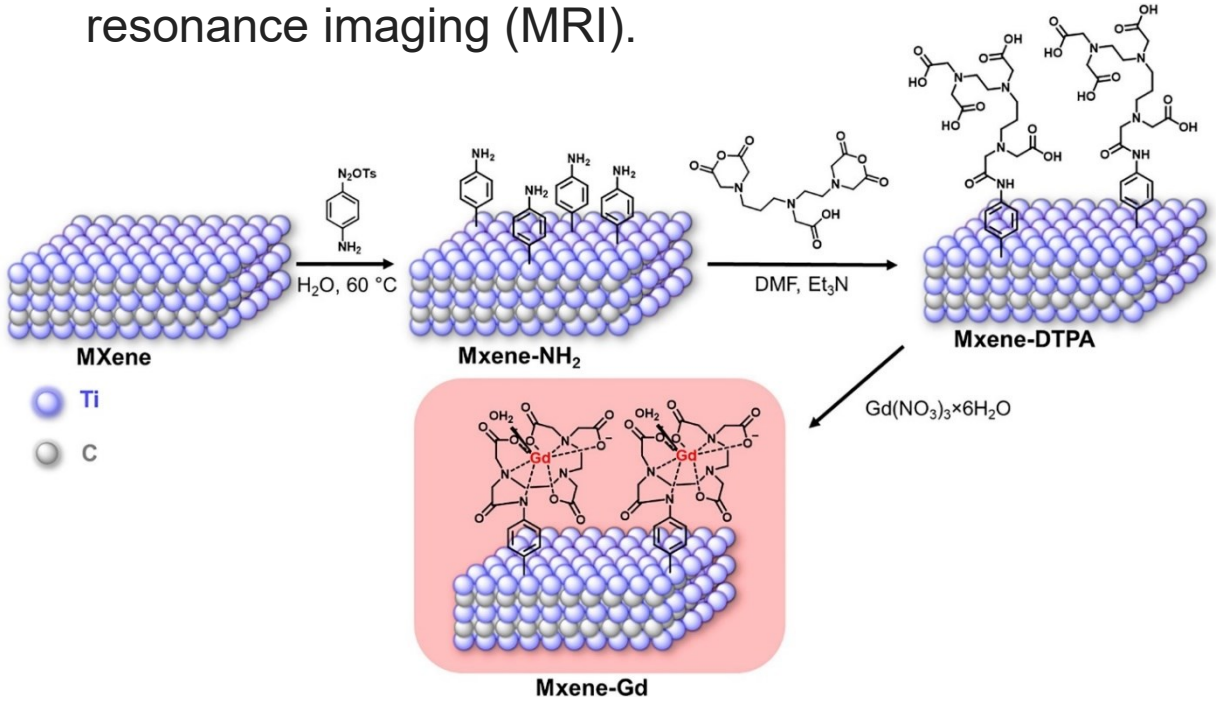
FZU Fyzikální ústav Akademie věd České republiky

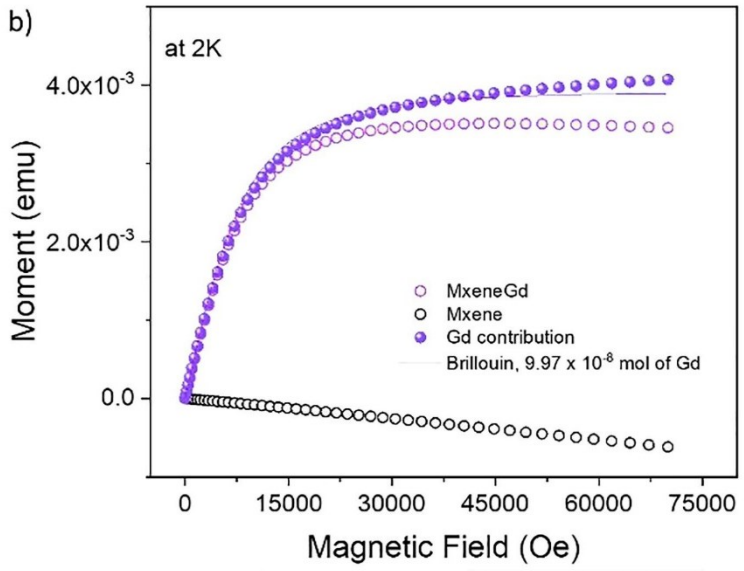
M5.15 Preparation of Heusler alloys with non-stoichiometry and defects in crystal lattices with extraordinary magnetic and optical properties

Ti_3C_2 MXene films – plasmon-assisted surface modification and properties tuning



Modified MXene as a material for positron emission tomography, computed tomography, and magnetic resonance imaging (MRI).





paramagnetic

diamagnetic

- J. Lancok, S. Chertopalov, O. Lyutakov et al. Chemical Engineering Journal, 2022.

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The project Solid state physics for the 21st century – SOLID21 CZ.02.1.01/0.0/0.0/16_019/0000760 is co-funded by the European Union.

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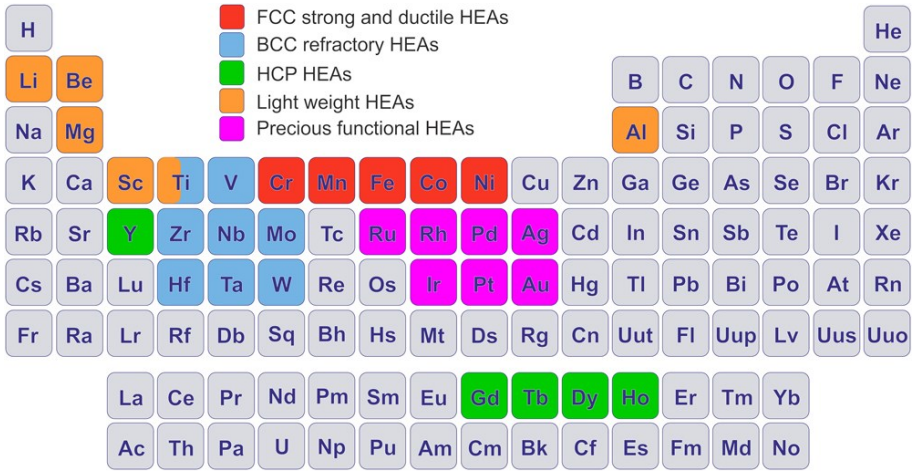
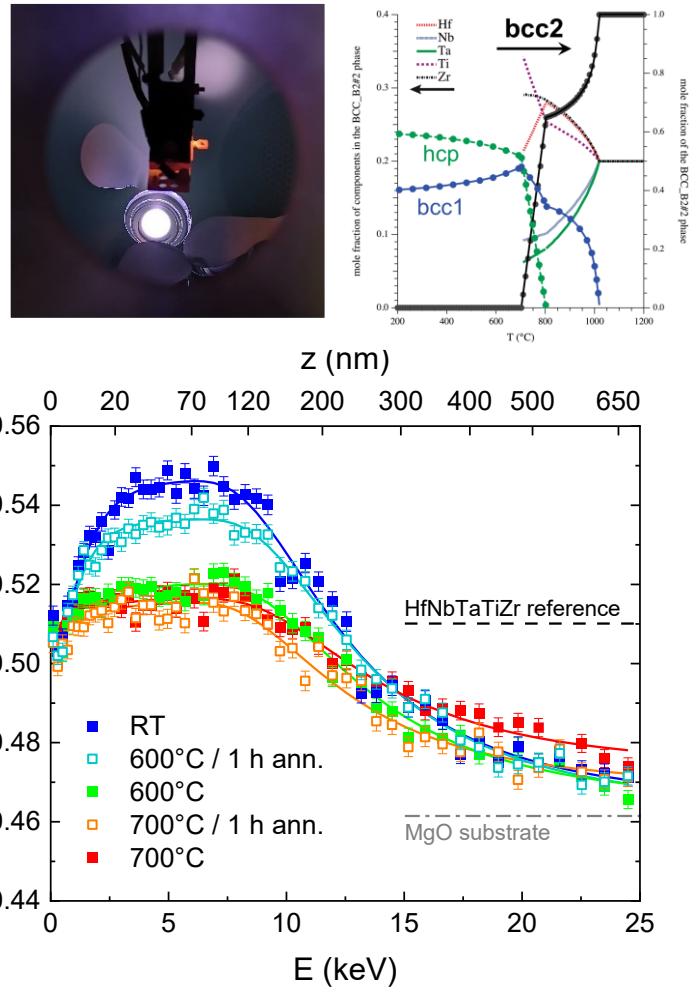
MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

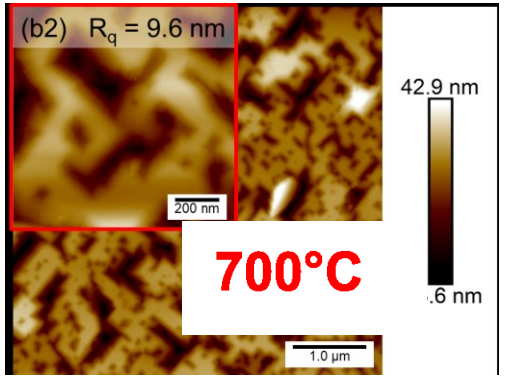
High-entropy Alloys (HEAs) thin films

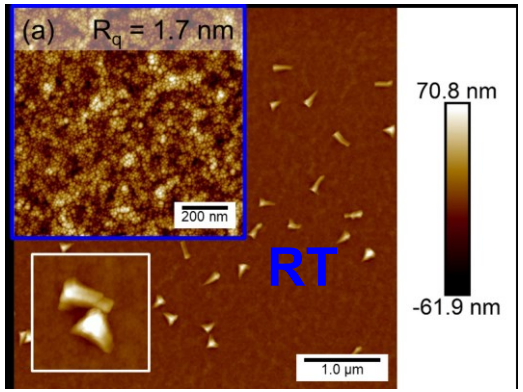
HEAs represent a new type of materials with

a unique combination of physical properties originating from the occurrence of single-phase solid solutions of numerous elements.









FZU Fyzikální ústav Akademie věd České republiky

- Hruška P., Lukáč F., Cichoň S., et al., J. Alloys Compds. 869 (2021) 157978

RA 4: Thin-film chemical sensors

Michal Novotný

FZU Fyzikální ústav Akademie věd České republiky

The project Solid state physics for the 21st century – SOLID21 CZ.02.1.01/0.0/0.0/16_019/0000760 is co-funded by the European Union.

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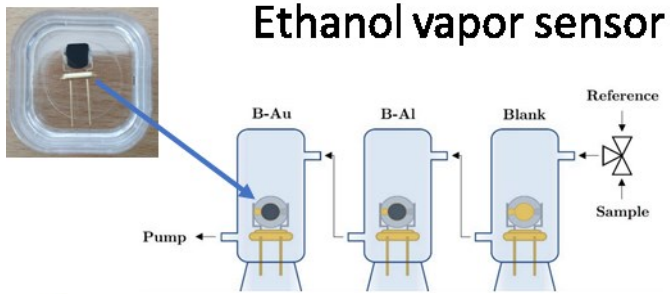
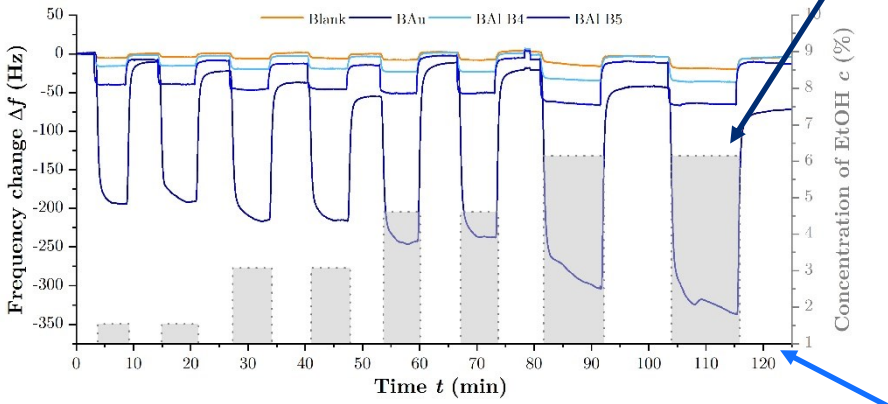
MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

Chemical sensors utilizing black metals

Ethanol vapor sensor

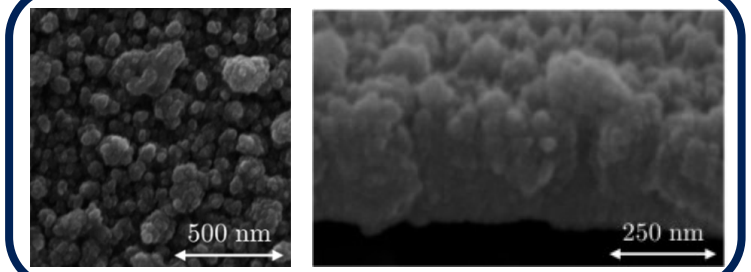




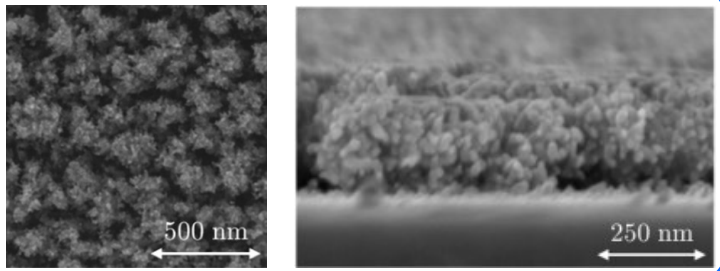
QCM	Sensitivity S	Sensitivity factor
Blank	2.1	1.0
B-Al 230 nm	4.0	1.9
B-Al 280 nm	5.3	2.6
B-Au 280 nm	21.3	10.2

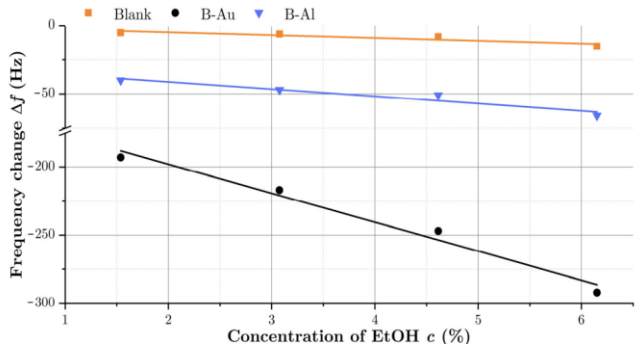
M.Hruška et al., Nanomaterials, 2022, 12, 4297

Black Al –DC pulsed magnetron sputtering



Black Au – thermal evaporation





Black Al surface el. structure studies

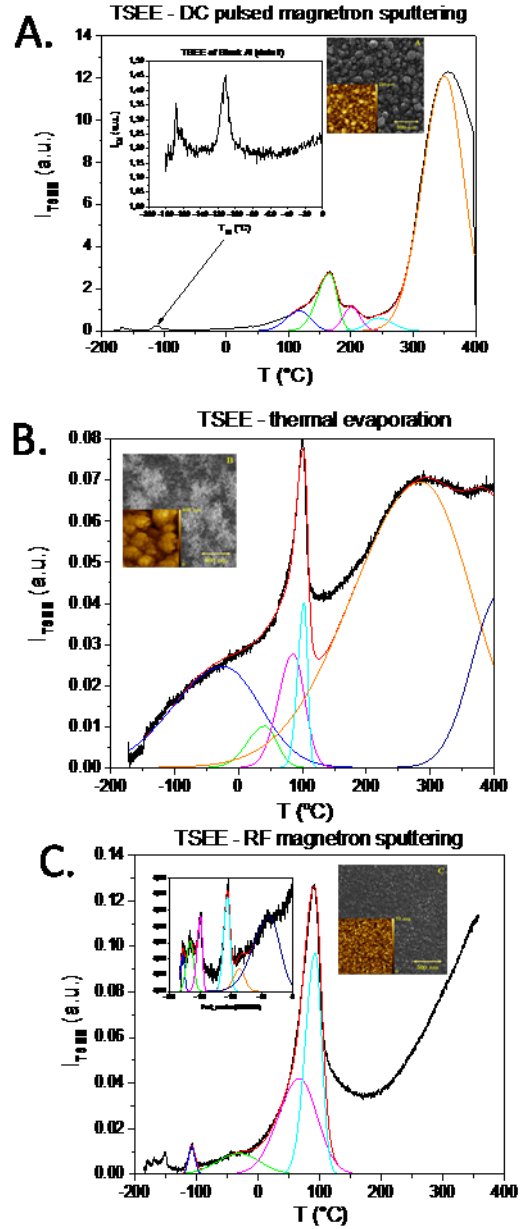
thermostimulated exo-electron emission (TSEE)

sample		A	B	C
T_{m1}	°C	166.1	102.7	91.7
T_{m2}	°C	349.2	286,8	
I_1	a.u.	2.83	0.04	0.13
I_2	a.u.	12.15	0.07	
E_1	eV	**0.95**	**0.81**	**0.79**
E_2	eV	**1.34**	**1.2**	

$E_{1,2}$ ... determined activation energies

Black Al

PVD techniques and surface properties



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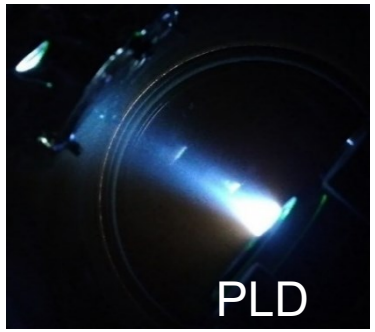
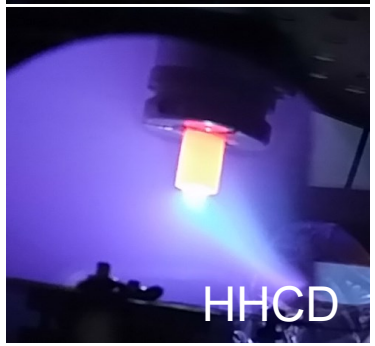
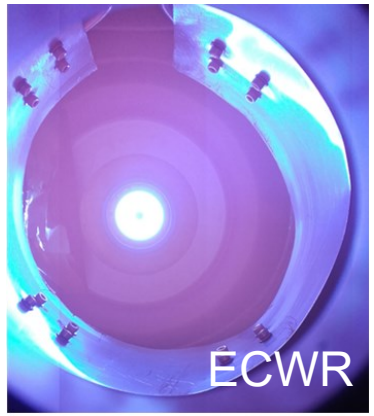
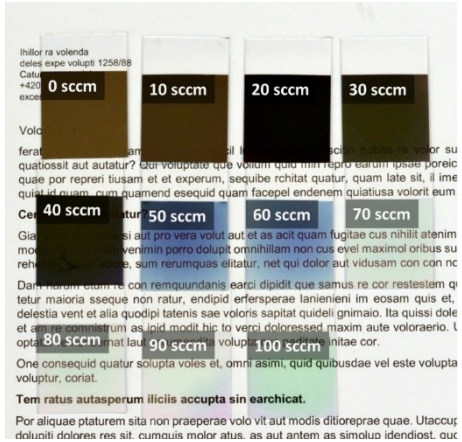
WO_3 Thin-film chemical sensors all VP5

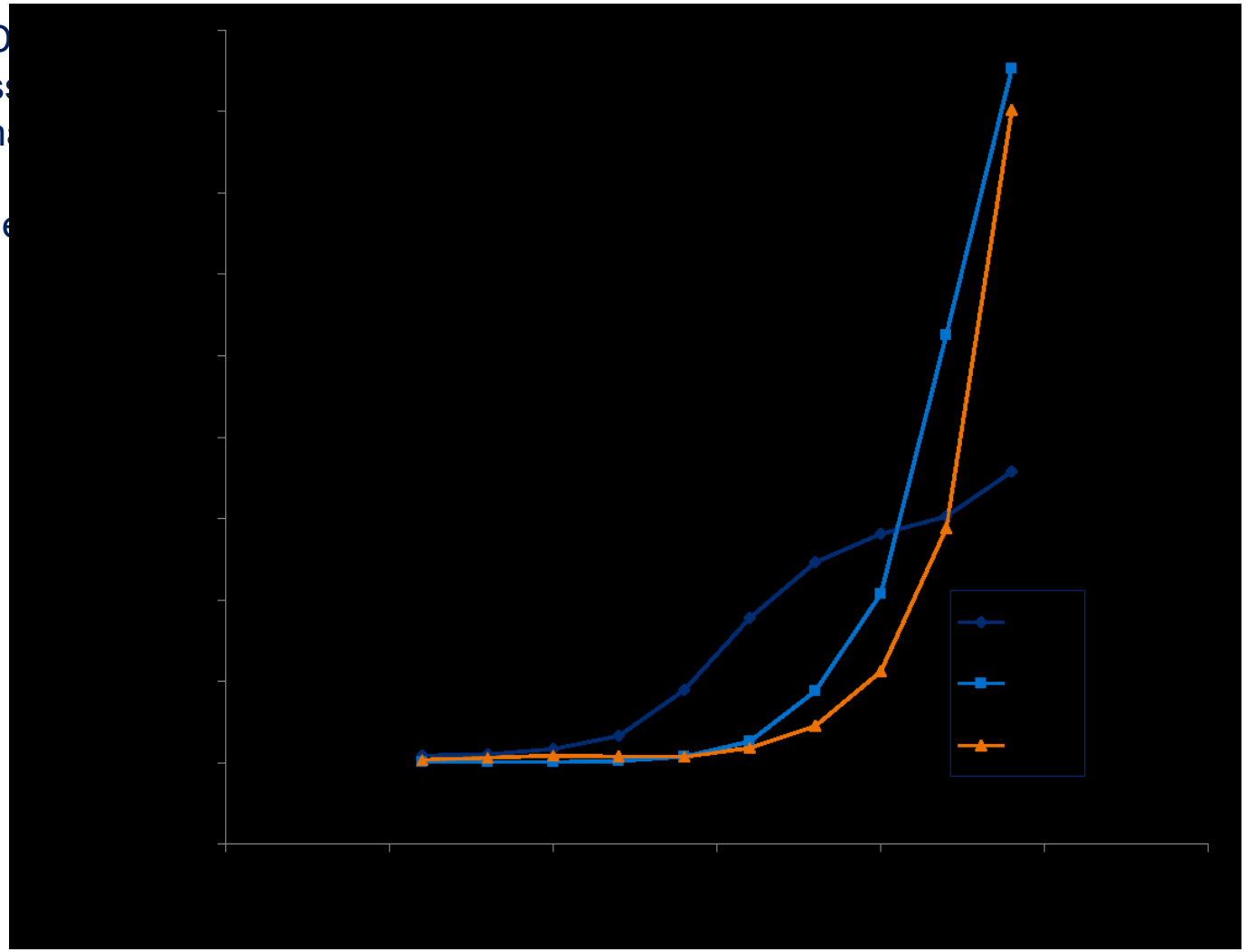






- Pulsed Laser Deposition (PLD
- HiPIMS reactive sputtering ass
  electron cyclotron wave reson
  plasma (ECWR)
- Hot Hollow Cathode Discharge





Invited lecture of EMRS 2023:

J. Lančok, Tungsten oxide thin films fabricated by PLD, HiPIMS and DC hollow cathode discharge for chemical sensor.

RA 5: Optical materials-plasmon structures

Jiří Bulíř

FZU Fyzikální ústav Akademie věd České republiky

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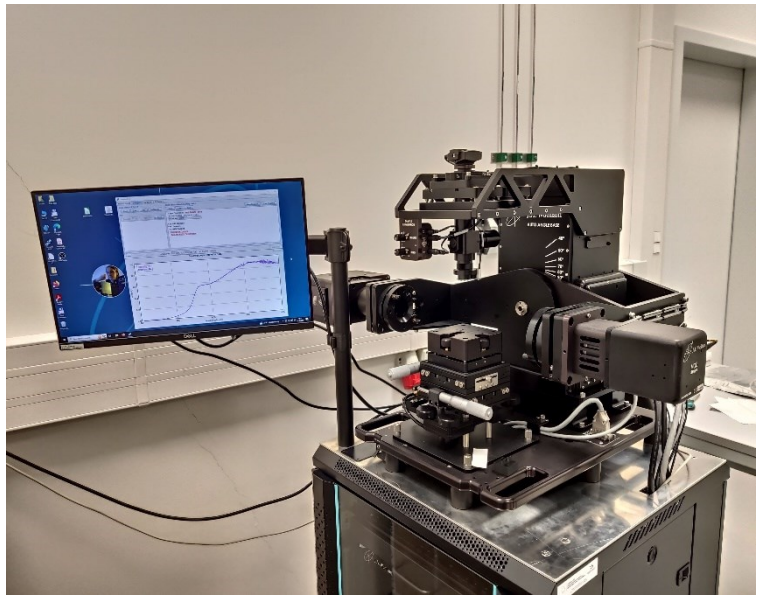
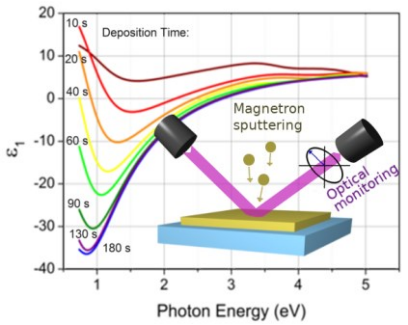
MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

Optical materials-plasmon structures

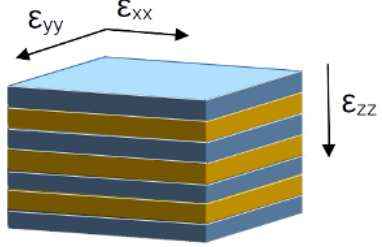
In-situ spectral ellipsometer (J.A.Woollam, M2000): monitoring of the growing films



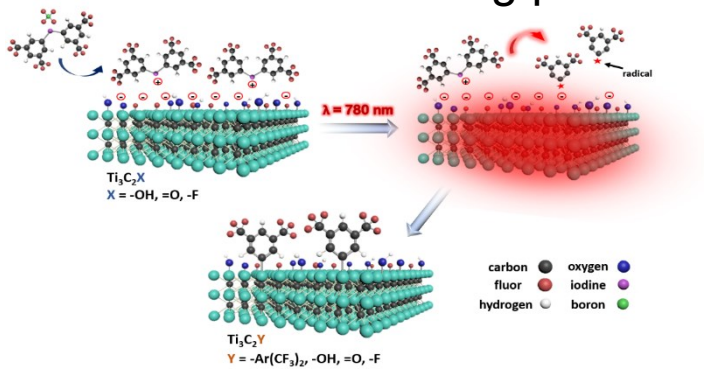
Optical dielectric functions can be obtained during the deposition process. The development of the dielectric function during the ZrN layer growth can be seen.



- Materials characterized by extreme anisotropy - it is formed as a layered structure of ultrathin epitaxial dielectric (ScN,CrN) and metallic film (TiN,ZrN)



- MXen materials with outstanding plasmonic behavior



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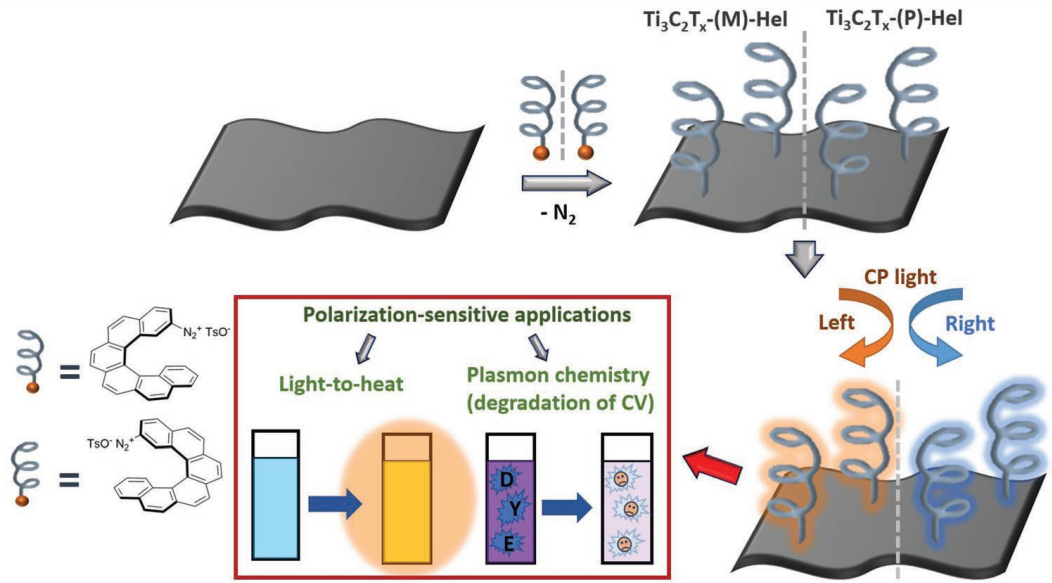
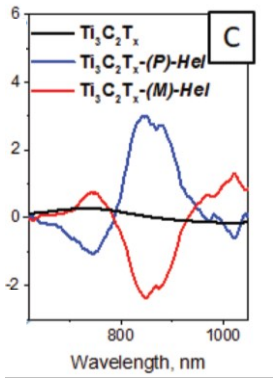
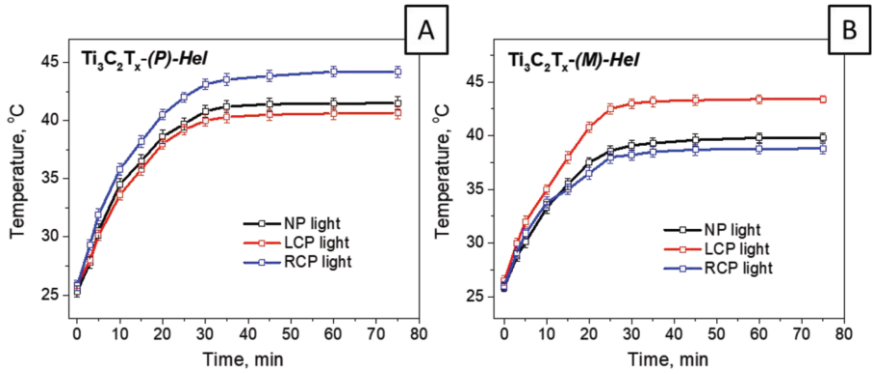
The project Solid state physics for the 21st century – SOLID21 CZ.02.1.01/0.0/0.0/16_019/0000760 is co-funded by the European Union.

Chiral Plasmonic Response of 2D $Ti_3C_2T_x$ Flakes



Circular dichroism





Demonstration of potential chiral 2D flakes utilization: Plasmon-induced heating

Adv. Funct. Mater. **2023**, 2212786

RA 6: Structures exhibiting combinations of ferroelectric and ferromagnetic properties

Maria Tyunina

FZU Fyzikální ústav Akademie věd České republiky

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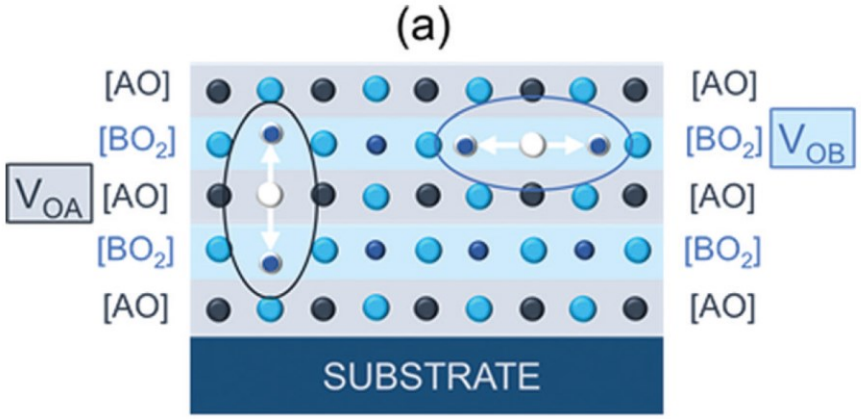
MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

Fabrication of epitaxial perovskite oxide films by PLD and tailored properties by defect and by thermal strain an oxygen vacancies

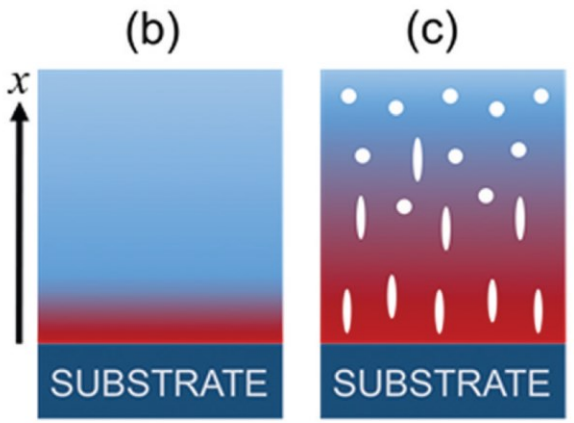
By PLD (KrF laser) thin (Th ~ 100 nm) films of:

- $SrTiO_3$
- $BaTiO_3$
- $NaNbO_3$
- $K_{0.5}Na_{0.5}NbO_3$
- $Ba_{0.5}Sr_{0.5}TiO_3$

- Anisotropic lattice distortions around oxygen vacancies are intrinsically inherent to all perovskite oxides.
- Therefore, we anticipate that the interaction of oxygen-vacancy stresses with substrate-induced strain fields is general for epitaxial perovskite oxide films.

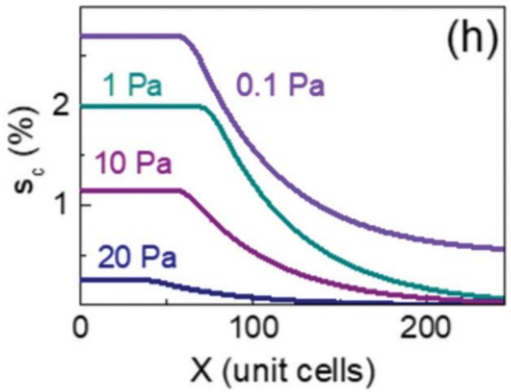


Schematics of exaggerated displacements of B-cations around oxygen vacancies in different atomic planes.



Stoichiometric

Oxygen-deficient films



Model strain profiles from the XRD peaks in as a function of the distance x from the film-substrate boundary

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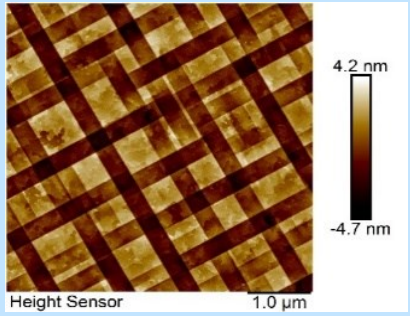
NEW PLD system: MnO-NiO heterostructures for new Multiferroic system

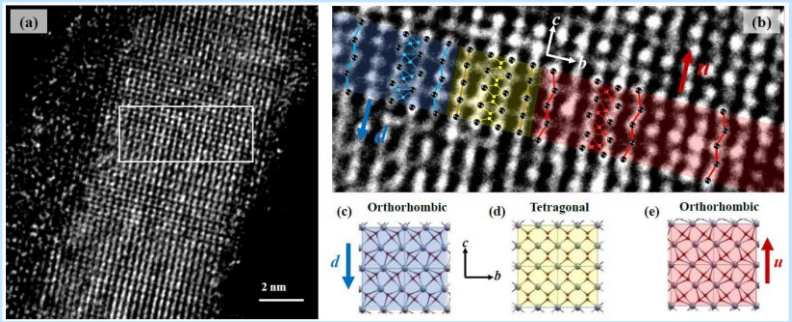
VP1 – Heusler thin films



Rh_2MnSb
RhMnSb
Co_2TiSn

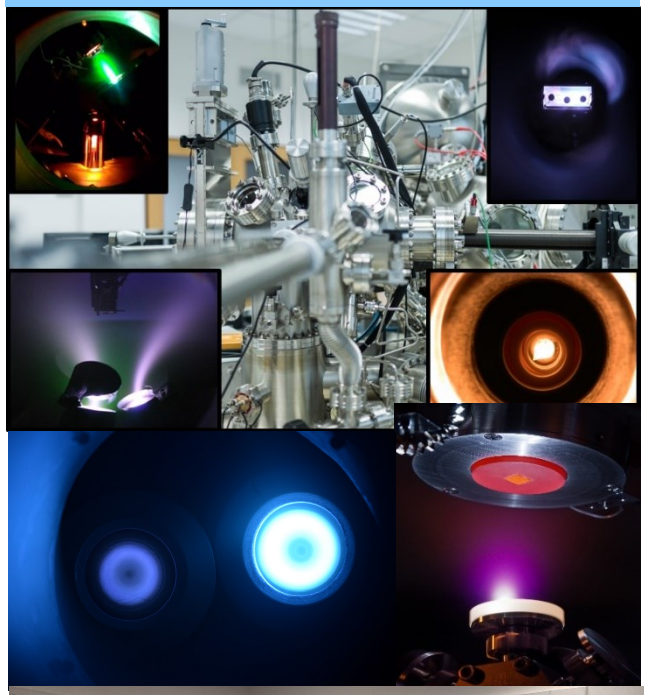
V. Chab, Effect of Twinning on Angle-Resolved Photoemission Spectroscopy Analysis of Ni49.7Mn29.1Ga21.2(100) Heusler Alloy, Materias 717 (2022)

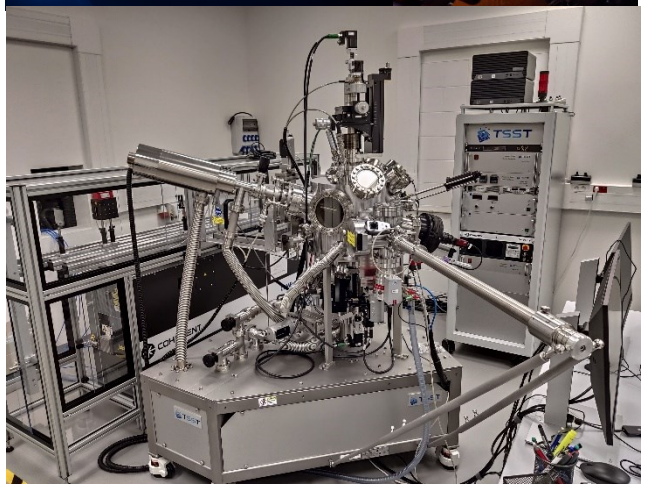
VP2 – Ferroelectrics films HfO_2 Multiferroic films



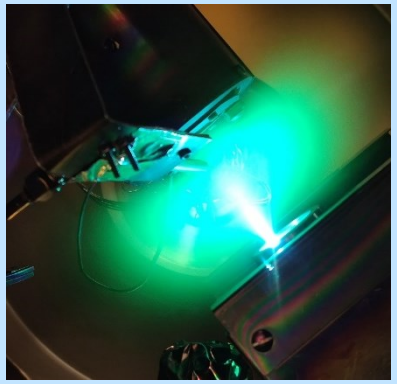
A. Kashir, Nanotechnology 33 (2022) 155703

VP5- Plasma technology



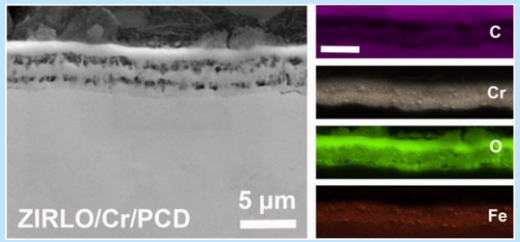


VP3 – oxides, iodines, garnets



I. Irimiciuc, Investigations on the CuI thin films production by pulsed laser deposition, Aplied Surface science 606 (2022)

VP4 - Diamond group, microvawe plasma and diamond thin films characterisation



I. Kratochvilova, Polycrystalline diamond and magnetron sputtered chromium as a double coating for accident-tolerant nuclear fuel tubes, Journal of Nuclear Materials (2023)

Influence of SOLID 21

International cooperation and

- V4+ Japan project focused on black metals for chemical sensors
- Royal Chemical Society with University Exeter UK - Mxene under dynamic strain
- Mobility project with University in Tartu, Estonia – chemical sensors

✓ Integration of SOLID laboratories to our current infrastructure

Year	Number of publications	Q1	IF average	FTE
2017-18	59	24	4.2	25.1
2022-23	56	32	6.2	22.3

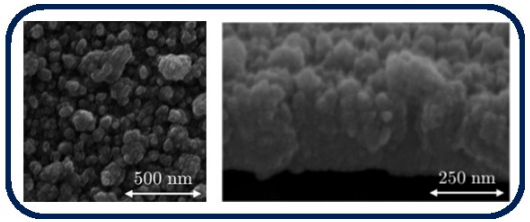
Sustainability

- M-ERA.NET project with EU partners (research institutions, industrial companies) Plasmon-Enhanced Nanostructured Optical Transparent Detectors ,
- NATO program (partner EXCALIBUR ARMY s.r.o.) - Stealth coatings based on 3D architectures of high entropy materials
- LA –Slovenia *Refractory high entropy alloy thin film photoelectrocatalyst: from synthesis to pharmaceutical wastewater treatment (RHEATREAT)*
- *TACR 2 project with TESLA, 7 GACR*
- *One MCSA – CZ*
- *Participation in COFUND project*

Cooperation with industry

Basic research → **Publications** → **Application project** → **Commercial outcomes**

Black Al –DC pulsed magnetron sputtering



nanomaterials MDPI

Article

Surface Enhancement Using Black Coatings for Sensor Applications

M.Hruška, 2022, 12, 4297

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Program Gama

Commercialisation of black metals films with Switzerland company

alphaSOL PREMIUM SOLUTIONS

Metal oxide chemical sensors

THE JOURNAL OF PHYSICAL CHEMISTRY C — Article — Cite This: J. Phys. Chem. C 2019, 123, 29739−29749 — pubs.acs.org/JPCC

New Insight into the Gas-Sensing Properties of CuO_x Nanowires by Near-Ambient Pressure XPS

P. Hozak, 2020

MPO
PROGRAM TRIO

Method of applying layers on sensor platforms for detecting gas

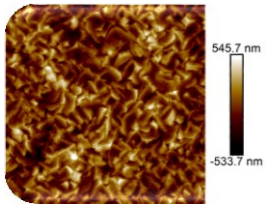
Patent number: 309041

TESLA

Cooperation with industry

Basic research → **Publications** → **Application project** → **Commercial outcomes**

High-entropy Alloys



Oxidation of amorphous HfNbTaTiZr high entropy alloy thin films prepared by DC magnetron sputtering

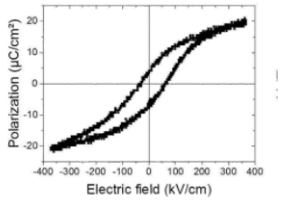
P. Hruska, 2021

THE NATO science for Peace and Security Programme

Stealth coatings based on 3D architectures of high entropy materials

EXCALIBUR ARMY

Perovskite oxide films PZT



RESEARCH ARTICLE | DECEMBER 22 2015

Magnetoelectric coupling in $Pb(Zr,Ti)O_3$—Galfenol thin film heterostructures

J. More-Chevalier; U. Lüders; C. Cibert; ... et. al

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Lithographic ultrasonic arrays from smart materials for Industry 4.0

Functional sample - SONOPOLYMERS WITH SMART MATERIALS FOR SONOLITHOGRAPHY

STARMANS

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Thank you for your attention.