Center of Energy Science and Technology

CEST

Skolkovo Institute of Science and Technology

Center of Energy Science and Technology

Artem Abakumov
Director, professor
h-index 44

Research interests:
materials for energy conversion and storage, scalable synthesis technologies, electron microscopy, crystallography, inorganic solis state chemistry.

Keith Stevenson, professor, *h-index* 60
- Materials Science and inorganic Chemistry
- Electrocatalysis, flow batteries

Evgeny Antipov, professor, *h-index* 42
- Materials Science and inorganic Chemistry
- Electrochemistry

Sergey Levchenko, professor, *h-index* 24
- Computational Materials Science

Stanislav Fedotov, assistant professor, *h-index* 13
- Materials Science and inorganic Chemistry
- Metal ion batteries

Victoria Nikitina, assistant professor, *h-index* 14
- Electrochemistry
- Materials Science and inorganic Chemistry

Dmitry Aksenov, assistant professor, *h-index* 11
- Computational Materials Science
- Computational methods for predicting the properties of materials

Alexey Buchachenko, professor, *h-index* 25
- Computational Materials Science
- Electronic structure of materials

Electrochemical Energy Storage

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Aim: creation of technological basis for the development of next generation materials for electrochemical energy storage and conversion solutions

Electrochemical energy storage

- Cathodes for lithium ion batteries
- Metal-ion batteries (potassium and sodium ion)
- Electrochemical energy conversion systems
- Redox flow battery

**Resident of SKOLKOVO*

Startups

Aim: creation of technological bases of production and commercialization of development results

Startup company "Rustor" Ltd*

The main areas of work are cathode materials based on phosphates with the structure of olivine ($LiFePO_4$, $LiFe_{1-x}Mn_xPO_4$, also known as LFP and LFMP) and layered oxides ($LiNi_{1-x-y}Mn_xCo_yO_2$, also known as NMC).

Startup company "K-plus" Ltd*

The goal of the project is a commercialization of promising electrochemical systems based on K-ion batteries. Develop technologies for cathode materials based on $K_xM[B(CN)_6]$ (where M, B are Fe, Co, Cr, Mn) cyanide transition metal complexes, and high-capacity carbon-based anode materials.

Current Lab Space State

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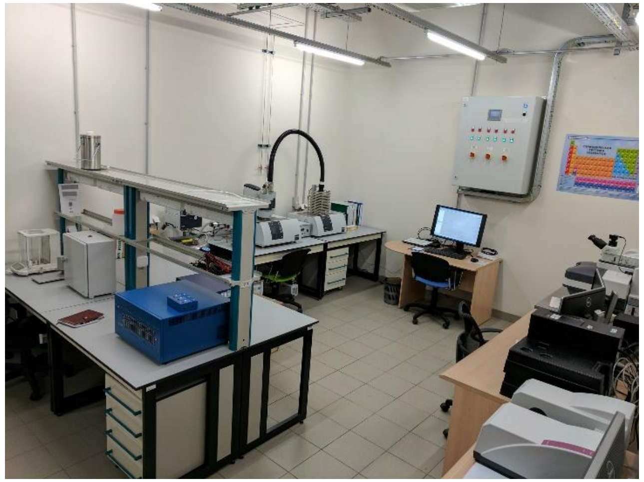
Glove box line I

Glove box line II

Cell assembling/
Structure characterization

Cell assembling

Material processing lab



Electrochemistry Analytical lab

- [x] Installed equipment for synthesis, including:
  - 100ml, 600ml Hydrothermal reactors Parr
  - Automated wet chemistry reactor Syrris
  - Microwave hydrothermal reactor
  - High energy ball mill SPEX, planetary ball mill Retzsch
  - Chamber, tubular and rotary furnaces Nabertherm
- [x] Installed analytical equipment, including:
  - High resolution Guinier diffractometer Huber
  - X-ray powder diffractometer Bruker
  - TG-DSC with QMS Netzsch
  - Atomic force microscope Cypher
  - HPLC Shimadzu
  - Particle size analyzer Fritsch
  - Potentiostats Autolab/Bio-Logic/Elins
- [x] Installed Device Fabrication Equipment
  - Two glove box lines MBraun
  - Battery assembling equipment (pouch and coin cells)
  - Battery testing stand Neware
- [x] Semi-automatic prototyping line 50 kWh per year
- [ ] Automatic Prototyping line10 MWh/year

Oxide cathode materials

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Material	Capacity, mAh/g, 0.1C	Voltage range, B	Storage capacity, 100 cycles	Bulk density, g/cm3	Availability
NMC 111	160	2.7-4.3	99%	1.9	in production, RUSTOR(up to 2000 kg/year)
NMC 622	180	2.7-4.3	>95%	2.4	in production, RUSTOR(up to 2000 kg/year)
NMC 811	>210	2.7-4.3	>90%	2.1	in production, Skoltech (up 100 kg/year)
Monocrystalline NMC622	160	2.7-4.3	98%	>3.0	in production, Skoltech (10 kg/year)
Monocrystalline NMC811	180	2.7-4.3	95%	>3.0	in production, Skoltech (10 kg/year)
Monocrystalline NMC952525	215	2.7-4.3	95%	2.3	in production, Skoltech (1 - 2 kg/year)
Li-rich NMC	260	2.2-4.8	99%	1.7	in production, RUSTOR(up 1000 kg/year)

Technological stages of the NMC project implementation

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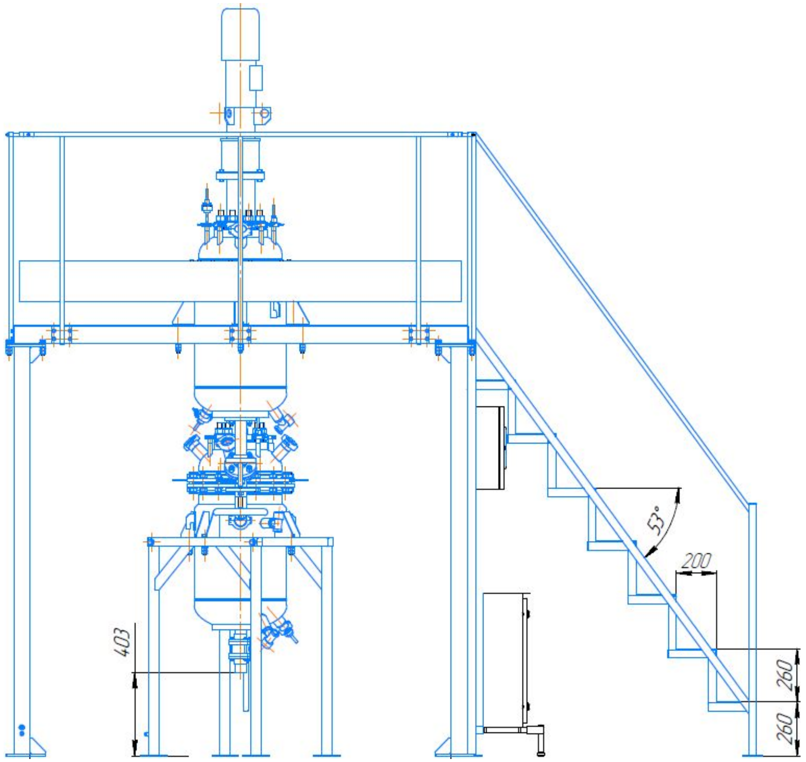

2018 - pilot reactor at Skoltech for 100 – 150 kg of material per year

2020 – 2021 –co–deposition reactors per 1000 - 1500 kg of material per year

2022-2023 – development of a continuous co-deposition unit up to 10-100 tons/year

Semi-automatic Cell Prototyping Line

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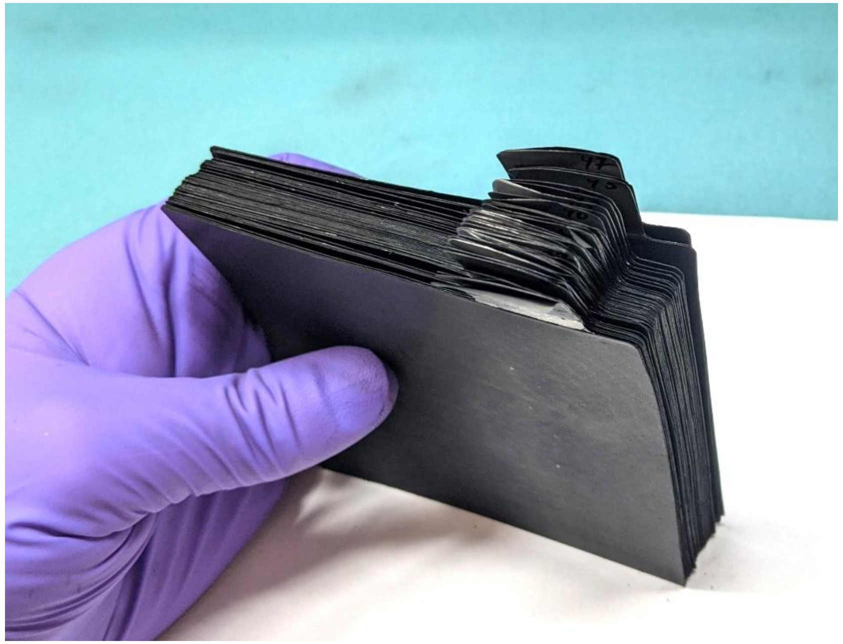
Battery Cell Prototyping Line:

- capacity: 50 kWh per year
- form factor: prismatic cells in a soft housing ranging in size from 50 mm x 50 mm to 100 mm x 100 mm



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Prototypes of lithium-ion battery cells

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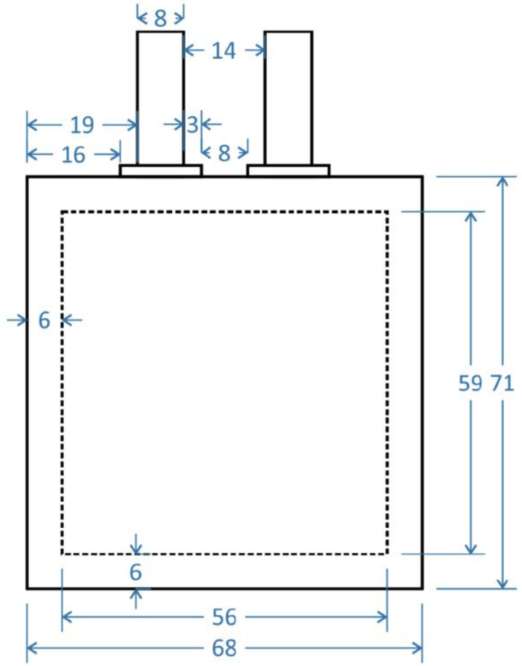
Skoltech CEST 50x50 pouch cell



Characteristics of battery cell prototypes:

- Capacity: 3-5 Ah and 12-15 Ah.
- number of electrode pairs: up to 21
- Specific energy: 200 Wh/kg and above
- proprietary cathode materials NMC111, NMC622, NMC811, NMC952525

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New Generation of Batteries

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Aim: creation of alternative systems for energy storage with significant cost advantages compare to existing Li-ion solutions.

- **Na-ion**

Cheap solution of ultra high power system based on $Na_3V_2(PO_4)_3$ or $Na_3V_2(PO_4)_2F_{3-x}O_x$ and carbon-based anode materials. Technology can be easily deployed on existing production capacity of Li-ion industry.

- **K-ion**

Extra cheap solution based on $K_xM[B(CN)_6]$ (where M, B are Fe, Co, Cr, Mn) cyanide transition metal complexes as a cathode, and high-capacity carbon-based anode materials for potential stationary battery application.

	Li-ion	Na-ion	K-ion
Cathode material	LCO, LFP, NMC	$Na_3V_2(PO_4)_3$	$K_2Mn[Fe(CN)_6]$
Capacity, mAh/g	140 – 170	~110	Up to 130
Average voltage (V)	3.5 – 3.9	3.3-3,9	3.9 – 4.0
Average energy density (Wh/kg)	490 – 660	350-430	480
Current collector	Cu	Al	Al
Cathode materials	Expensive (Li, Co, synthesis and processing)	Cheap	Extra cheap (low cost raw materials, easy synthesis)
Competitive advantages vs Li-Ion		~10% cheaper, due to the cheaper cathode materials, higher voltage	~20-40% cheaper, due to the cheaper cathode, anode and current collector materials
Competitors	Panasonic, SDI, LGChem, etc	HiNa battery, Faradion, Tiamt	Sharp Corp

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Na-ion batteries

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Cathode materials
Sodium Vanadates

Anode materials
Hard carbon (HC)

Full cell
prismatic in a soft case

- Synthesis development and upscaling

-Synthesis development and upscaling

- Assembling cell prototypes

Developed materials:

$Na_3V_2(PO_4)_3$: capacity 115 mAh/g, 99% retention of capacity after 100 cycles, fast cycling

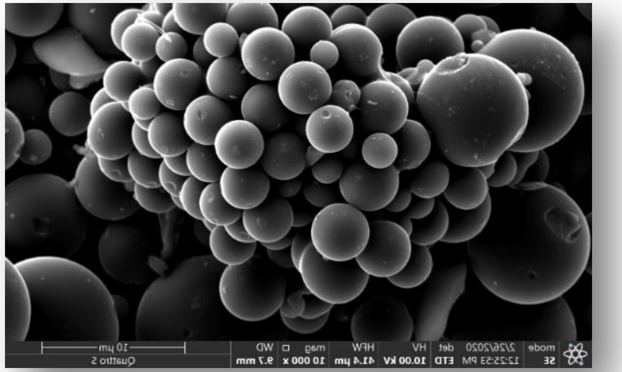
$Na_3V_2(PO_4)_2O_2F$: capacity 110 mAh/g, 90% retention of capacity after 100 cycles

On development stage :

$NaVPO_4F$, working potential 4 V, capacity up to 130 mAh/g

$NaVP_2O_7$, working potential 3,8 V, capacity up to 108 mAh/g

Hard carbon: capacity >250 mAh/g



Stable prototypes of 150-450 mAh cells are assembled

Know-how in upscaling of electrode materials production technologies
Know-how in anode pretreatment technologies
Know-how in the preparation of electrode mixtures, electrode deposition and cell assembly

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Na-ion batteries

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Russian T-90 1:18, factory power supply: Li-ion, 7.4V, 1.8Ah

K-ion batteries

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Cathode materials
$K_2Mn[Fe(CN)_6]$ (KMF)
$K_2Fe[Fe(CN)_6]$ (KFF)

Anode materials
Hard carbon (HC)

Full cell
prismatic in a soft case

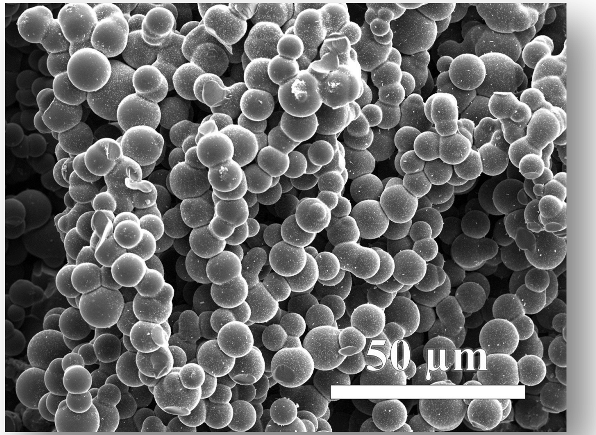
-Synthesis development and upscaling

***KMF**: capacity 120 mAh/g, 90% retention of capacity after 100 cycles, fast cycling*

***KFF**: capacity 110 mAh/g, 90% retention of capacity after 100 cycles*

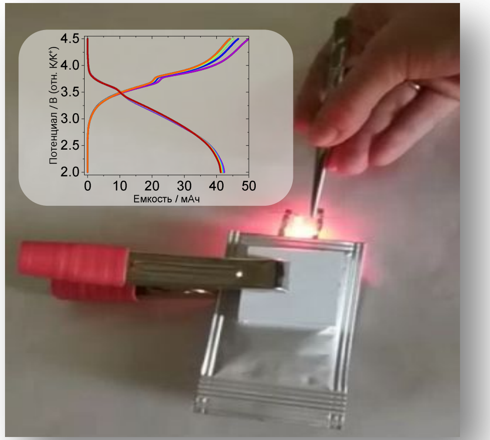
- Synthesis development and upscaling

Hard carbon: capacity >250 mAh/g



- Assembling cell prototypes.

In order to demonstrate the efficiency of the system, a prototype of a two-pair cell with a capacity of 30 mAh was assembled



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Electrochemical energy conversion systems

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Electrocatalysts for alkaline electrolyzers

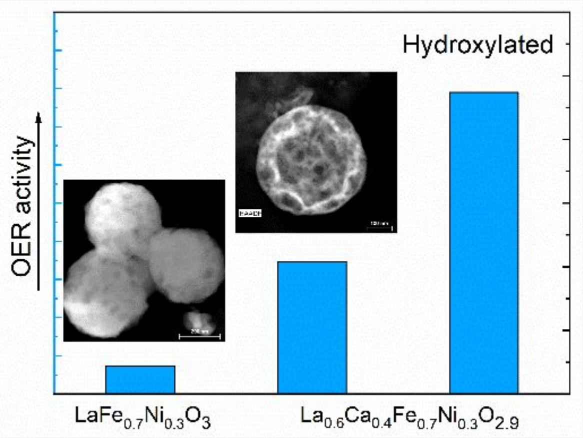
- Catalysts based on transition metal oxides
- Stability in alkaline solutions
- Low oxygen release overvoltage
- Perovskites, layered nickel-iron oxyhydroxides

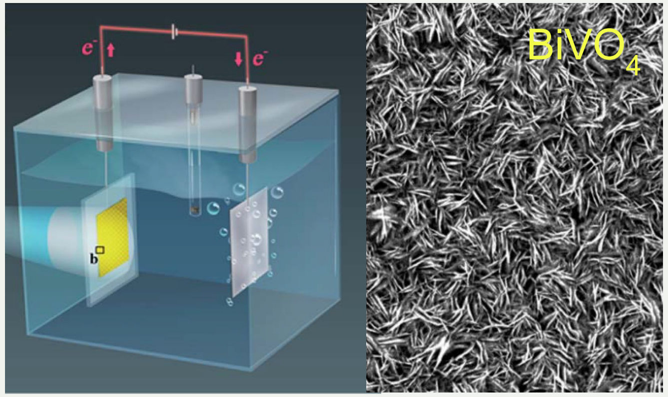
Photo electrocatalysts for hydrogen production

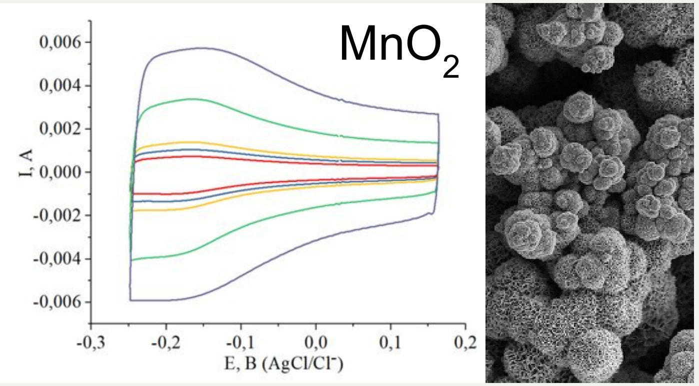
- Photo electrocatalysts based on semiconductors - transition metal oxides
- Electrolysis under the influence of visible light
- Electrodeposition of catalysts with control of film morphology

Supercapacitors based on transition metal oxides

- Synthesis of materials with a high specific surface area and pseudo-intensive contribution
- Porosity and morphology control
- Stability in aqueous solutions
- Oxides of manganese, titanium, tungsten







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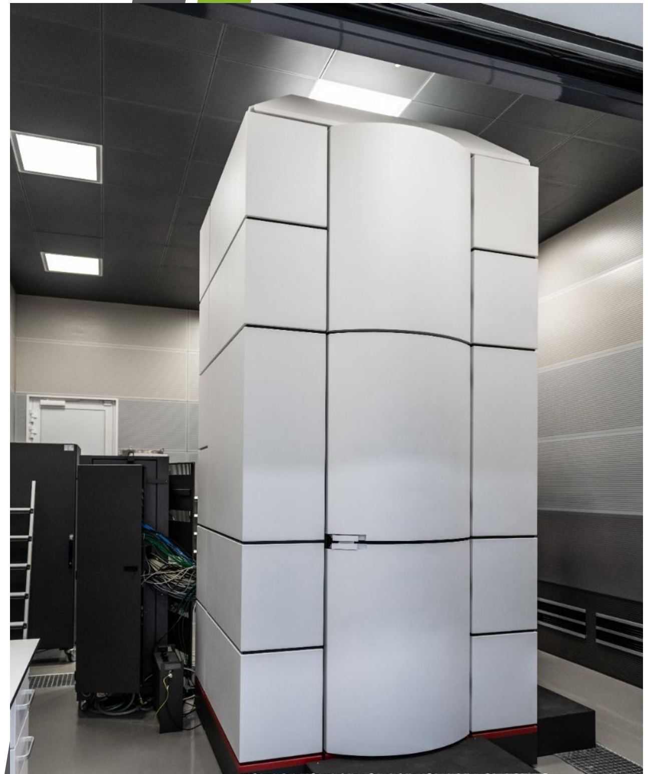
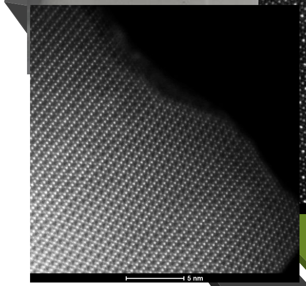
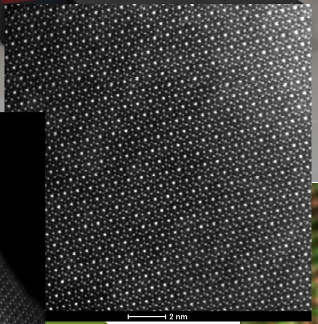
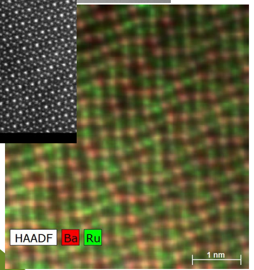
Advanced Imaging Core Facility

Titan Themis Z

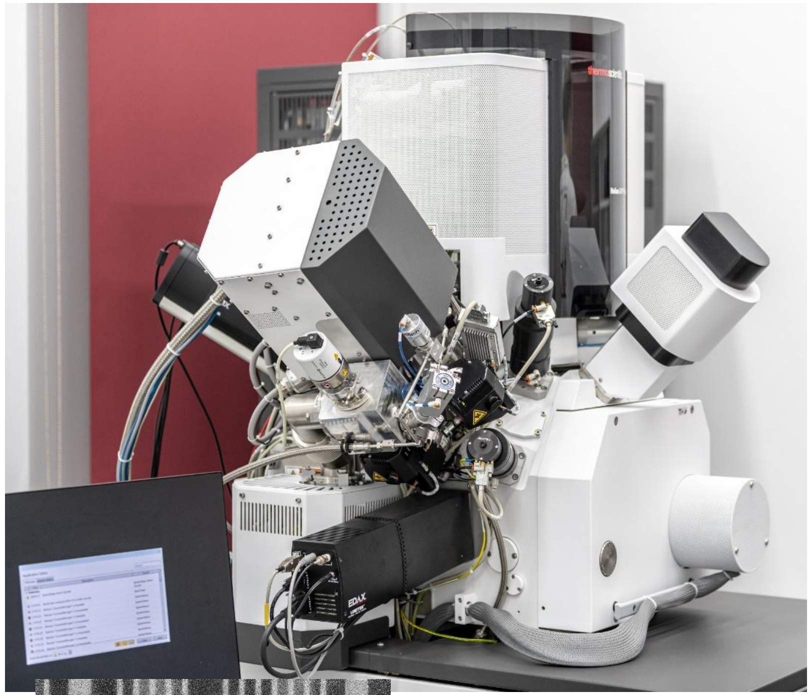


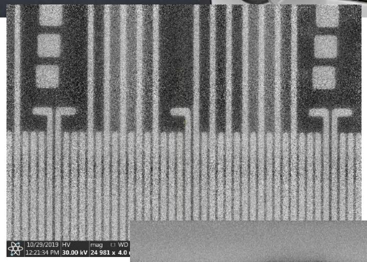


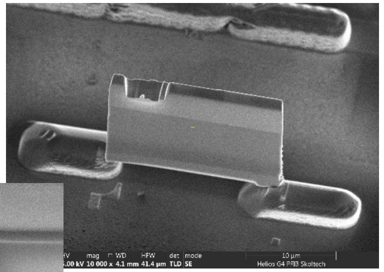


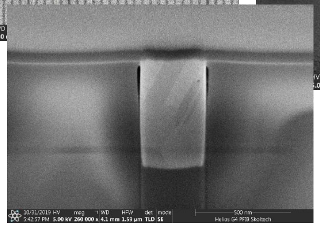


Helios G4 PFIB UXe









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