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A New Perspective on Material Recovery in Photovoltaic Module Recycling Processes

Anna Kuczyńska-Łażewska

Department of Energy Conversion and Storage

Faculty of Chemistry

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Plan of presentation

1) Backstory

2) My research

3) New approach

4) Future?

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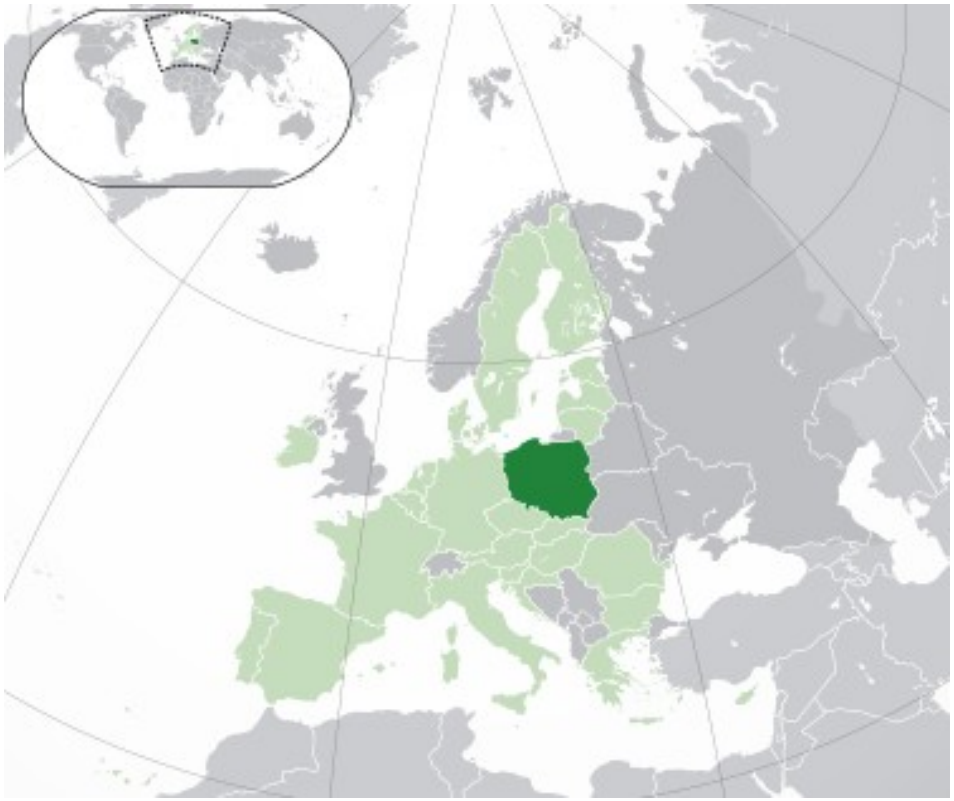
Self-presentation

- **Born** in 07/11/1990 in Gdańsk
  - The same date as Maria Skłodowska-Curie only 123 years later.

  The same city as Daniel Gabriel Fahrenheit only 304 years later.



- I'm from **Republic of Poland.**
  - Area: 313 000 km^2
  - Population: 38 mln
  - Capital city: Warsaw

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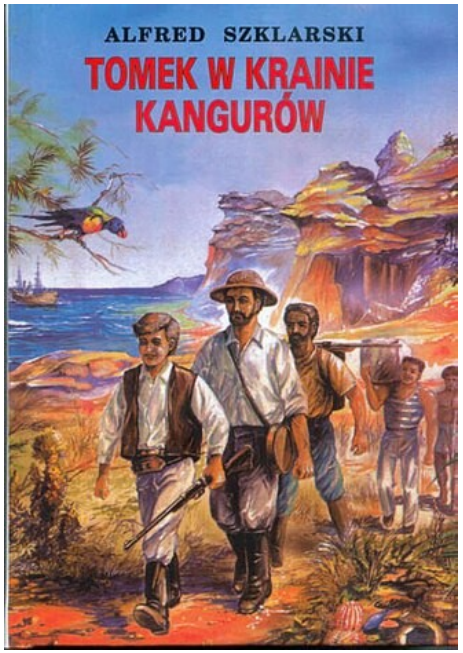
Self-presentation



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Self-presentation

Biography

- **Studies** at Gdańsk University of Technology, Faculty of Chemistry

Eng. degree – Chemistry

„Heterogeneous photocatalysts alternative to TiO_2. Literature review, preparation and characterization of strontium titanate"

M.Sc. degree – Environmental Protection Technologies – Environmental Protection Systems

„Preparation and characterization of nanocomposites type: TiO_2-$SrTiO_3$-CdS"

- **International practice:**

3-months in Leibniz Institute for Catalysis in Rostock (Germany)

„Preparation and characterization of nanocomposites based on TiO_2-$BiVO_4$ with Au nanoparticles"

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But were is recycling and photovoltaics?

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Self-presentation

- PhD – Chemical Technology
- „Technologies of recycling end-of-life and waste solar modules
- of I and II generation"

I'm working in **Gdańsk University of Technology** as assistant professor. I'm a researcher and a lecturer in **Department of Energy Conversion and Storage** in Faculty of Chemistry.

1904

2022

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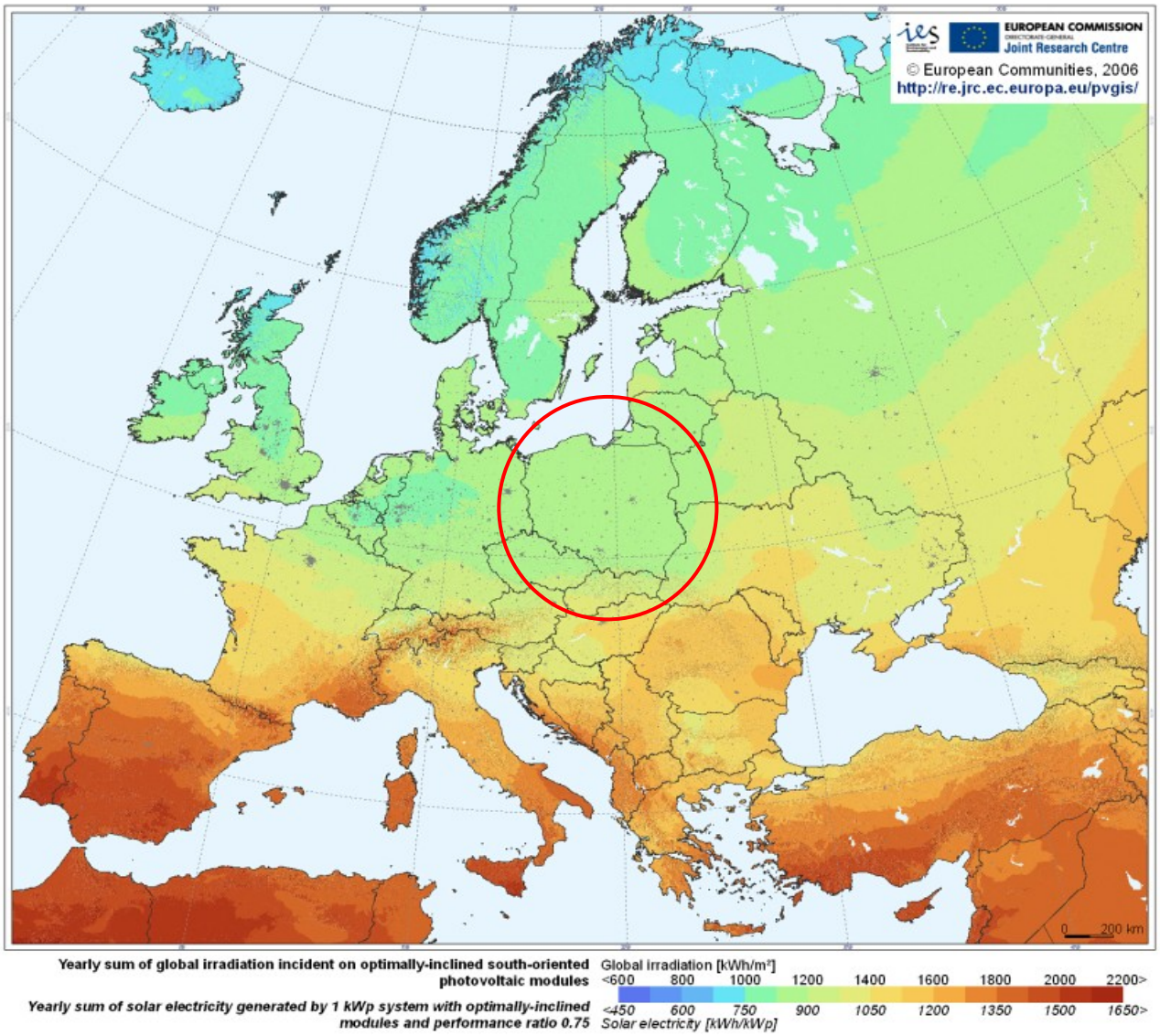
Why photovoltaics?



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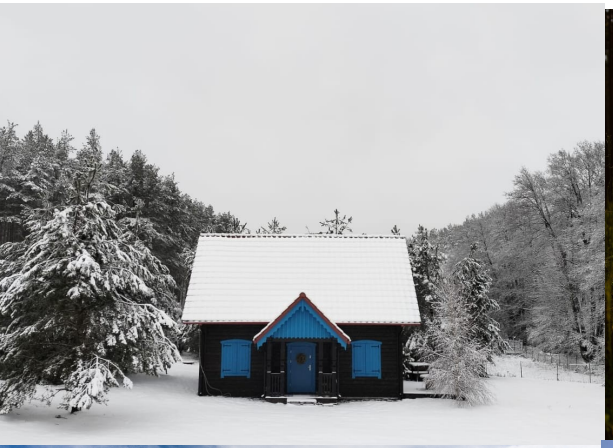
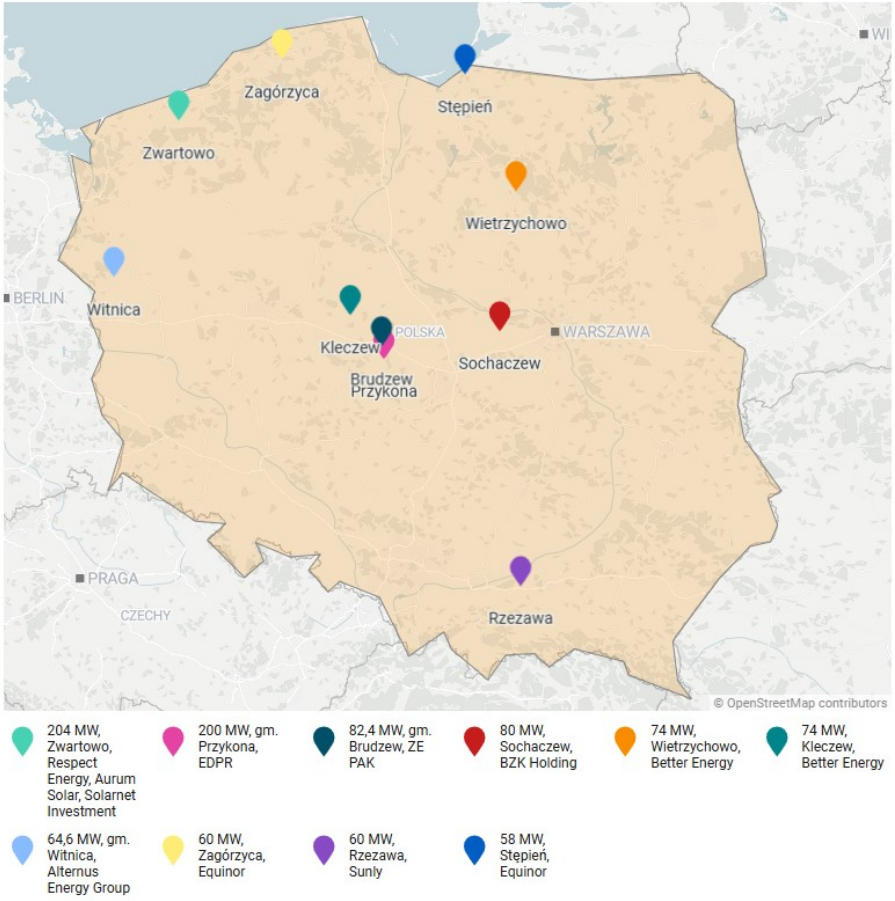








PV in Poland



Type	Number of installations	Installed capacity [MW]
Micro-installations	7 558	78.17
Photovoltaic farms (51-999 kW)	105	74.46
Photovoltaic farms (above 1000 kW)	23	121.00

Data for January 2025

Zwartowo

https://enerad.pl/najwieksze-farmy-fotowoltaiczne-w-polsce/ data for 2024
https://www.rynekelektryczny.pl/moc-zainstalowana-fotowoltaiki-w-polsce/ data for January 2025

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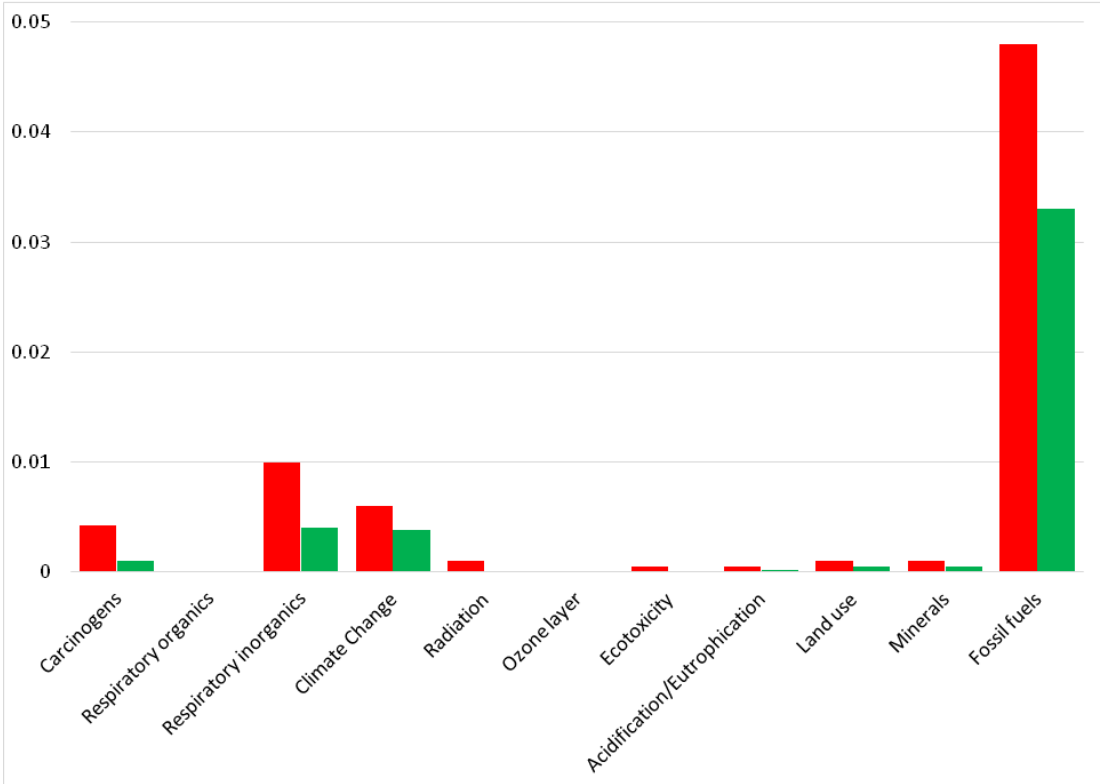
My research

Research activities - Life Cycle Analysis of photovoltaic modules



The results after normalization for the production of silicon solar cell without (red bars) and with the use of recycled silicon (green bars)

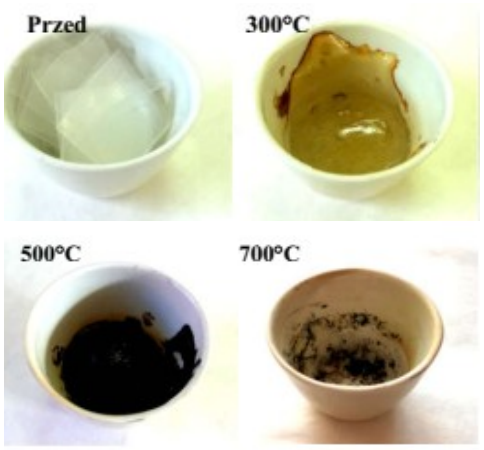
LCA characterisation results for impact category.

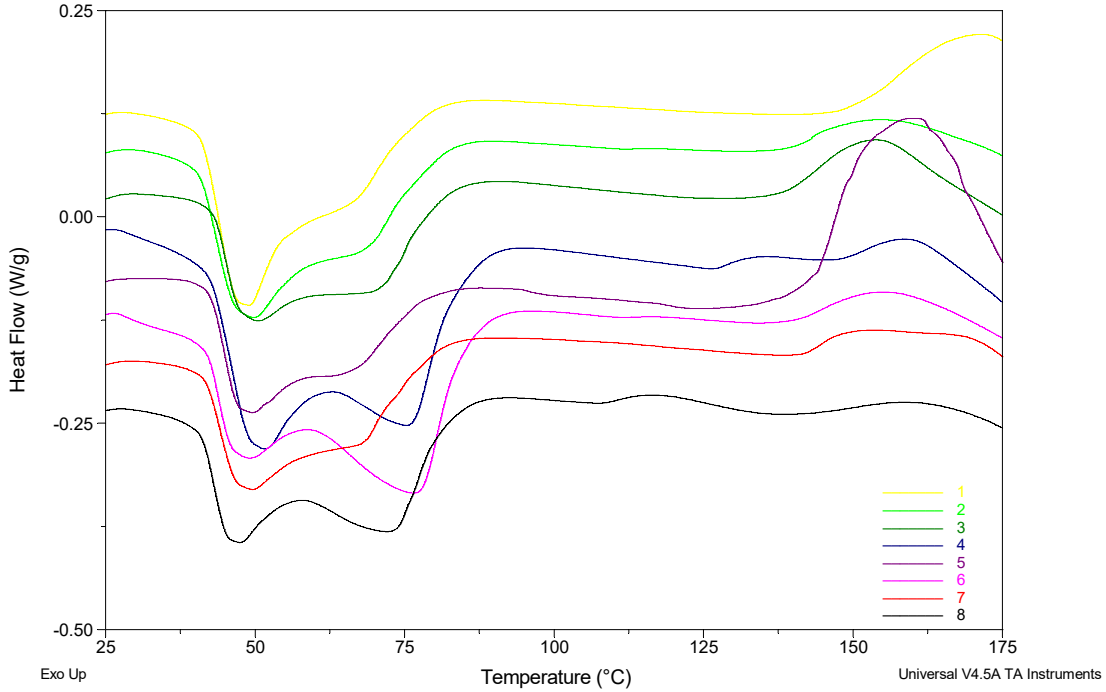
Impact category	Unit	c-Si cells at plant	c-Si cells using recycled materials
Carcinogens	DALY	4.2E-5	6.55E-6
Respiratory organics	DALY	1.04E-7	8.02E-8
Respiratory inorganics	DALY	8.9E-5	3.6E-5
Climate Change	DALY	5.25E-5	3.1E-5
Radiation	DALY	1.88E-6	1.72E-7
Ozone layer	DALY	3.33E-8	2.86E-8
Ecotoxicity	PAF·m^{2}year	31.4	5.96
Acidification/ Eutrophication	PDF·m^{2}year	2.0	1.56
Land use	PDF·m^{2}year	1.39	0.823
Minerals	MJ surplus	1.44	0.71
Fossil Fuels	MJ surplus	272	185

E. Klugmann-Radziemska and A. Kuczyńska-Łażewska, “Solar Energy Materials and Solar Cells The use of recycled semiconductor material in crystalline silicon photovoltaic modules production - A life cycle assessment of environmental impacts,” Sol. Energy Mater. Sol. Cells, vol. 205, 2020, doi: 10.1016/j.solmat.2019.110259.

Research activities

Research activities - Delamination of photovoltaic modules





Kuczyńska-Łażewska A., Klugmann-Radziemska E.: Influence of Fragment Size on the Time and Temperature of Ethylene Vinyl Acetate Lamination Decomposition in the Photovoltaic Module Recycling Process// Materials. -Vol. 12, iss. 18 (2019), s.2857-2867

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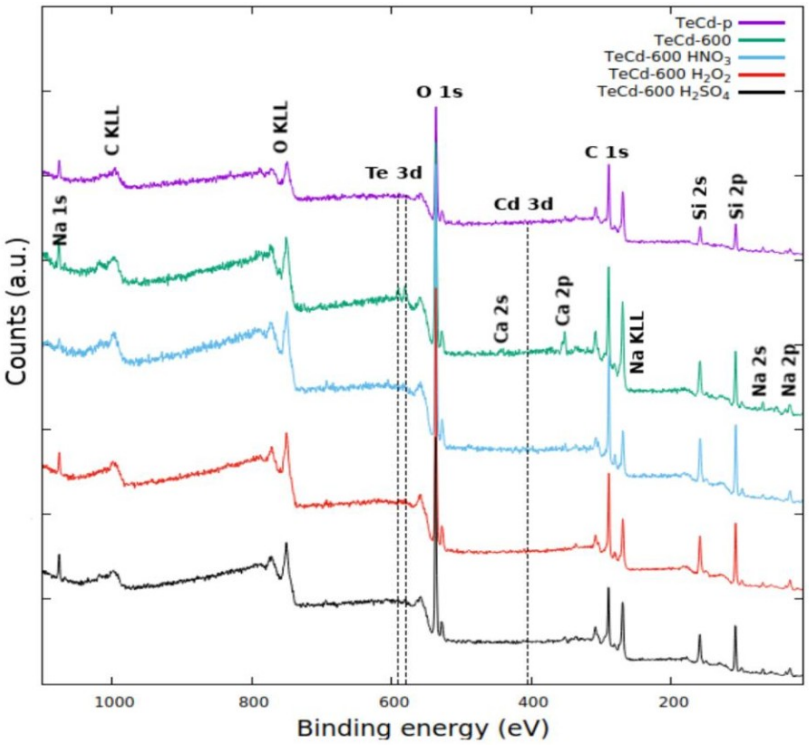
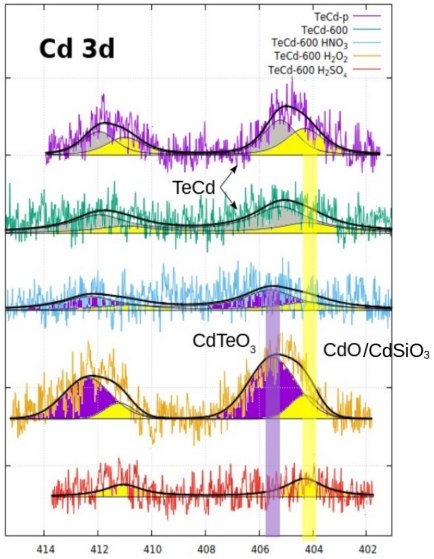
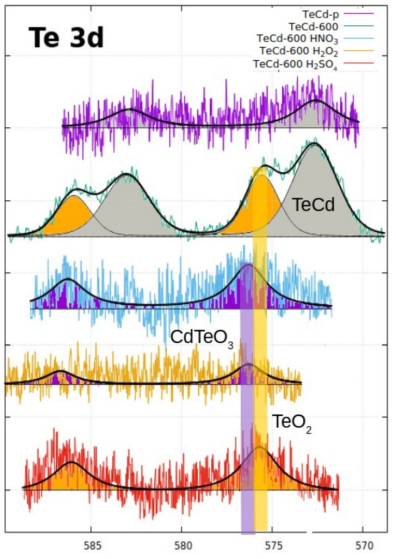
Research activities

Research activities - Recycling of 2nd generation modules based on CdTe



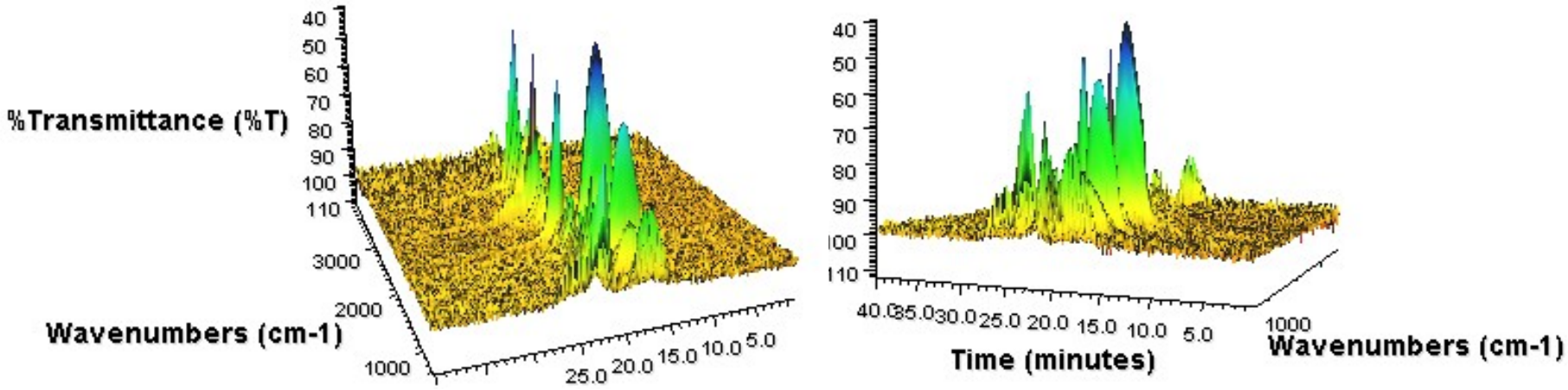
XPS survey-scan spectrum of samples before (TeCd-p) and after thermal treatment (TeCd-600) and after leaching for 2 h at 50 ◦C in 1 M H2SO4 (TeCd-600 H2SO4), 3 M HNO3 (TeCd-600 HNO3), and 30% H2O2 (TeCd-600 H2O2)





Kuczyńska-Łażewska A., Klugmann-Radziemska E., Witkowska A.: Recovery of Valuable Materials and Methods for Their Management When Recycling Thin-Film CdTe Photovoltaic Modules// Materials -Vol. 14,iss. 24 (2021), s.7836

Research activities - Life Cycle Analysis of photovoltaic modules



Presented results are related with project MINIATURA 7 “Comparative LCA analysis of recycling methods for photovoltaic modules made of CdTe - preliminary research” founded by National Science Centre.

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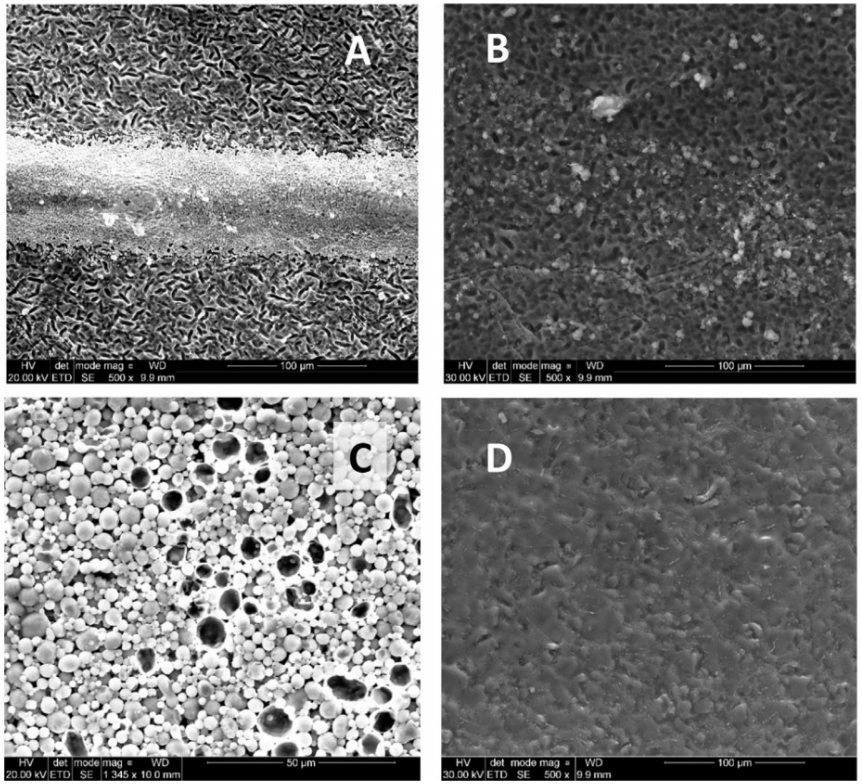
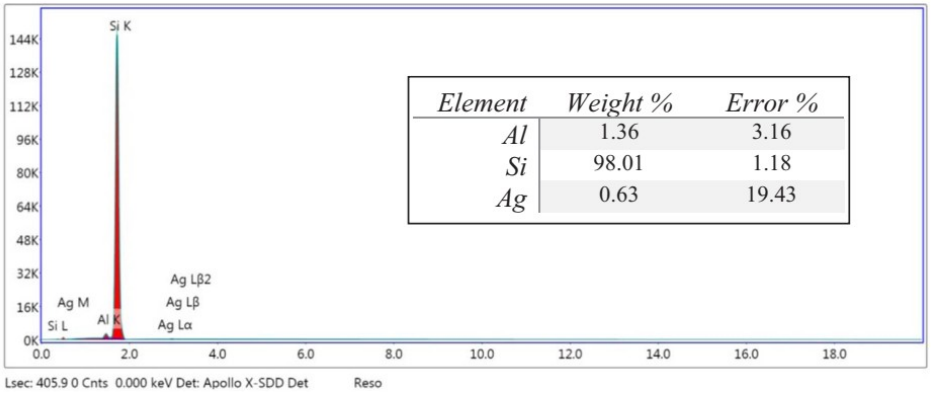
Research activities

Research activities - Silver recovery from 1st generation photovoltaic cells



SEM pictures of front contact A-before etching process, B-after etching with 1 M HNO3 at 50 °C during 1 h and back contact C-before etching process, D-after etching with 1 M NaOH at 50 °C during 30 min at stirring speed 250 rpm.



Element	Weight %	Error %
Al	1.36	3.16
Si	98.01	1.18
Ag	0.63	19.43

EDX analysis of sample content after etching process with 1 M HNO3 at 50°C during 1 h at stirring speed 250 rpm

Kuczyńska-Łażewska A., Klugmann-Radziemska E., Sobczak Z., Klimczuk T.: Recovery of silver metallization from damaged silicon cells// SOLAR ENERGY MATERIALS AND SOLAR CELLS. -Vol. 176, (2018), s.190-195

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New approach

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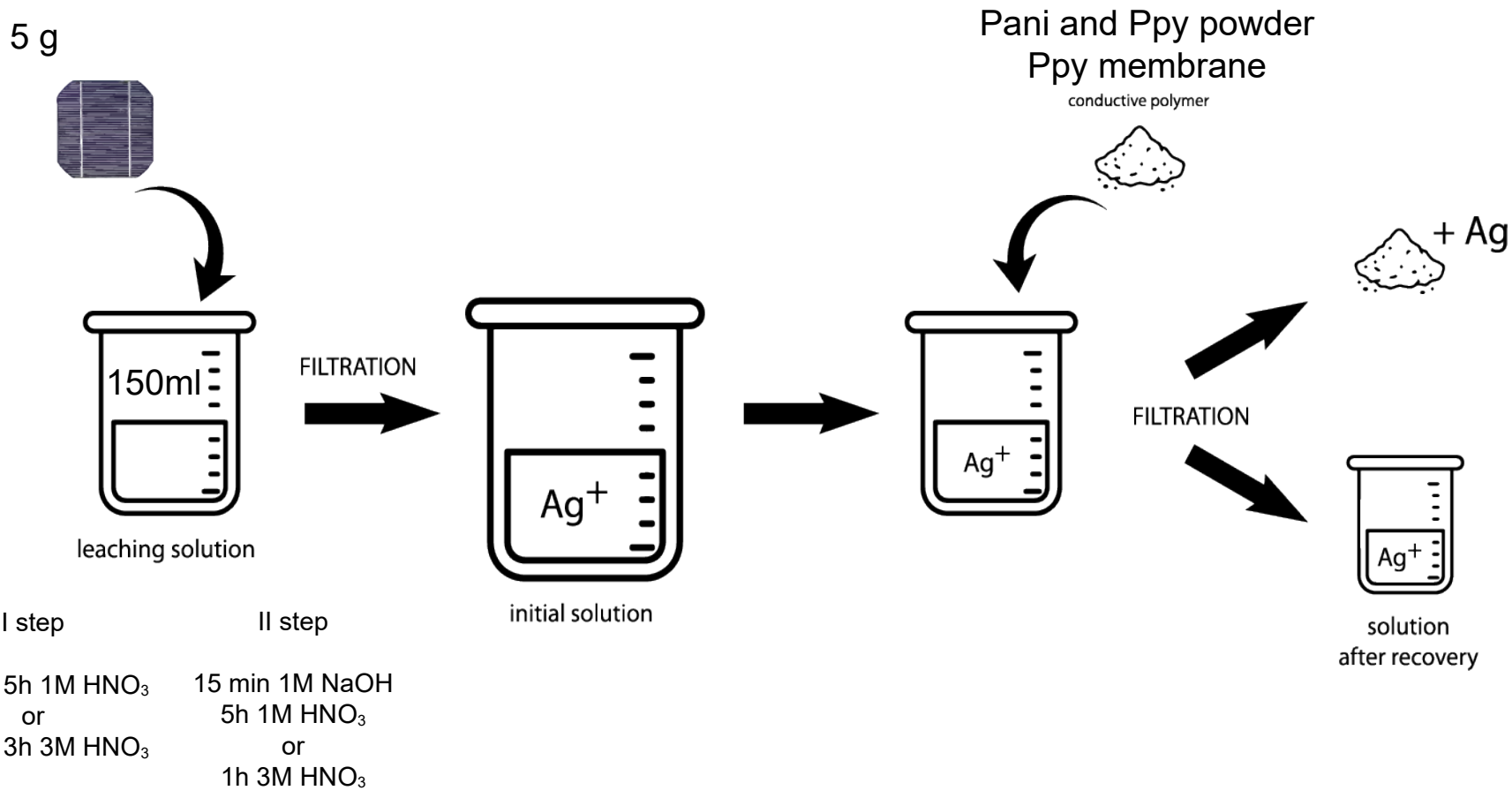
MATERIALS & METHODS



I step

3h and 5h 1M HNO_3
or
1h and 3h 3M HNO_3

II step

15 min 1M NaOH
5h 1M HNO_3
or
1h 3M HNO_3

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RESULTS

Sample number	Technological solutions	Silver mass in cells [mg]	Initial Ag concentration in solution [mg/L]	Electrodeposition		Electroless recovery (PAni)		Electroless recovery (PPyr)		Electroless recovery (PPyr membrany)	
				recovery [%]	mass of Ag [mg]	Ag concentration [mg/L]	recovery [%]	Ag concentration [mg/L]	recovery [%]	Ag concentration [mg/L]	recovery [%]
1	3h 3M HNO3	81±13	448.00±7.4	10.0%	0.9	448.00±10.1	0.00%	260.83±5.9	41.8%	448.00±7.4	0.0%
6	15min NaOH 3h 3M HNO3	81±13	395.75±11.7	99.8%	7.9	395.75±11.7	0.0%	241.56±11.2	39.0%	395.75±11.7	0.0%
9	model solution	-	100.00	100.0%	2.0	57.22±1.94	42.8%	39.49±1.13	60.5%	49.79±1.34	50.2%
	Literature	-	-	-	-	-	97.0%	-	94.0%	-	94.0%

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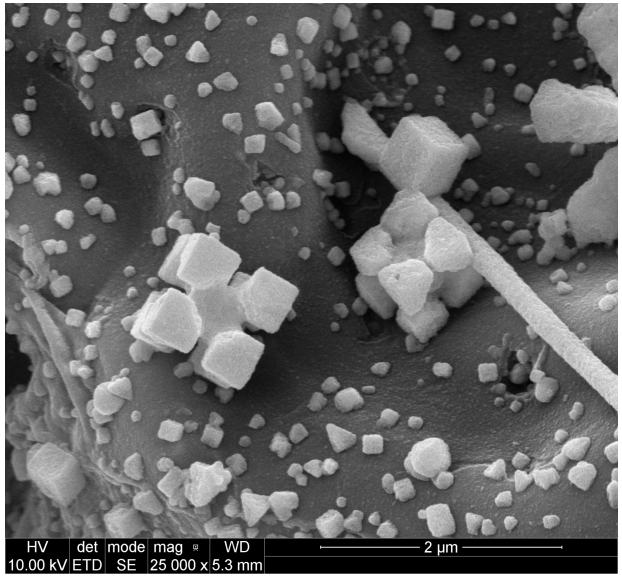
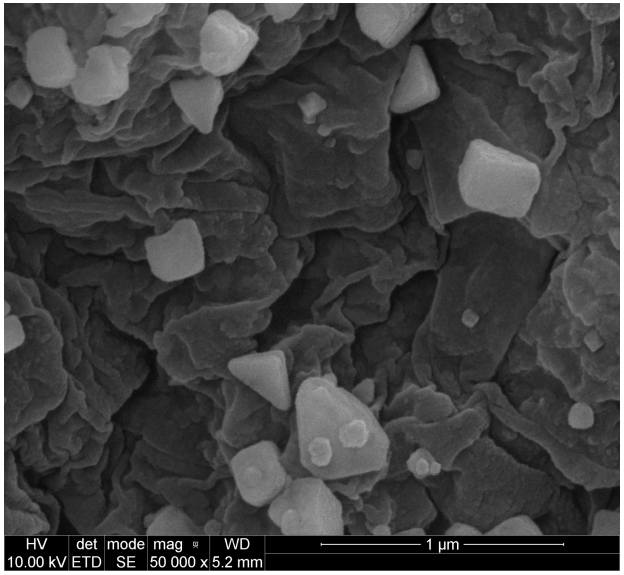
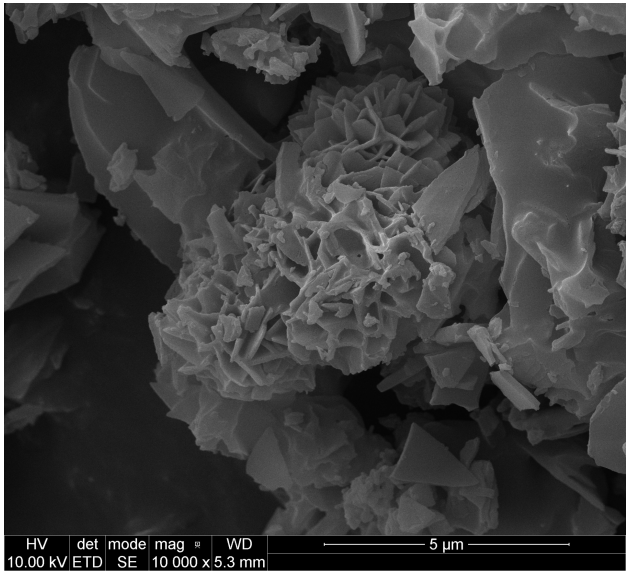
RESULTS



Membrane PPy1



Powder PPy6



Powder PAni1

Set of SEM images for samples recovered with powder polypyrol (PPyr6), powder polyaniline (PAni1) and membranes from polypyrol (PPyr1).

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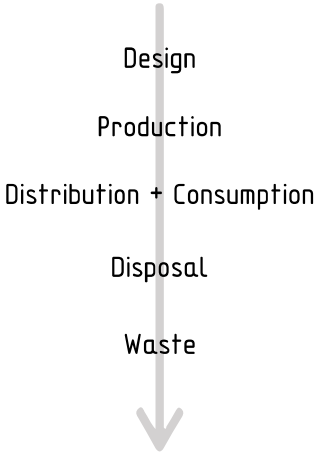
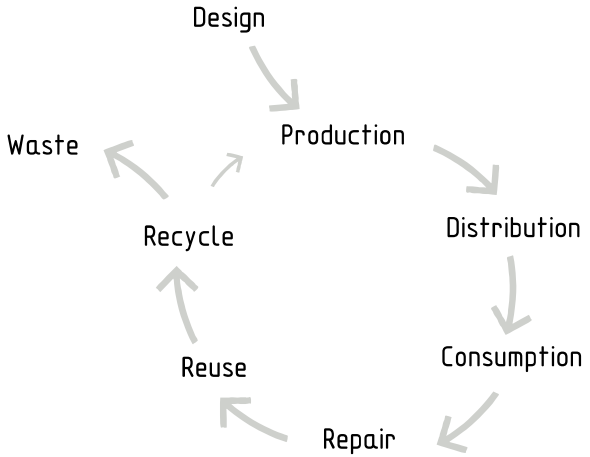
CHANGE

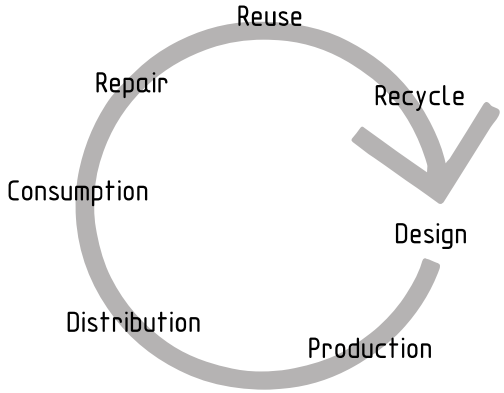
Linear Economy



Recycle Economy



Circular Economy



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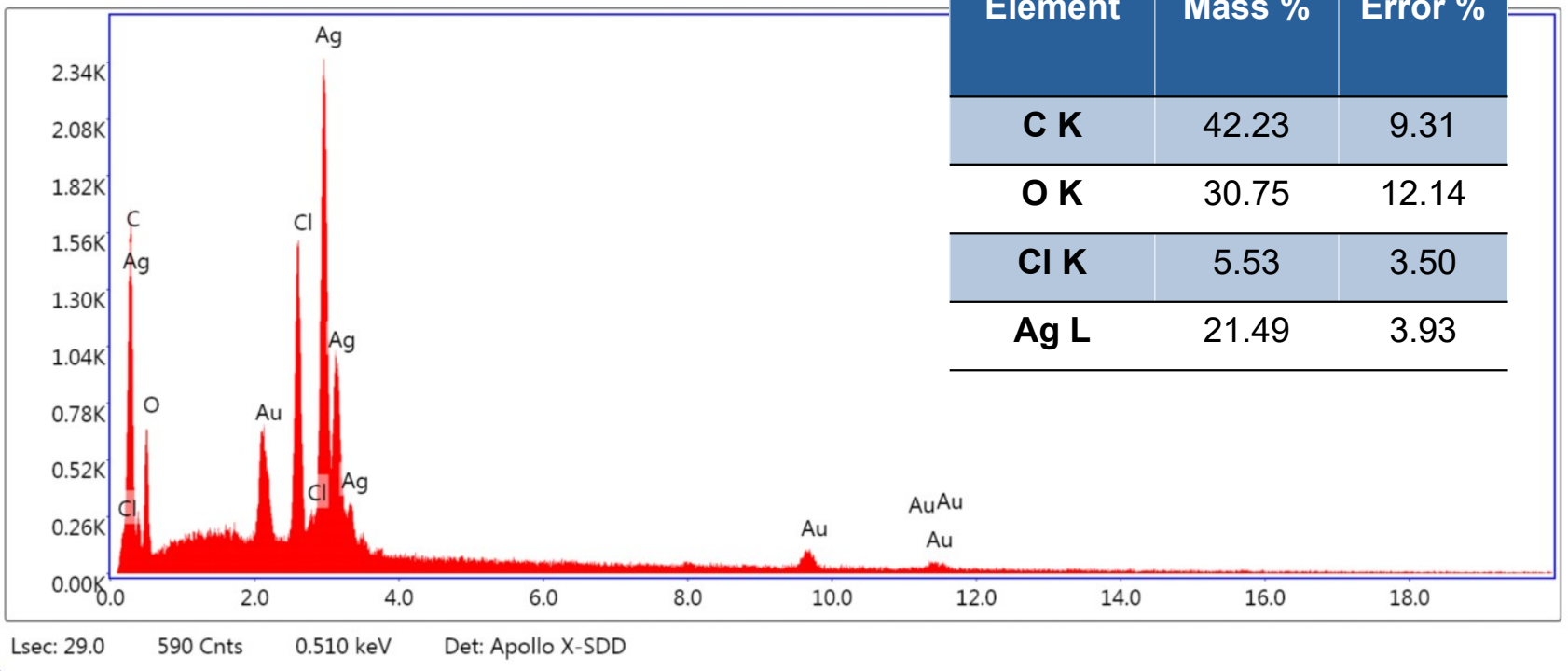
RESULTS



Element	Mass %	Error %
C K	42.23	9.31
O K	30.75	12.14
Cl K	5.53	3.50
Ag L	21.49	3.93

EDS analysis results for samples recovered with membrane (PPyr1) from polypyrrol

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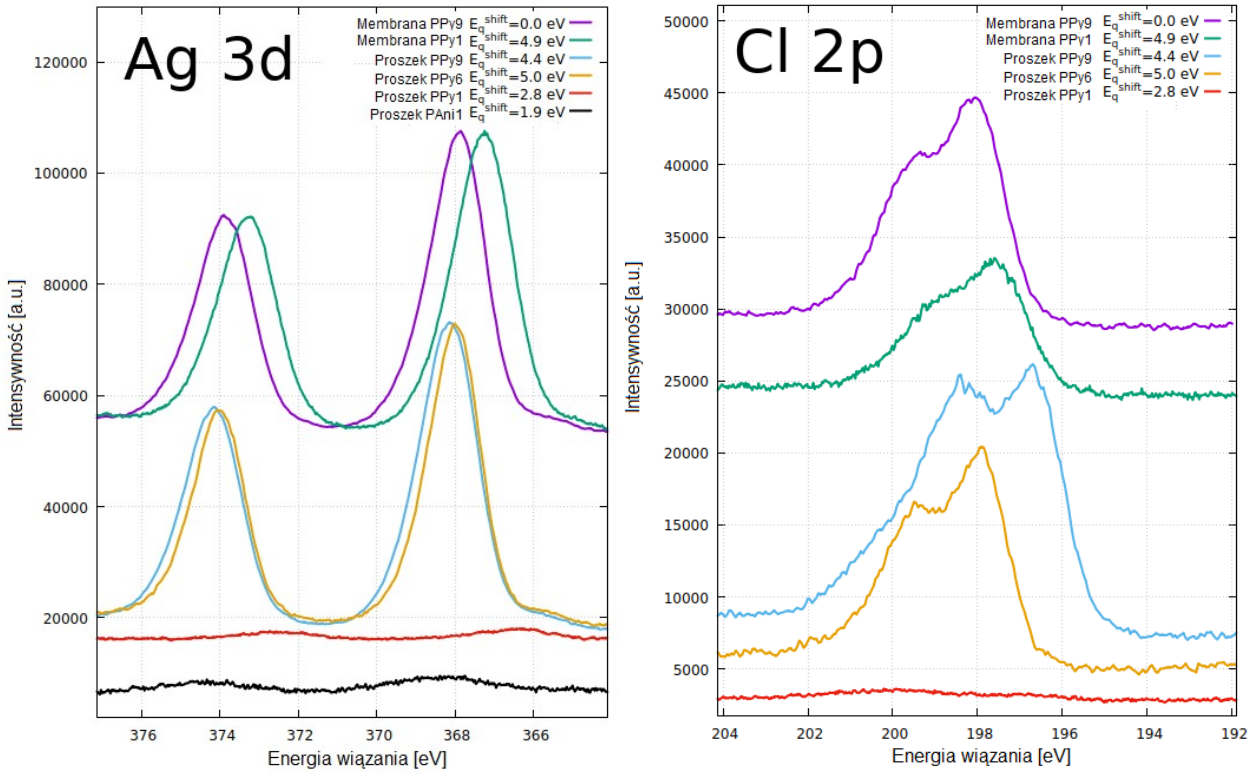
RESULTS



XPS results for samples recovered with powder polypyrol (PPyr1, PPyr6, PPyr9), powder polyaniline (PAni1) and membranes from polypyrol (PPyr1, PPyr9)

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DISCUSSION & CONCLUSIONS

Nanoparticles may have core-shell structer with silver on the outside. With chloride ion beeing nessesary to initiate forming of the AgCl structures on the surface of the polymer.

Potential influence of the interfering ions from the solution, and the impact of counterions on changes in the yield of the recovery process. – in progress

Composite materials can be used in different branches of the industry according to their properties and characteristation.

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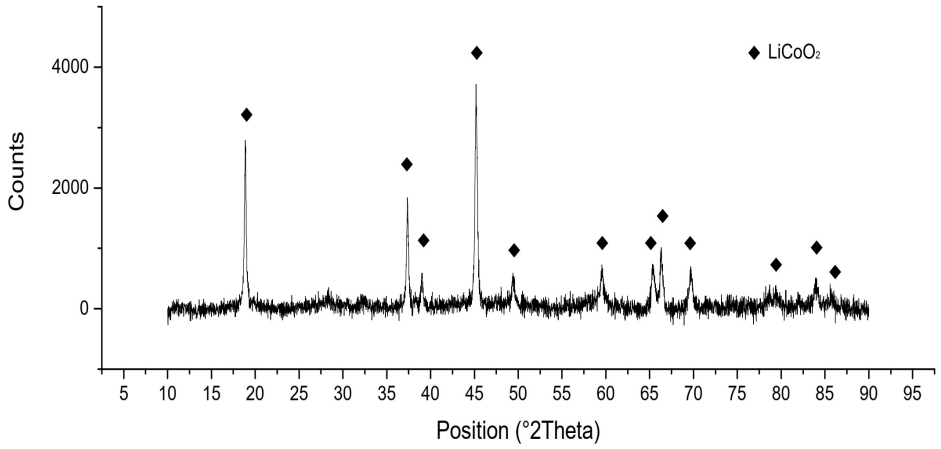
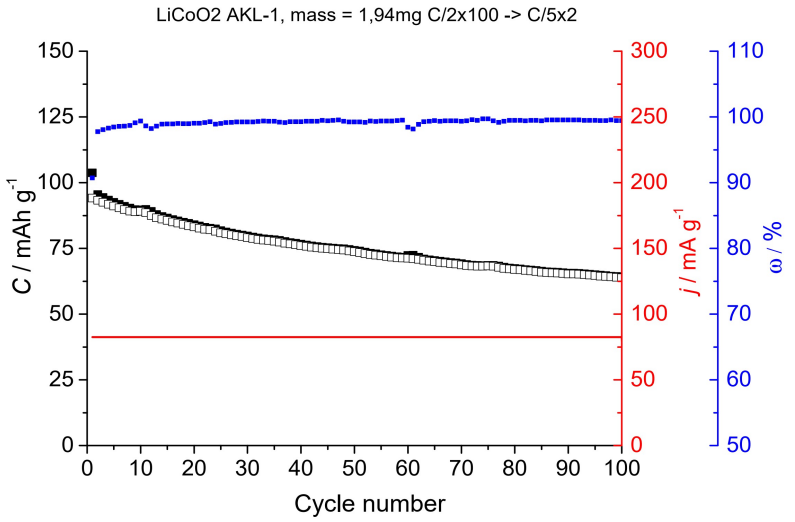
Future?

Research activities

Research activities - Lithium-ion batteries?





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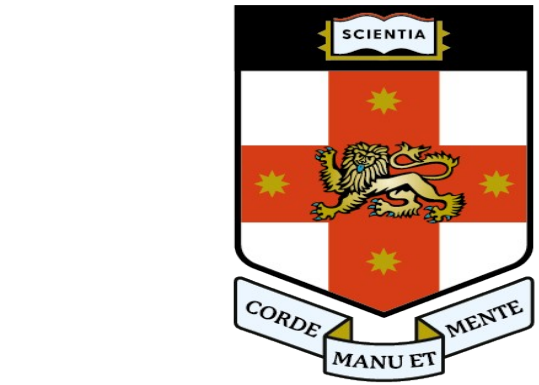
Appreciations



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