ScuDo

Scuola di Dottorato ~ Doctoral School

WHAT YOU ARE, TAKES YOU FAR

XXXIV Cycle

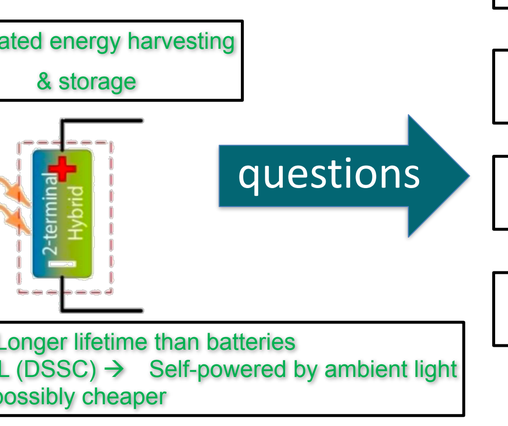
# Integrated energy havresting & storage systems for a sustainable future


## Roberto Speranza

## Supervisor: Prof. Andrea Lamberti


## Research context and motivation

30 billion of connected Internet of Things (IoT) devices by 2025 (source: IoT Analytics)

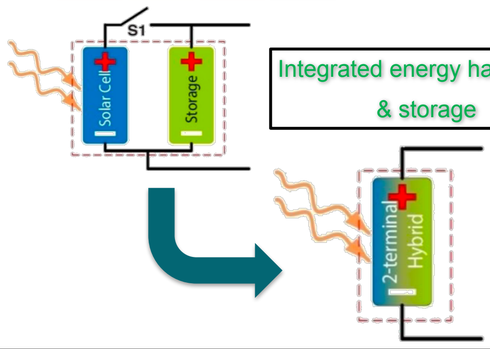



Waste management

BILLIONS OF BATTERIES

Raw materials availability

## Addressed research questions/problems


Integrated energy harvesting & storage

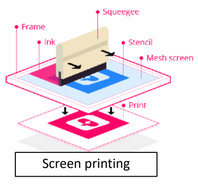
questions

- Real life application (can it really work?)
- Scalability (can be done at large scale?)
- Efficiency (is it worth it?)
- Flexibility (wearable application?)

- SUPERDAPACITOR (SC) → Longer lifetime than batteries
- DYE-SENSITIZED SOLAR CELL (DSSC) → Self-powered by ambient light
- SC+DSSC → Greener, safer, possibly cheaper

## Adopted methodologies

### Scalable fabrication techniques




Screen printing

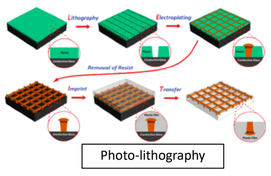
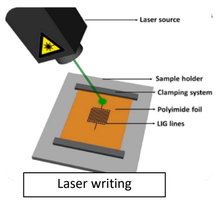
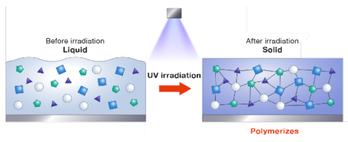



Photo-lithography

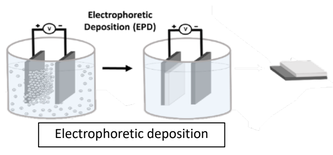



Laser writing




UV photo-polymerization

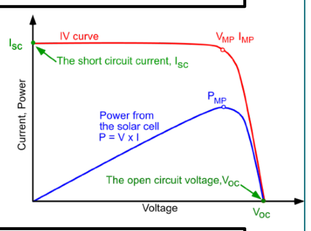
Vacuum pouch-sealing




Electrophoretic deposition

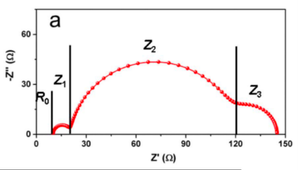
### Electrical

- Current-voltage measurement
- Standard characterization technique for solar harvesting device
- Performed under different light sources



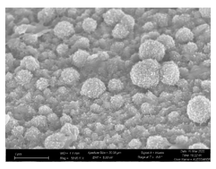

### Electrochemical

- Electrochemical impedance spectroscopy
- Investigate electrochemical processes happening inside the device (e.g. charge transfer, redox reaction, charge diffusion)



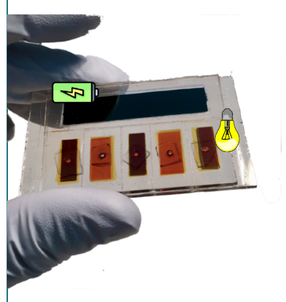

### Morphological

- E.g. scanning electron microscopy (SEM)
- Characterize micro and nanostructured materials



## Novel contributions

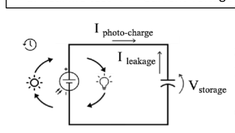
Integrated indoor energy harvesting & storage system

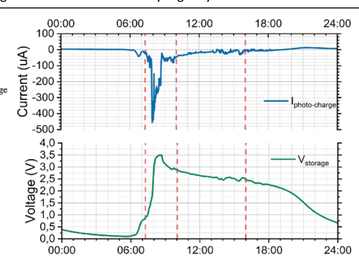


Highlights:
- High output voltage of 3,2 V
- Conversion efficiency of 13 % under indoor light
- Integration on same substrate

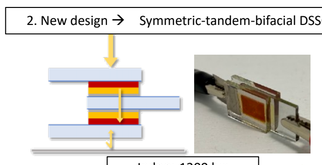
Possible Advancements:
1. Real life compatibility
2. Higher efficiency with new design
3. Higher efficiency with new materials
4. Long-time stability

1. Real life test → Current-voltage behaviour under real day-night cycle in indoor environment

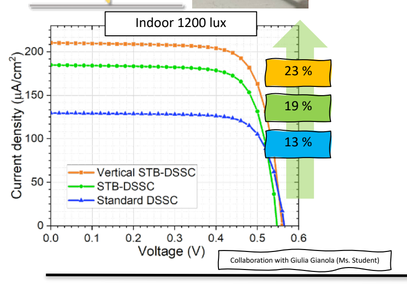



2. New design → Symmetric-tandem-bifacial DSSC

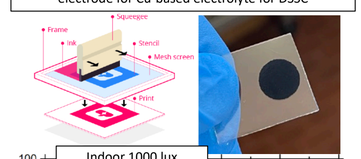


Indoor 1200 lux

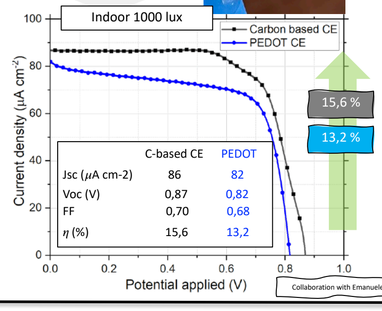



Collaboration with Giulia Gianola (Ms. Student)

2. New materials → Printed carbon-based counter electrode for Cu-based electrolyte for DSSC



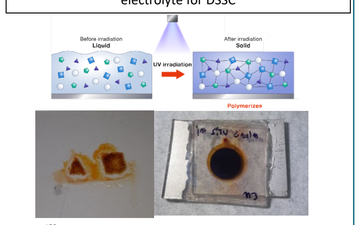

Indoor 1000 lux

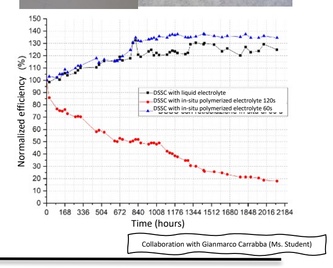



| | C-based CE | PEDOT |
|---|---|---|
| Jsc (μA cm-2) | 86 | 82 |
| Voc (V) | 0,87 | 0,82 |
| FF | 0,70 | 0,68 |
| η (%) | 15,6 | 13,2 |

Collaboration with Emanuele Nettis (Ms. Student)

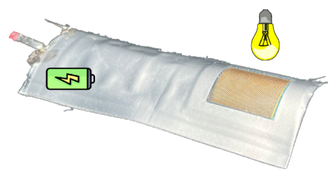
3.Stability → In-sity polymerization of Cu-based electrolyte for DSSC




Collaboration with Gianmarco Carrabba (Ms. Student)

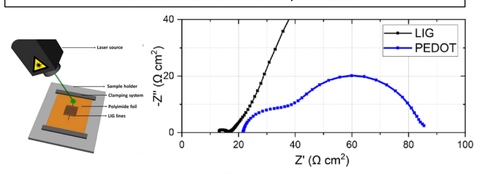
Integrated flexible energy harvesting & storage system

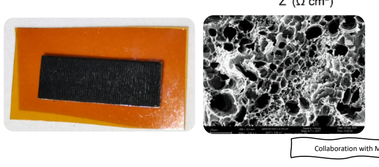


Highlights:
- Shared pouch-sealing fabrication
- Good stability under bending stress

Possible Advancements:
- Higher efficiency with new materials
- Easier fabrication process

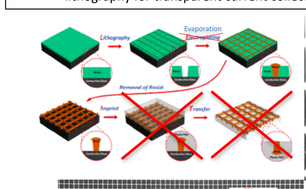
Higher efficiency with new materials→ Laser-induced graphene as counter electrode for Cu-based electrolyte for DSSC

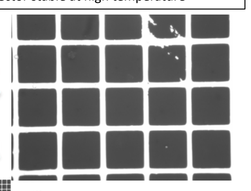


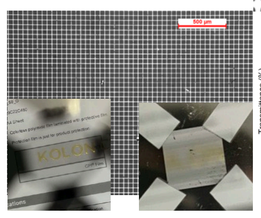



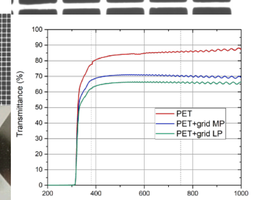
Collaboration with Marco Reina (Ph.d. Student)

Easier fabrication process→ Micro-grid deposited on transparent polyimide by photo-lithography for transparent current collector stable at high temperature



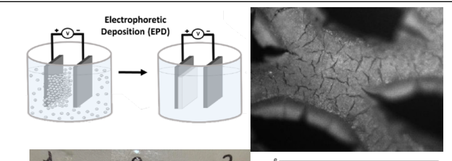



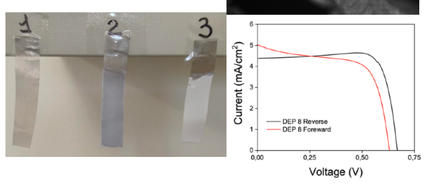





Collaboration with Davide Arcoraci (Ph.D. Student)

Easier fabrication process→ Electrophoretic deposition of $TiO_2$ for flexible photoanode fabrication




Collaboration with Irene Canale (Internship Student)

## Future work

- Time abroad at Tyndall National Institute (Ireland) to interact with experts on real IoT device and sensors and perform real-life test of the prototypes
- Keep working on open projects

## Submitted and published works

Submitted and published Papers:

- Sacco, A. , Speranza, R. , Savino, U. , Zeng, Jq. , Farkhondehfal, Ma. , Lamberti, A. , Chiodoni, A. , Pirri, C.F., "*An Integrated Device for the Solar-Driven Electrochemical Conversion of CO2 to CO*", ACS Sustainable Chemistry & Engineering, vol. 8, no. 20, 2020, pp. 7563–7568
- Speranza, R. , Zaccagnini, P. , Sacco, A. , Lamberti, A. , "*High-Voltage Energy Harvesting and Storage System for Internet of Things Indoor Application*", Solar RRL, vol. 6, no. 9, 2022, 2200245
- Gianola, G. , Speranza, R. , Bella, F. , Lamberti, A. , "*Symmetric-tandem-bifacial dye-sensitized solar cell: a new paradigm to boost photoconversion efficiency above limit*", Applied Energy, 2022, (Submitted)
- Speranza, R. , Zaccagnini, P. , Scalia, A. , Tresso, M. E. , Lamberti, A. , "*Pouch-sealing as an effective way to fabricate flexible dye-sensitized solar cell and their integration with supercapacitor*", Journal of Power Sources, 2022, (Submitted)

Conference contributions:

- Speranza, R. , Stratakis, I. , Zaccagnini, P. , Sacco, A. , Scalia, A. , Tresso, E. M. , Pirri, C. F. , Lamberti, A. , "*Energy harvesting and storage system for indoor application*", ENERCHEM2, Padova, 2020, pp. 160
- Speranza, R. , Reina, M. , Pirri, C. F. , Lamberti, A. ,"*Laser induced graphene for flexible hybrid energy harvesting and storage devices*", 3rd International School on Hybrid, Organic and Perovskite Photovoltaics , Ernogolovka , 2021, pp. 72
- Speranza, R. , Zaccagnini, P. , Lamberti, A. "*High voltage indoor photo-capacitor: flexible and rigid energy source for IoT devices under ambient light* ", ISEECap2022, Bologna, 2022, pp 152

## List of attended classes

- 01SHMRV – Entrepreneurial Finance (14/2/2022, 5)
- 01DMMKG – Impedance spectroscopy for electrochemical processes (20, 10/2/2022)
- 08IXTRV – Project management (31/1/2022, 5)
- 01UNVRV – Navigating the hiring process: CV, tests, interview (13/7/2021, 2)
- 01LXBRW – Life Cycle Assessment (13/7/2021, 25)
- 02RBYKI – From science to business: how to get technology out of laboratories and into practical applications (8/7/2021, 20)
- 01LEXRP – Strumenti e tecnologie per lo sviluppo del prodotto (7/6/2021, 25)
- 02LWHRV – Communication (20/11/2020, 5)
- 01UNXRV – Thinking out of the box (6/11/2020, 1)
- 01UKHKI – Applied spectroscopic methods (15/6/2020, 27)
- 01QORRV – Writing Scientific Papers in English (5/6/2020, 15)
- 01SWPRV – Time management (20/3/2020, 2)
- 01RISRV – Public speaking (19/3/2020, 5)
- 01UOGIY – Photo-Electro-Catalytic Technologies for a Sustainable Chemical Industry (19/12/2019, 20)

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