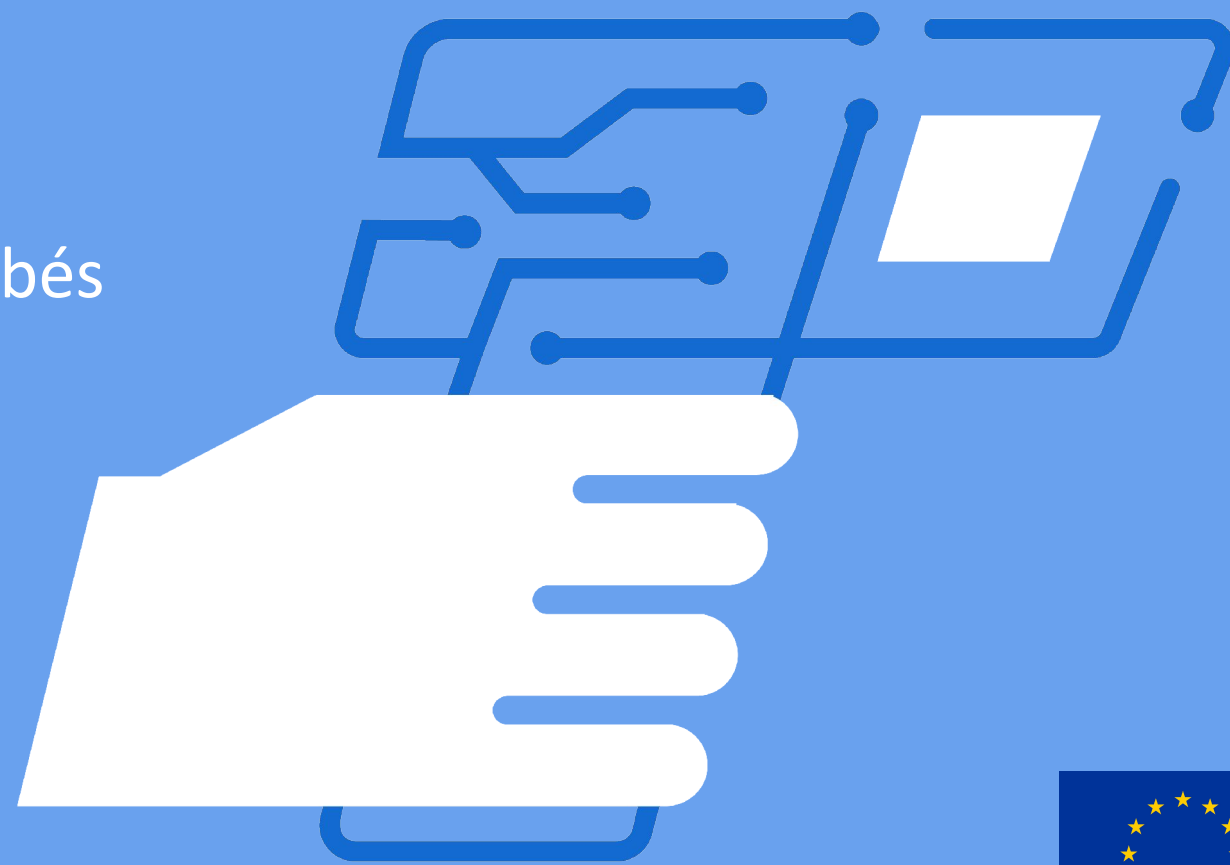


An embedded Optoelectronic system for non-destructive monitoring of polymer ageing

Presented by :

Mohamed Ben Chouikha & Alejandro Ribés



CONTEXT & CHALLENGES

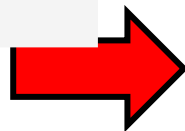
Why do we care about polymer ageing?



126
operational
nuclear
reactors in the
EU



Source
Foratum



Lot of applications !

Cables



1500 km of cables
on a nuclear unit
including 50 km in
reactor building

Seals



Painting



But also,
pipes, seal valve for tap, etc ...

These materials play a crucial role in
nuclear security issues



CONTEXT & CHALLENGES

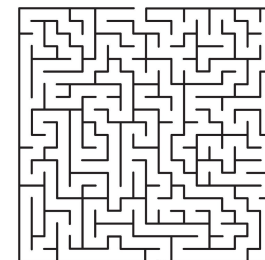
Few figures...



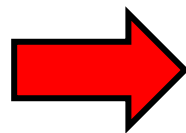
5 Tons of polymers are present in reactor building

□ Surface $\approx 8000 \text{ m}^2$

(equivalent to the surface of a football field)



□ **1500 km** of cables on a nuclear unit including 50 km in reactor building



Ageing monitoring is therefore crucial

CONTEXT & CHALLENGES

- CURRENT SAMPLING

- High costs of maintenance
Inspection of a couple of hundred meters of water pipes (non contaminated) : 400 k€ every 18 months
- Invasive sampling
- Time-consuming
- Difficulty of sampling for various reasons (for example radioprotection)

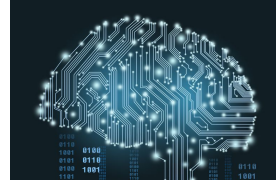


Need for non-invasive polymer ageing characterization

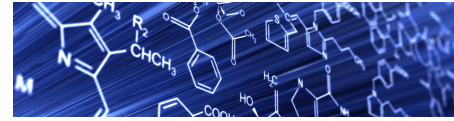


From ambition to implementation

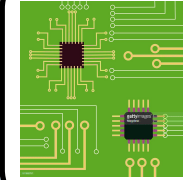
- Synergy of skills
- Solid partnership Sorbonne Université-EDF
 - Several internship
 - Several Ph.D.



DATA
SCIENCE



MATERIAL SCIENCE



MICRO-
ELECTRONICS

French Patent: N° 3 059 104
International patent:
PCT N° EP2017/079543



les
TROPHÉES
de la R&D

Prix Scientifique : Mention spéciale du jury

- EU funded project





El-Peacetolero

EUROATOM

European Project

Grant agreement 945320 - El Peacetolero

EUROATOM - Innovation Action

Sept 2020 – Fev 2025

Grant amount : 2 999 236.00 €



Consortium



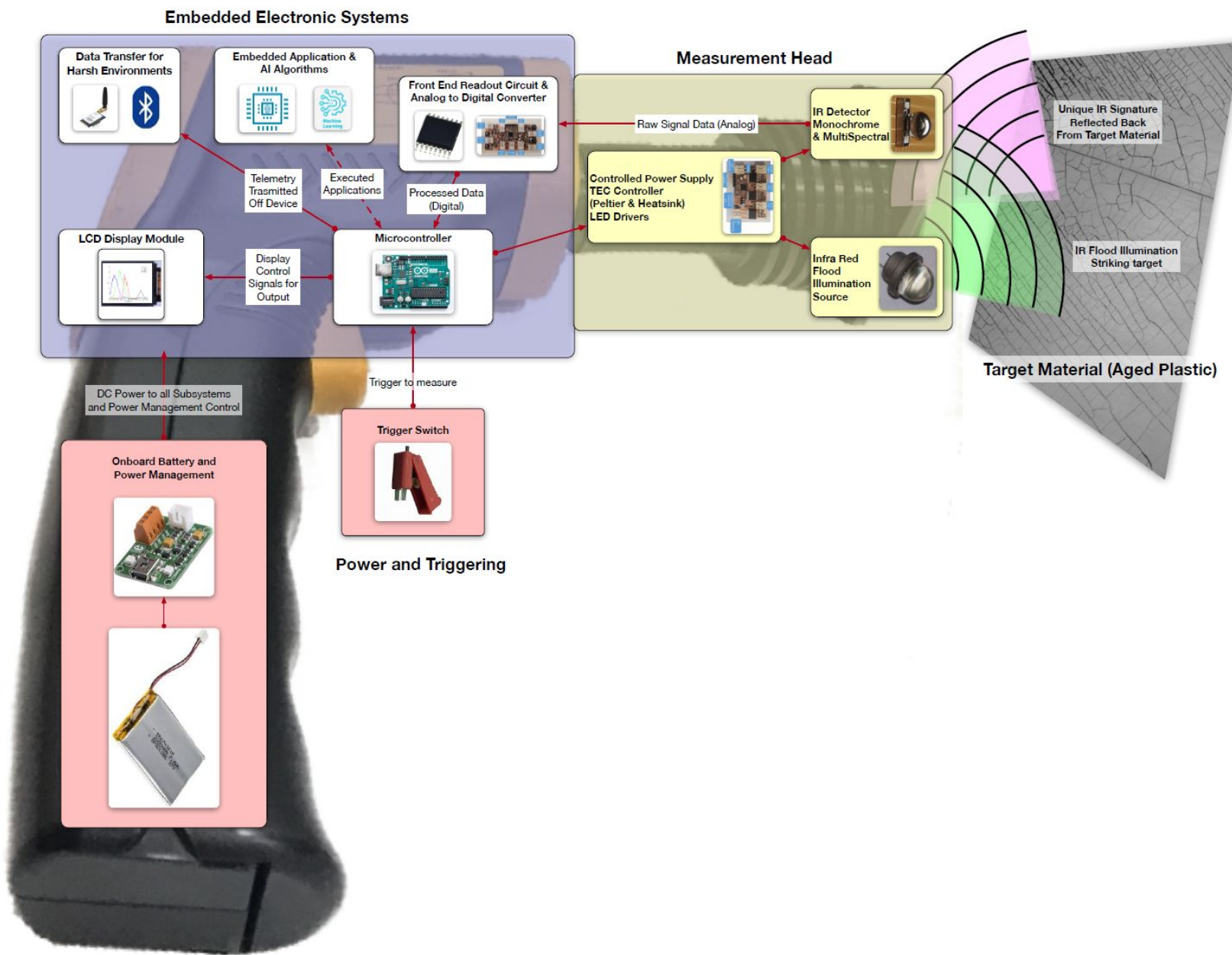
INSTITUTE OF ENERGY AND CLIMATE RESEARCH



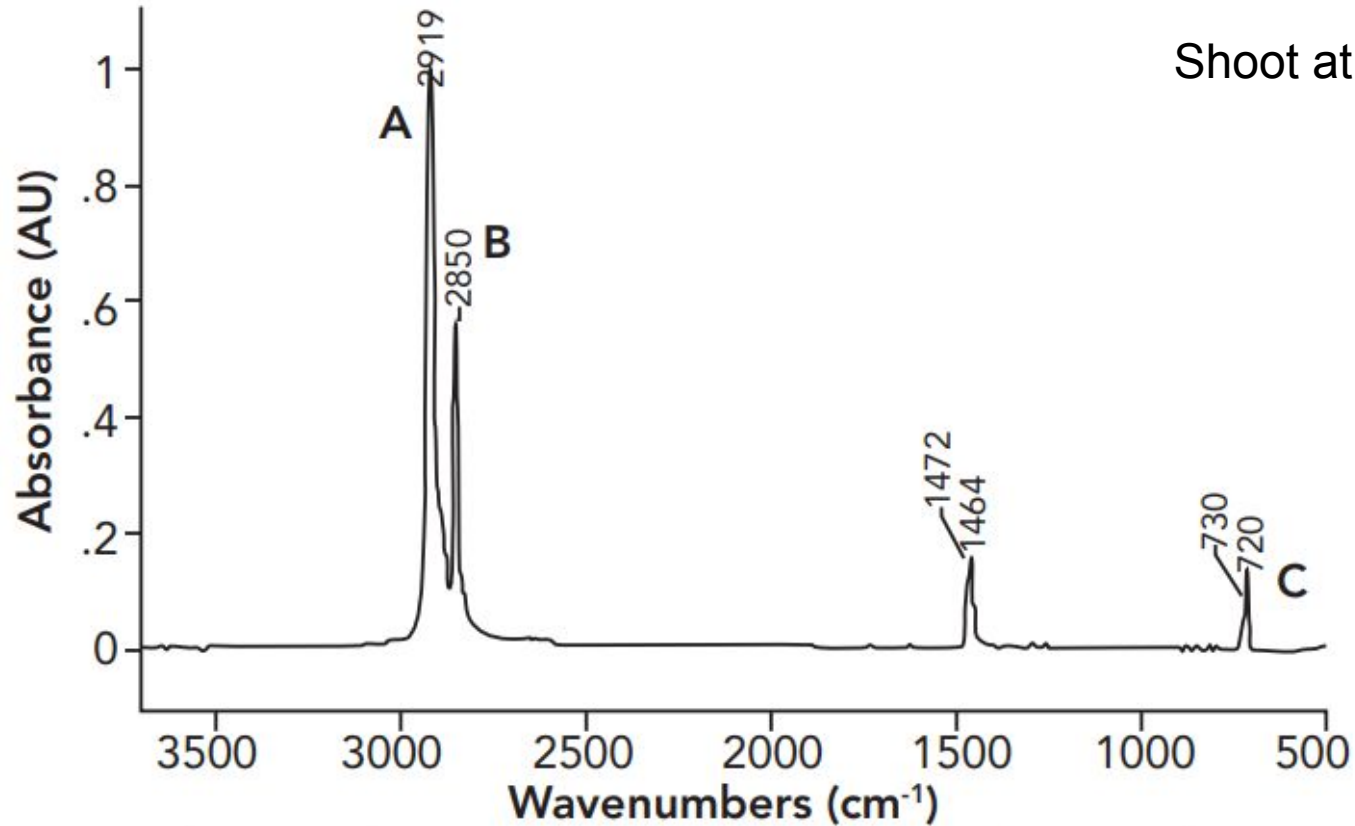
Laboratoire UMR 8507



The tool



Principle of operation



Shoot at the specific wavelengths

A	2919	CH ₂ Asymmetric C-H stretch
B	2850	CH ₂ Symmetric C-H stretch
C	730, 720	Split CH ₂ rock



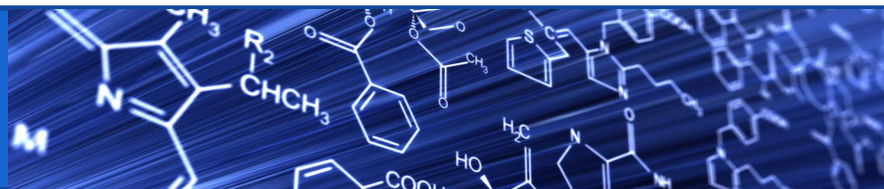


EI-Peacemaker

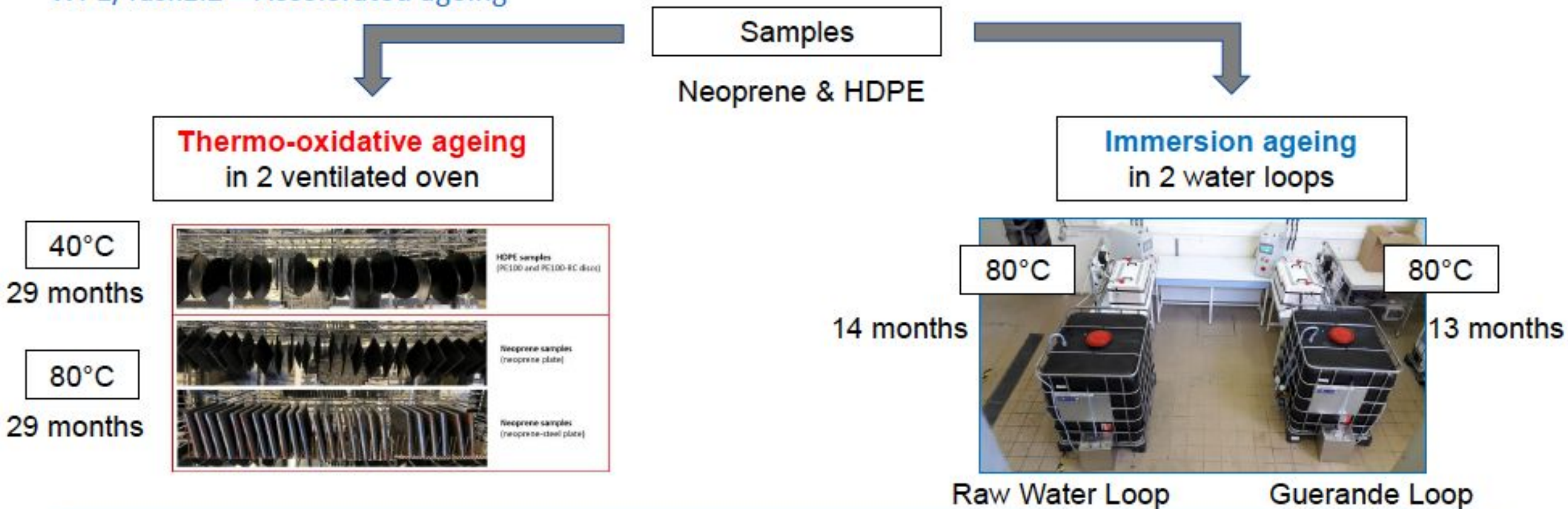
Key Results

Monitoring Ageing Markers



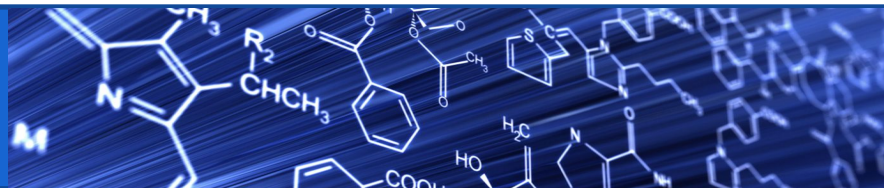


WP1/Task1.2 – Accelerated ageing

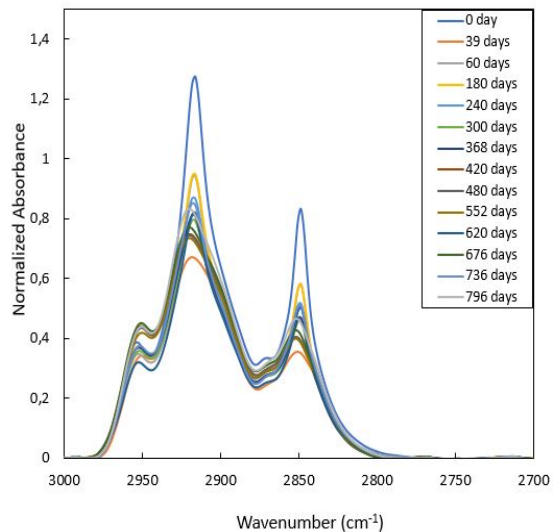


- Raw Water Loop: reconstituted **river water** = demineralized water + river water ($7.5 < \text{pH} < 9$)
- Guerande Loop: reconstituted **chlorinated salt water** = demineralized water + salt + bleach water ($[\text{NaCl}] = 35 \text{ g/L}$, $[\text{free chlorine}] = 1\text{-}2 \text{ ppm}$, $7.5 < \text{pH} < 9$)

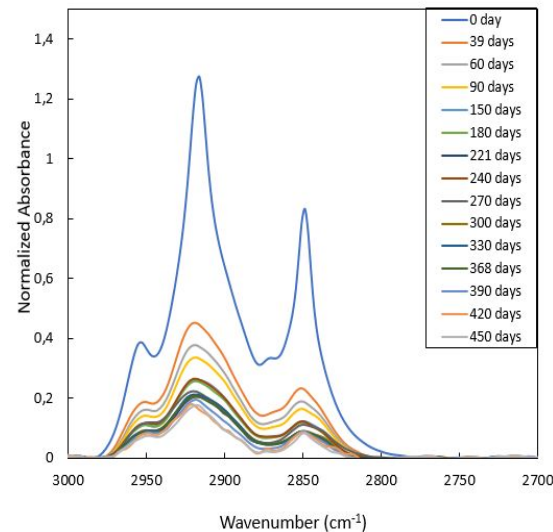




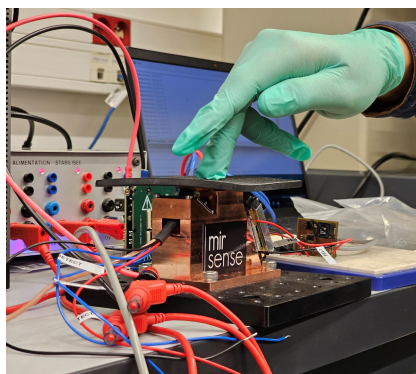
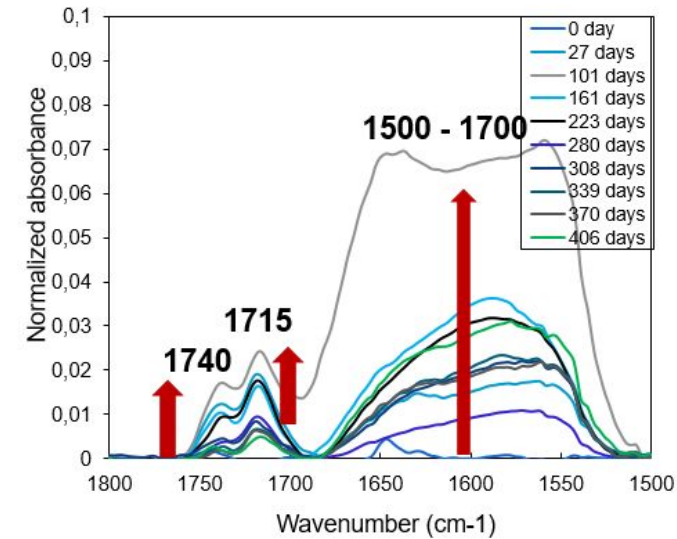
Neoprene Air 40°C



Neoprene Air 80°C



PE100 eau salée chlorée reconstituée 80°C



Ageing Criteria





EI-Peacetero

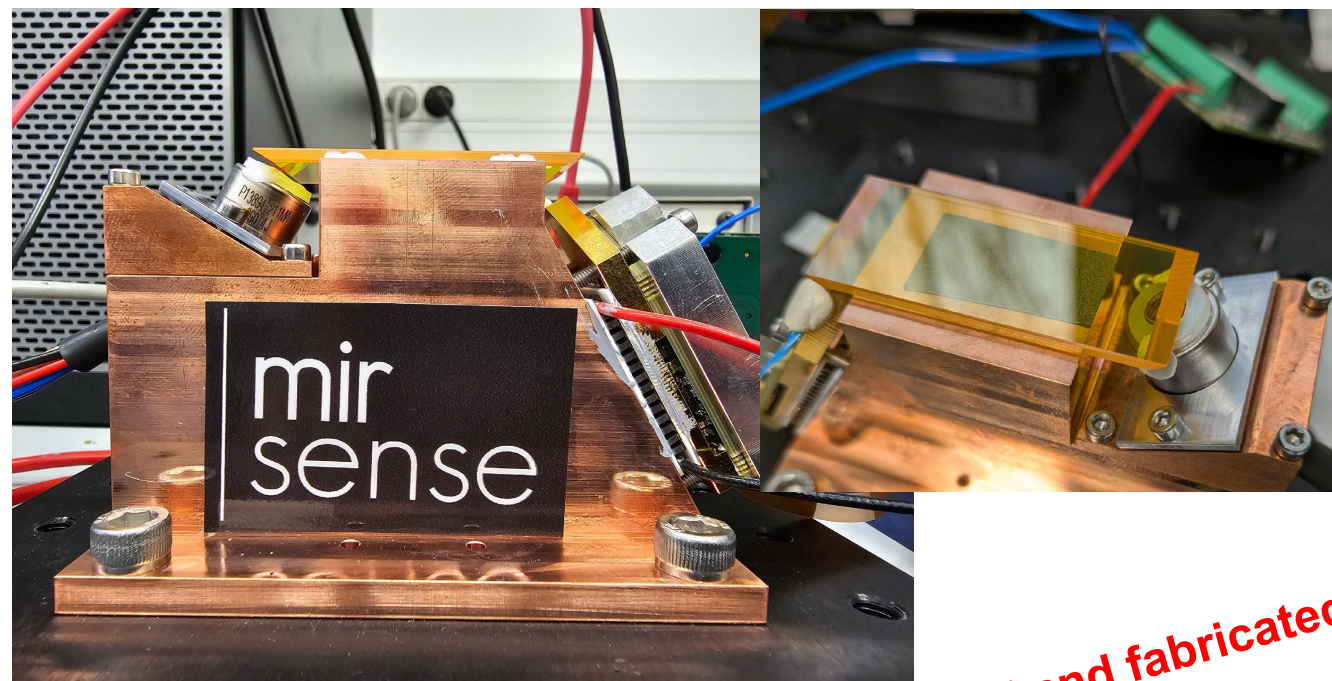
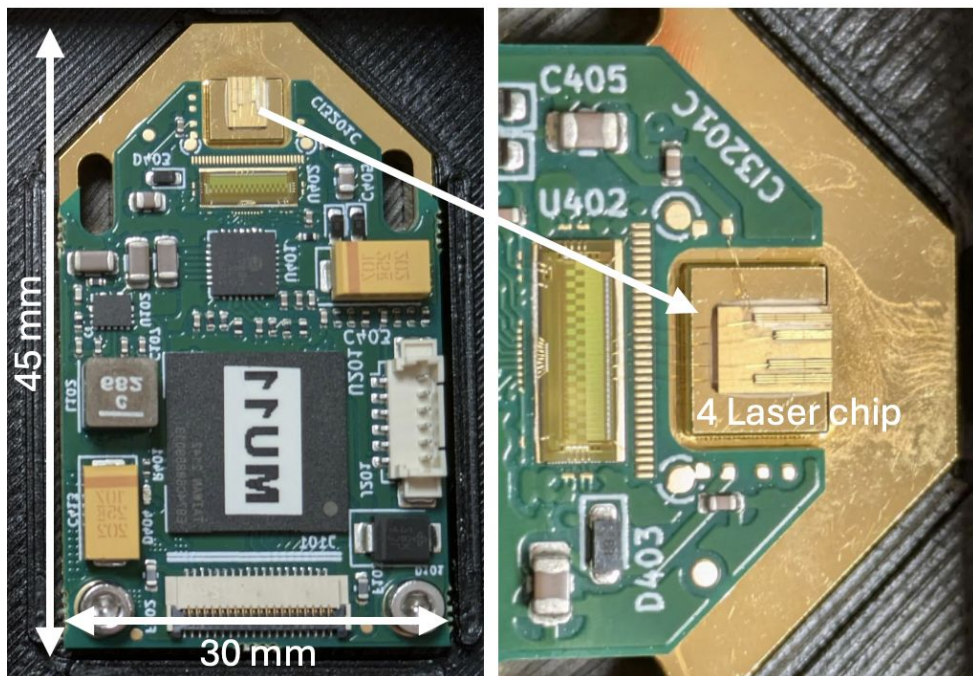
Key Results

**Compact LED & QCL
measurement Heads**



Key results

Compact Multi-Lambda (4 QCL Laser head)



Designed and fabricated
by mirSense





EIPeacetero

Key Results

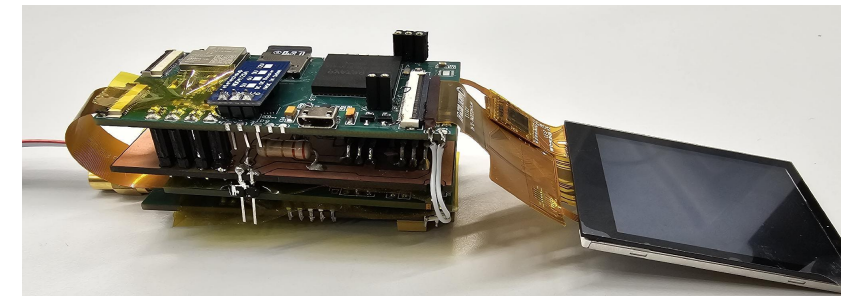
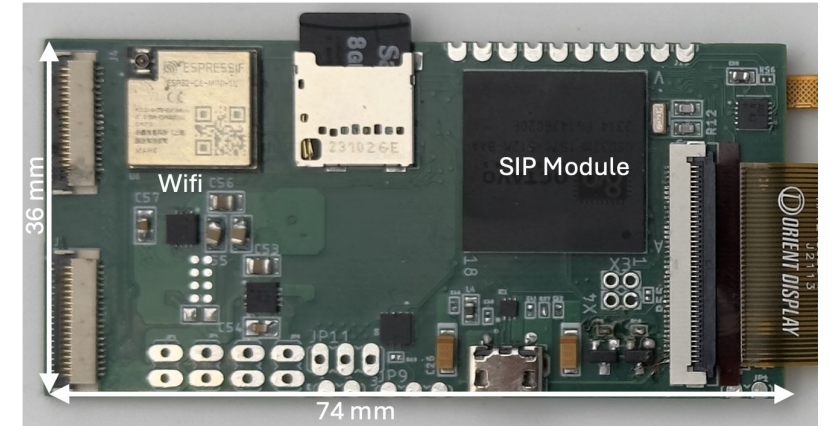
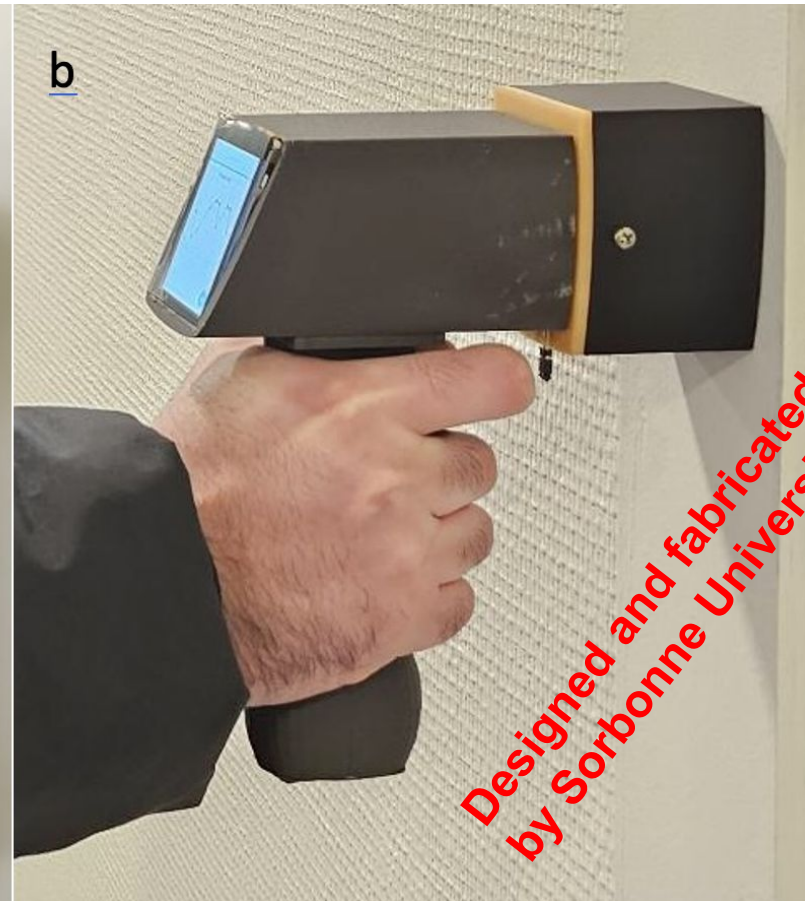
**Embedded
Optoelectronic System**



Embedded Electronic System

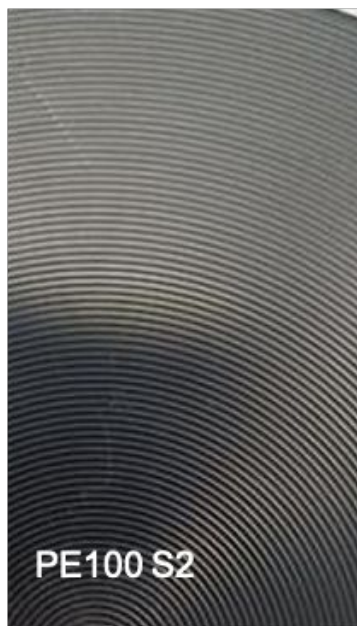
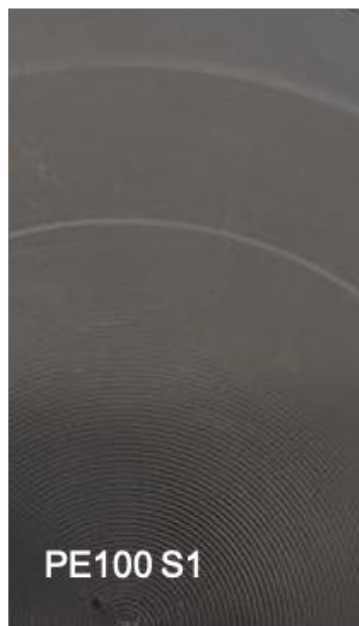
WP3 KEY RESULTS

Compact hardware for Edge computing and Tiny ML



Key results

EI-Peacetolero measurements vs FTI-ATR spectroscopy



Surface1
K/S : 40
Initial Sample

Surface2
K/S : 18
Initial sample

Neoprene
K/S : 400
Initial sample

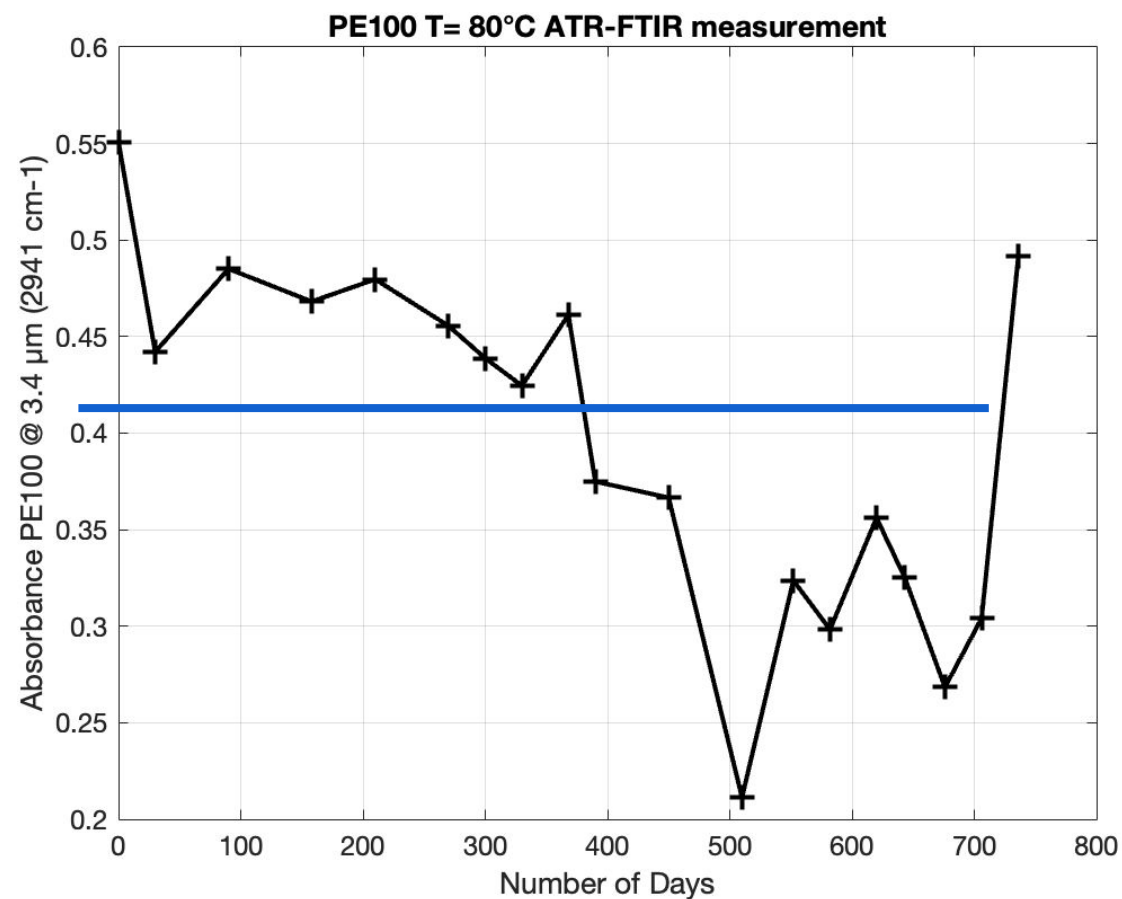
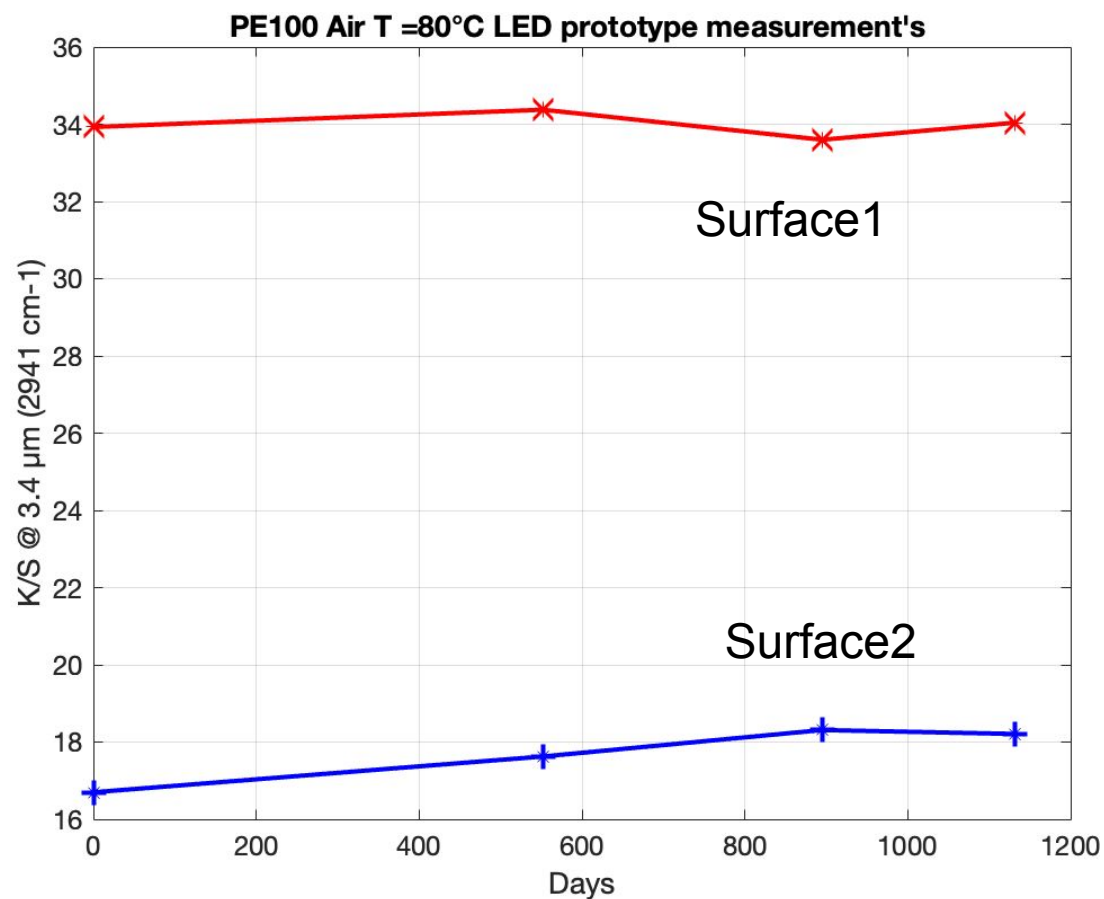
EI-Peacetolero measurements @ 3.4 μm

EI-Peacetolero measurements can be used for polymer identification



Key results

El-Peacetolero measurements vs FTI-ATR spectroscopy

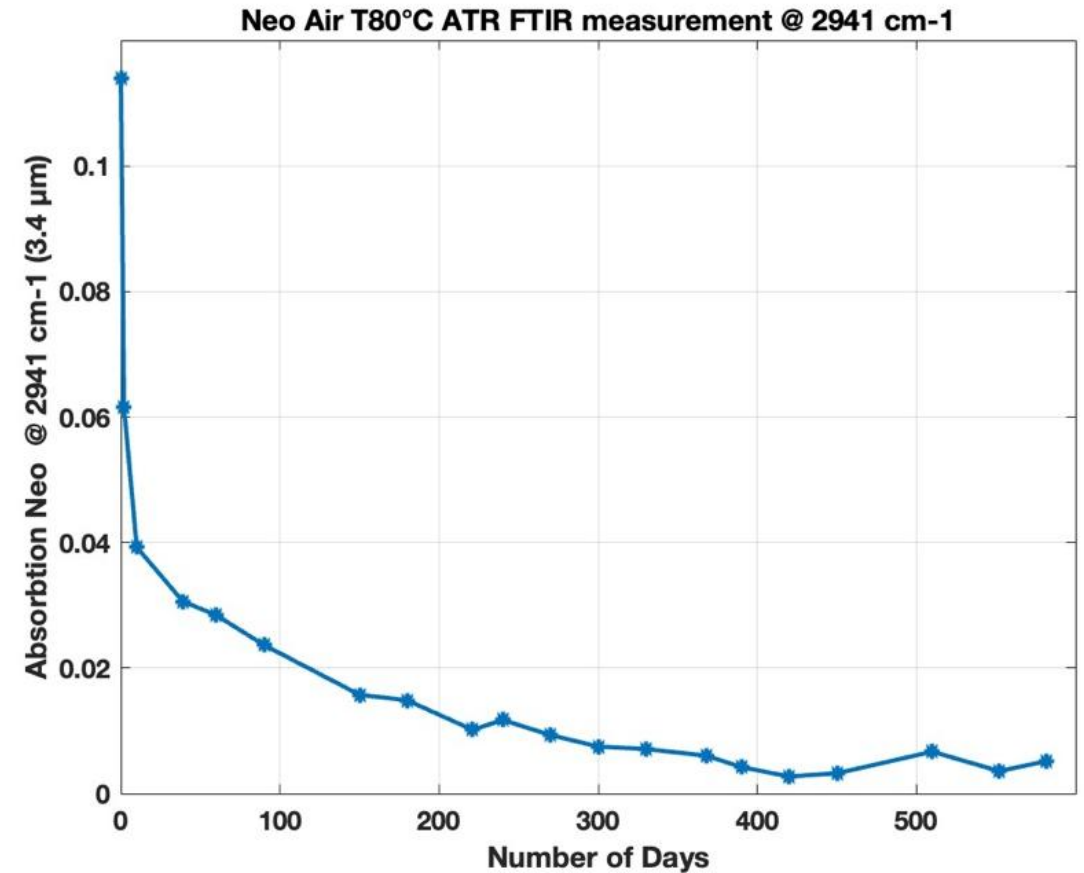
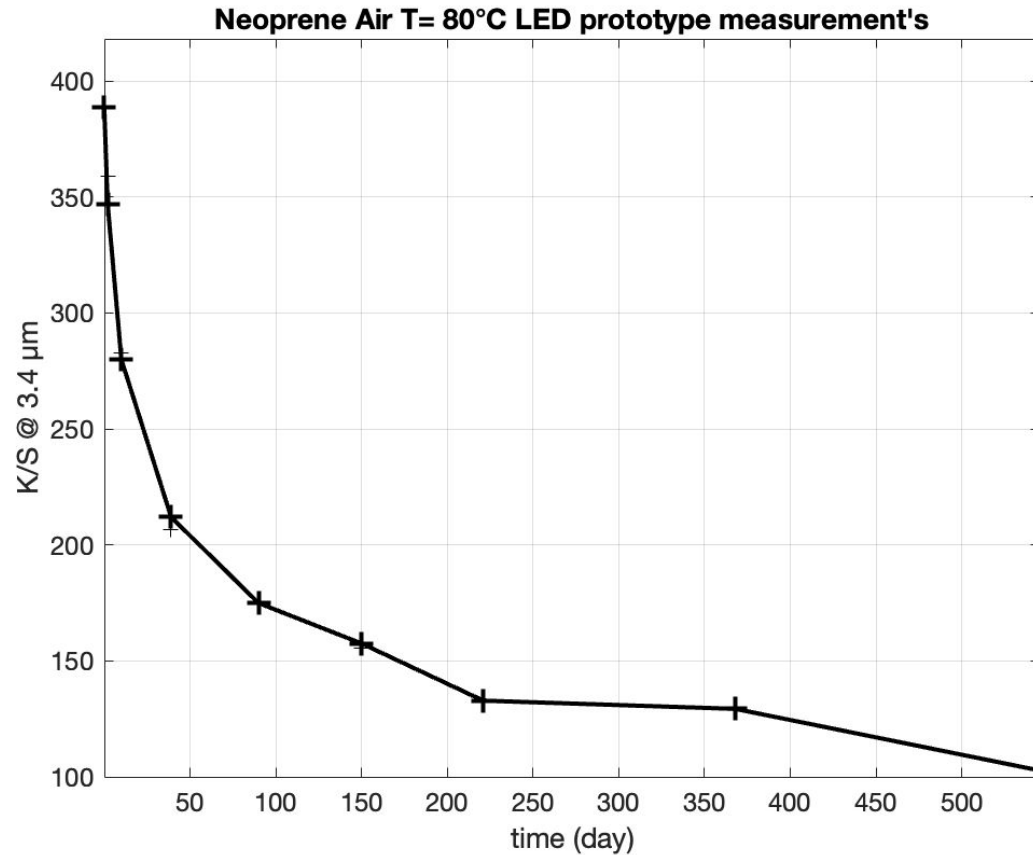


PE100: El-Peacetolero K/S measurements @ 3.4 μm are consistent with ATR-FTIR absorption measurements



Key results

El-Peacetolero measurements vs FTI-ATR spectroscopy

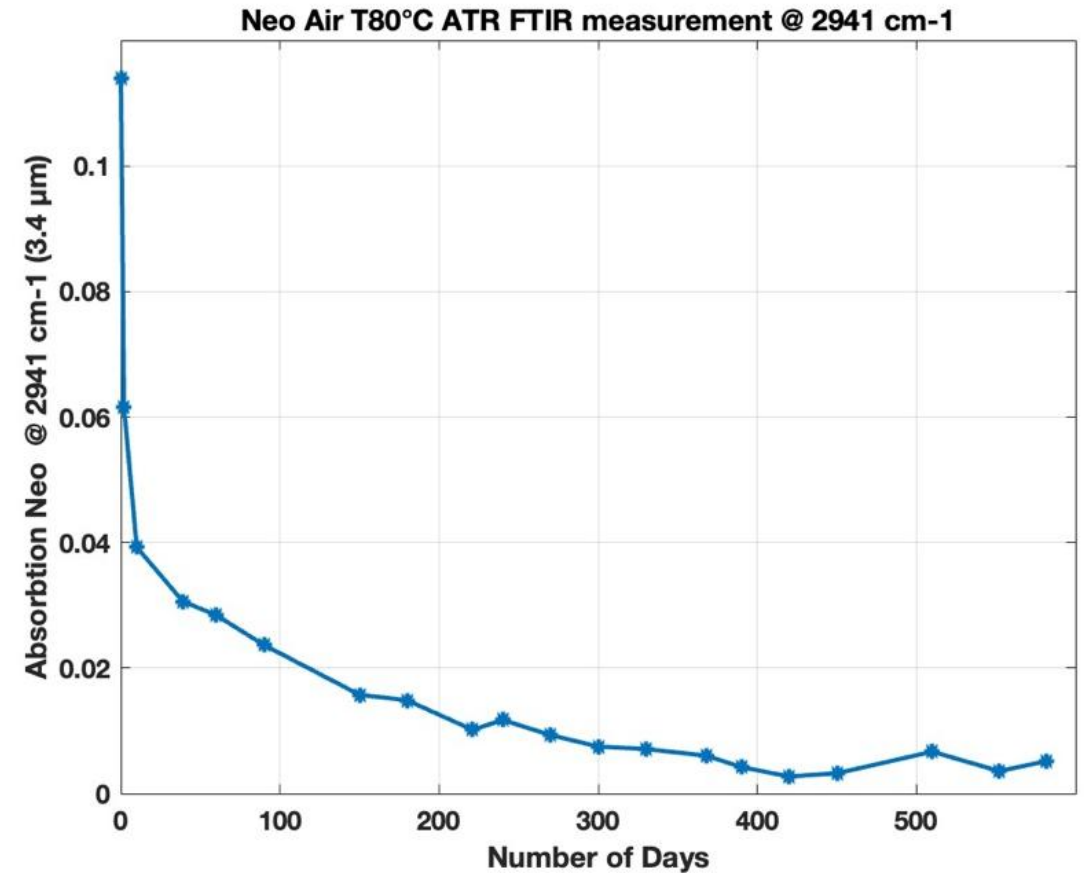
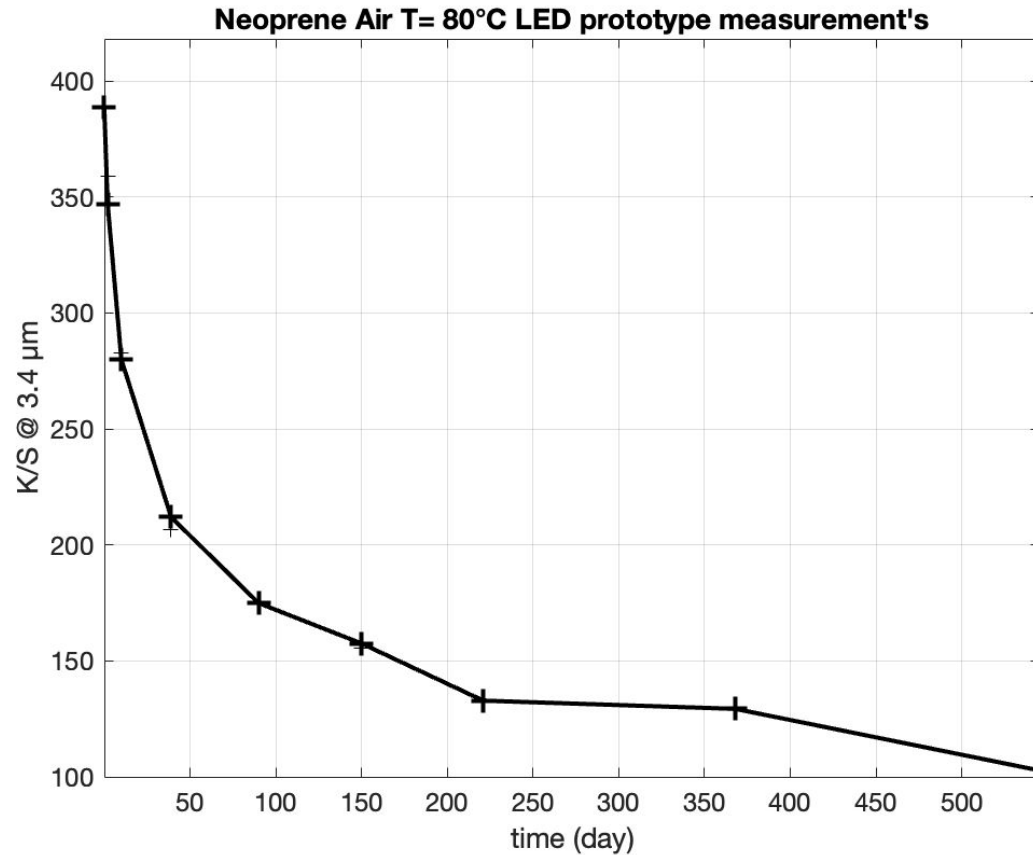


Neoprene: El-Peacetolero K/S measurements @ 3.4 μm are consistent with ATR-FTIR absorption measurements



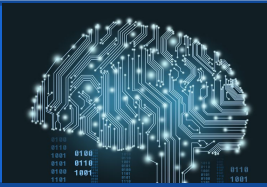
Key results

El-Peacetolero measurements vs FTI-ATR spectroscopy

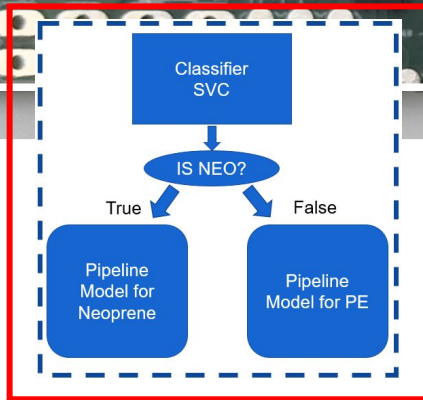
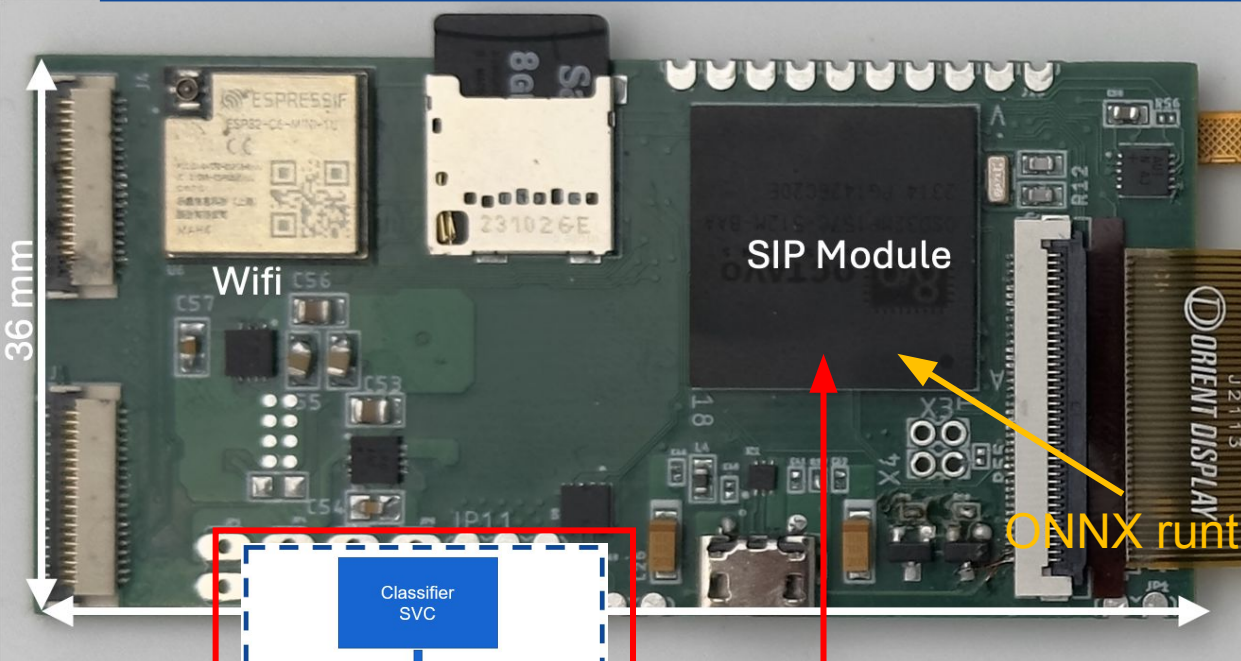


El-Peacetolero measurements can be used for ageing diagnosis





$$c_k = \int_{\lambda_{min}}^{\lambda_{max}} l_k(\lambda)r(\lambda)o(\lambda)\alpha(\lambda)d\lambda$$



- ONNX models executed on the **Tiny ML** platform
 - Runtime on the Tiny board
 - Time performance of the algorithm is excellent
 - Very low memory usage

```

root@stm32mp157c-osd32:~# python3.11 onnixinfer_tests.py
Batch size: 1
  Avg inference time: 0.000850 seconds
  Avg memory used: 0.025000000 MB
  Throughput: 1176.85 inferences per second
=====
Batch size: 5
  Avg inference time: 0.000733 seconds
  Avg memory used: 0.000781250 MB
  Throughput: 6820.01 inferences per second
=====
Batch size: 10
  Avg inference time: 0.000729 seconds
  Avg memory used: 0.000781250 MB
  Throughput: 13724.82 inferences per second
=====
Batch size: 50
  Avg inference time: 0.000812 seconds
  Avg memory used: 0.002343750 MB
  Throughput: 61572.28 inferences per second
=====
Batch size: 100
  Avg inference time: 0.000855 seconds
  Avg memory used: 0.001562500 MB
  Throughput: 116904.62 inferences per second
=====
  
```

Inference time

Less than one millisecond

Memory usage

A few Kb



El-Peacetero

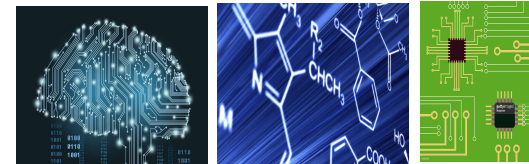
Current Ambitions

Industrial implementation



What are the next steps ?

- VALIDATION OF INDUSTRIAL PROTOTYPE TRL8 TRL9
 - Test on other polymers
 - Prototype Test in NPPs: GenII, GenIII+, GenVI
- INCORPORATING TECHNOLOGICAL ADVANCES
 - AI-Augmented Sensor
- TAILORING TO OTHER APPLICATIONS
 - Aerospace,
 - Automotive
 - Environment
 - ...
- SET UP A START-UP
 - Connection to investors



Polymers are Everywhere !



- **VALIDATION OF TRL6 PROTOTYPE**
 - Non-invasive polymer ageing management (NPP's LTO)
 - Synergy of skills
 - Solid collaboration between industry and University
 - # EURATOM
- **CURRENT AMBITIONS AND NEXT STEPS**
 - Validation of higher TRL prototype
 - Industrial Implementation and start-up
- **NEEDED CONNECTIONS TO MOVE FROM AMBITIONS TO IMPLEMENTATION**
 - Prototype test and validation in NPPs (GenII, GenII+, GenIV)
 - Incorporate other innovations: AI augmented sensor
 - Connection to industry: other applications
 - Investors: Financing and subsidies

