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2D Printed Sensors and Their Application

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Welsh Centre for Printing and Coating

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Welsh Government

Cronfa Datblygu Rhanbarthol Ewrop
European Regional Development Fund

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Sensors for Aquatic Monitoring

- Several commercial systems available to measure key parameters:

1. Temperature (5 - 25°C)
2. pH (6-10)
3. Salinity (0-50pss)
4. Dissolved oxygen (0-20mg/l)
5. Total dissolved solids (0-60g/l)
6. Dissolved organic matter
7. Chlorophyl (0-200µg/l)
8. Turbidity (0-3000NTU)
9. Ionic salts (Nitrates etc)
10. …….

Multiparameter Sonde and example sensor units – courtesy RS Hydro

Values in brackets are typical, generally commercial sensors have a wider working range

Data Capture, Retrieval and Management

- Several options available
  - Hand held from the sonde
  - Wireless transmission to a receiving portal
  - Very large data volumes can be generated

- Management
  - Time trend displays
  - Space variation displays
  - ……….
  - Big data analytics

The Need for Printable Sensors and Challenges

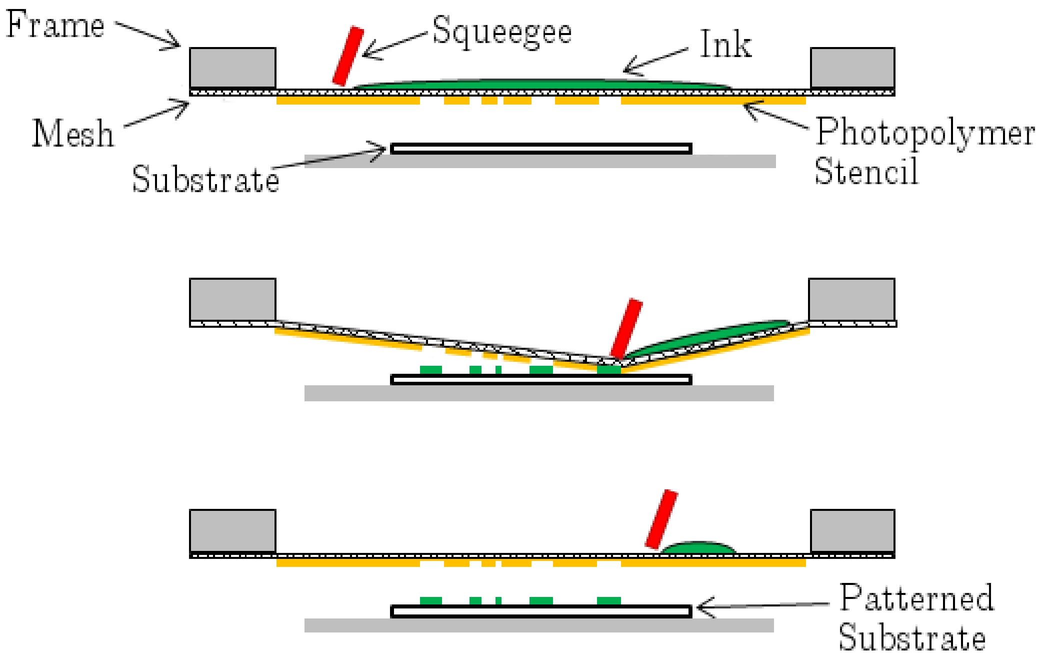
- Commercial systems are accurate, but high cost
  - Sonde + sensors – typically £30k
  - Prevents widespread monitoring of aquatic environments
  - Too costly for farm adoption
- Printable sensors
  - Offer potential for lower cost solutions
  - Sensors to measure a range of parameters may be fabricated as an integrated system
- Challenges
  - Measurement accuracy – calibration against laboratory and commercial devices
  - Survival in a harsh environment
  - Working duration

Potential Printed Sensors

1. Temperature (5 - 25°C)
2. Conductivity
3. pH (6-10)
4. Dissolved oxygen (0-20mg/l)
5. Salinity (0-50pss) – via conductivity
6. Total dissolved solids (0-60g/l) – via conductivity and temperature

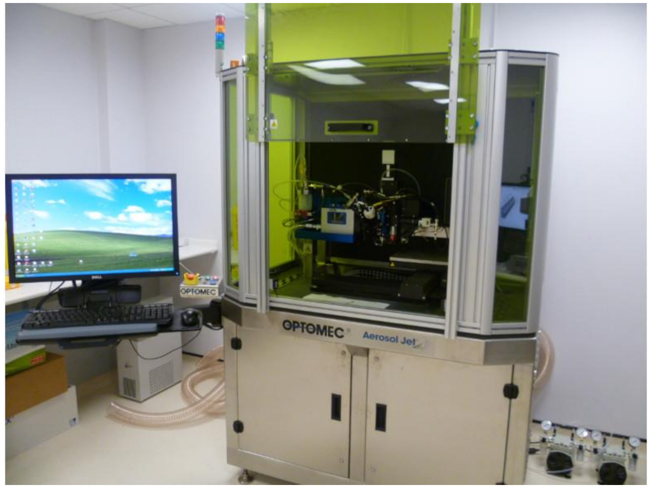
Remaining parameters may be measured by optical methods (being developed by Waterford)

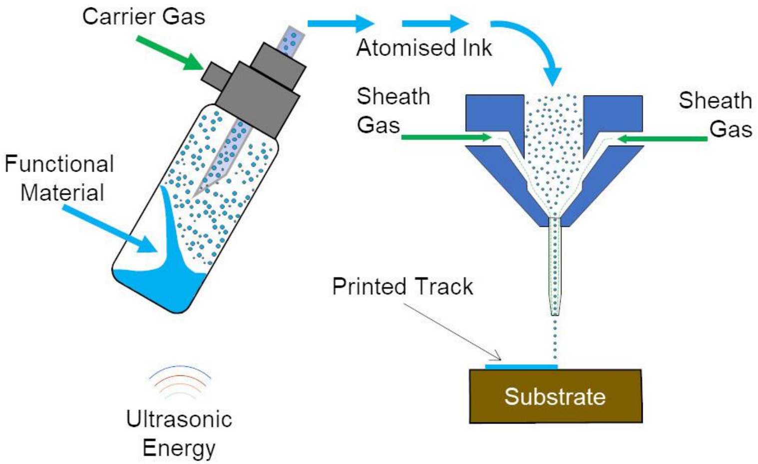
Potential Printing Methods - Screen

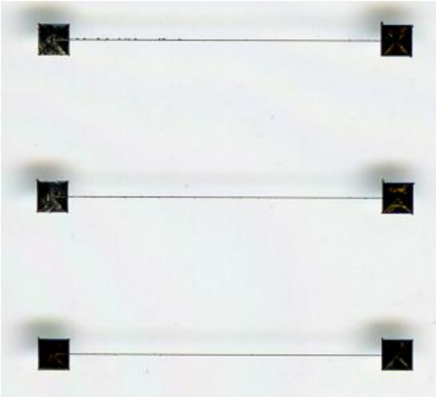


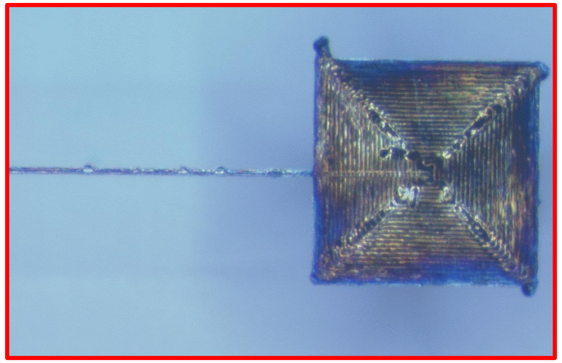
Screen is the current principal process for commercial sensor printing

Potential Printing Methods – Aerosol Jet

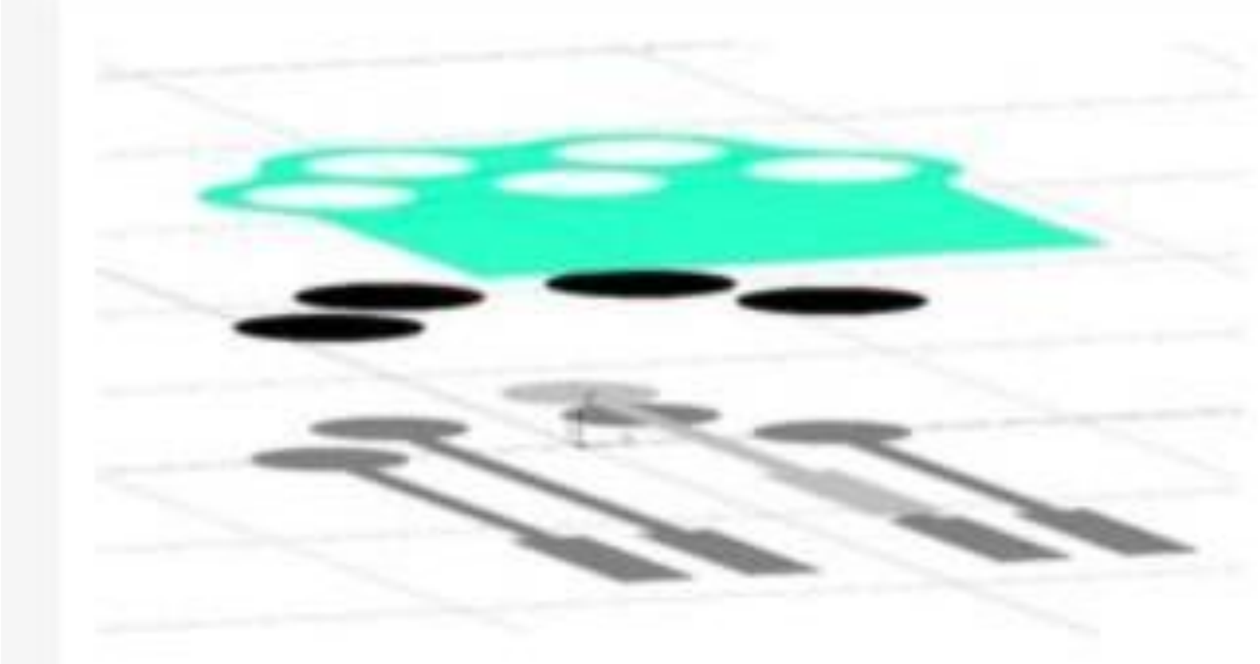


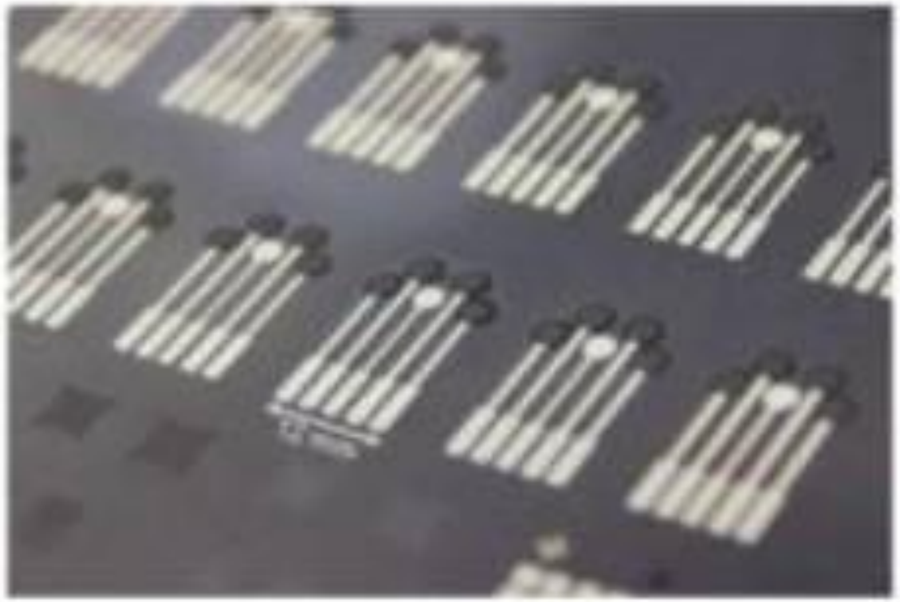




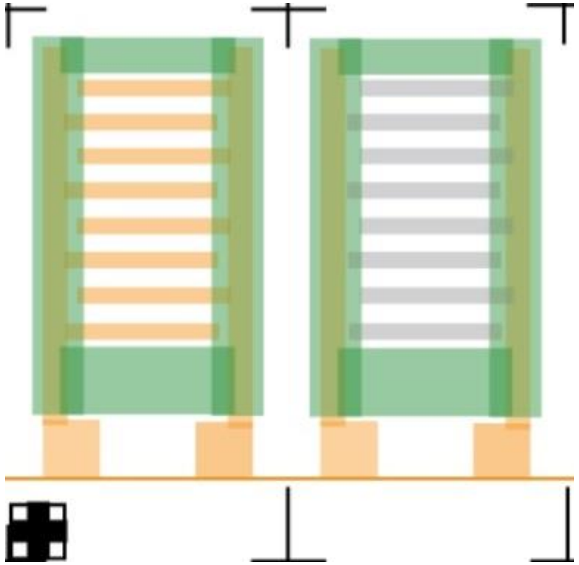


Fabricating a Sensor – multiple layers

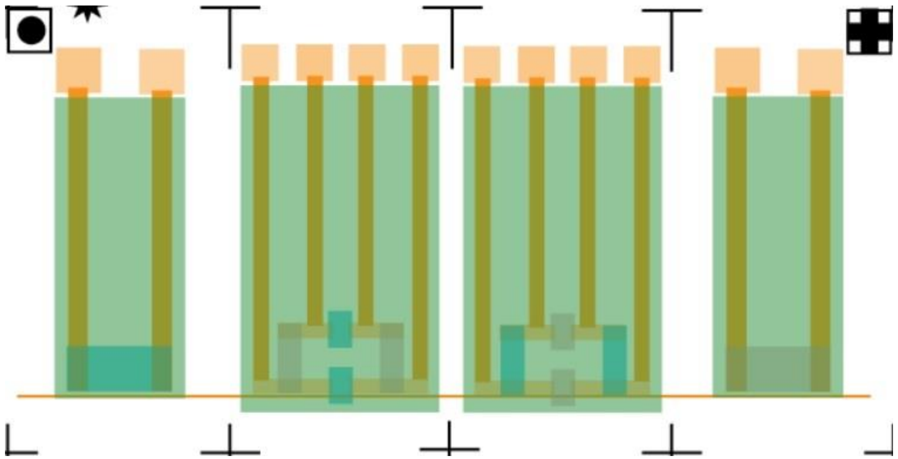




Screen Printed STREAM Sensors – Initial Study



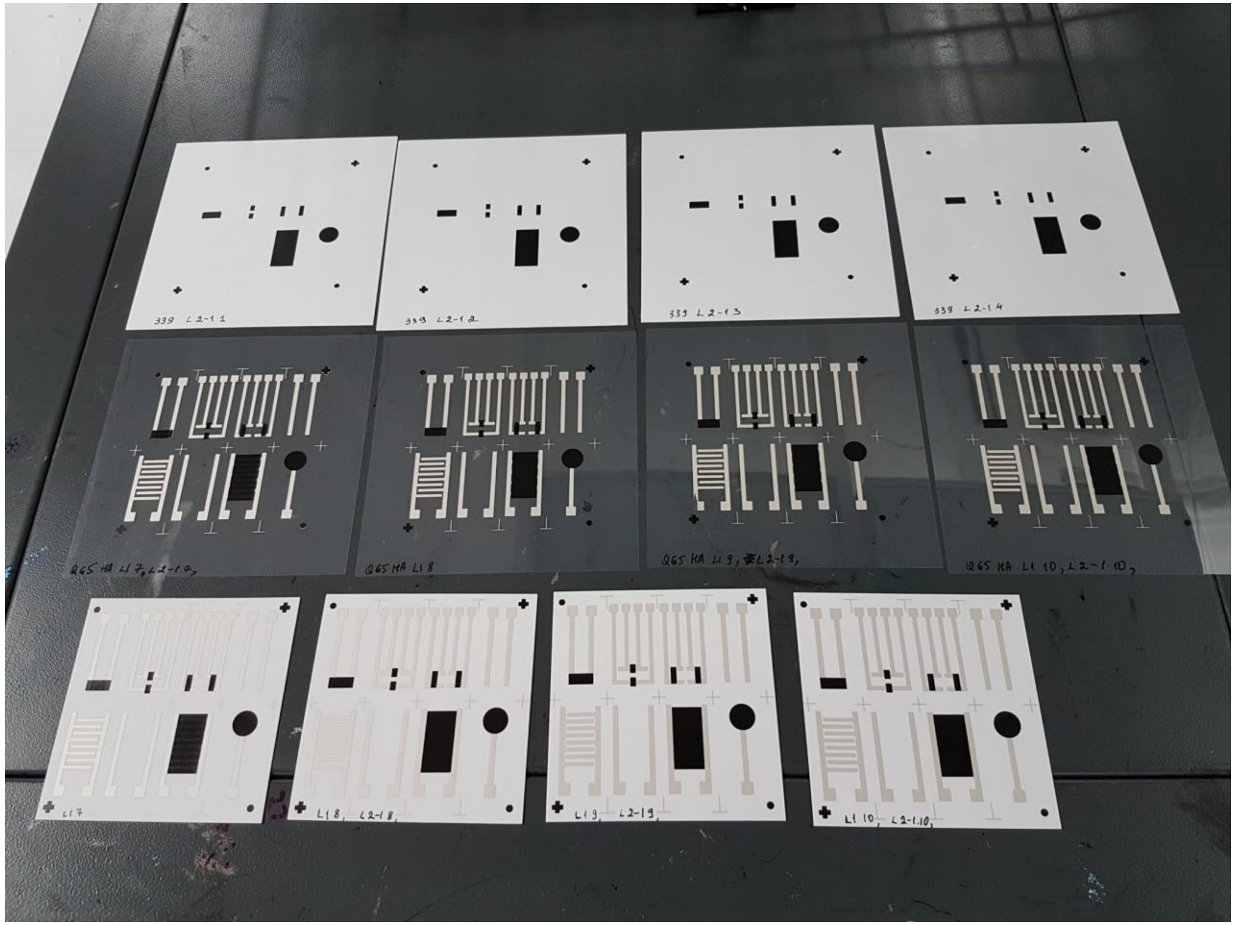
Conductivity



Temperature

Silver Conducting Track Layer

Carbon PEDOT:PSS Sensing Layer



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Dielectric/Protecting Layer

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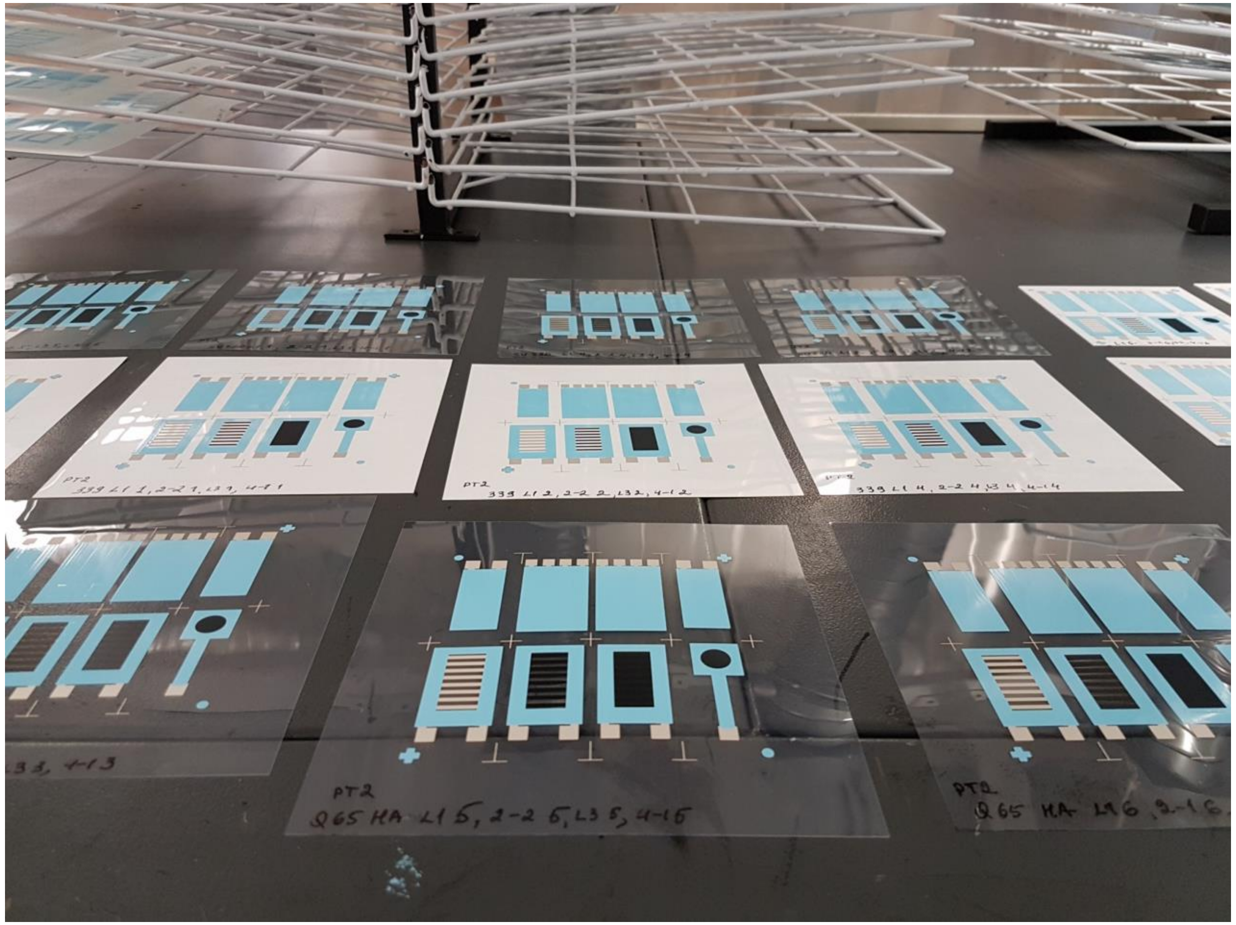
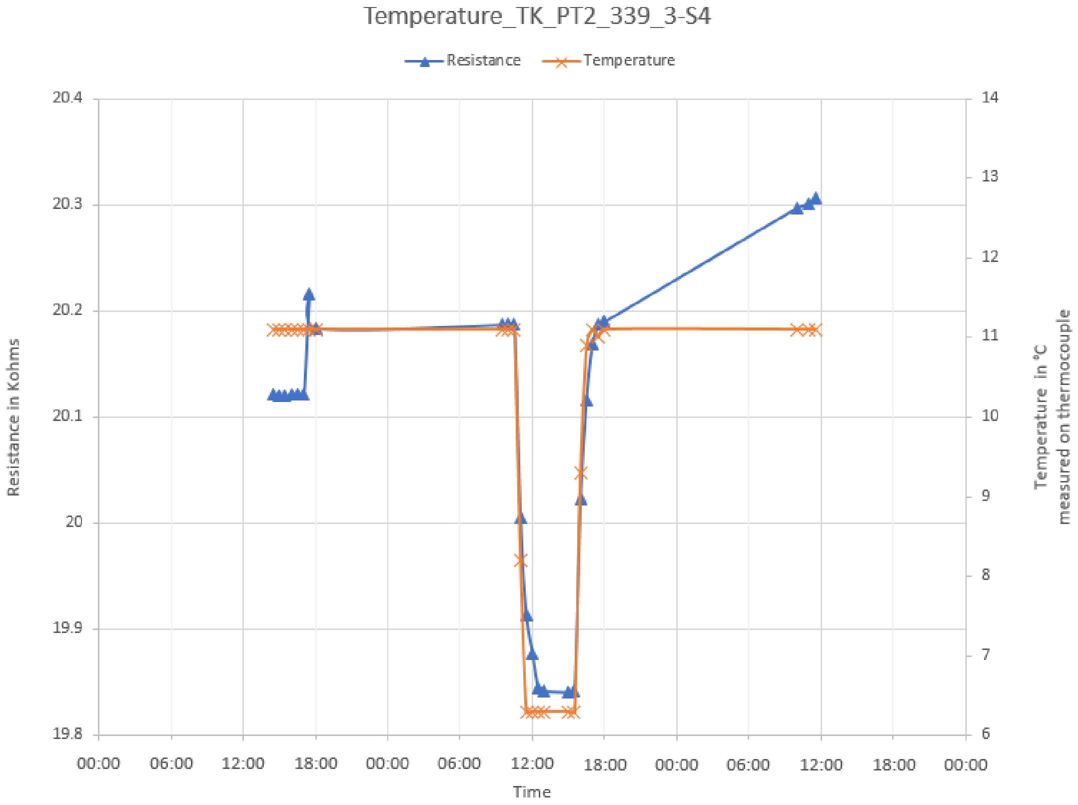
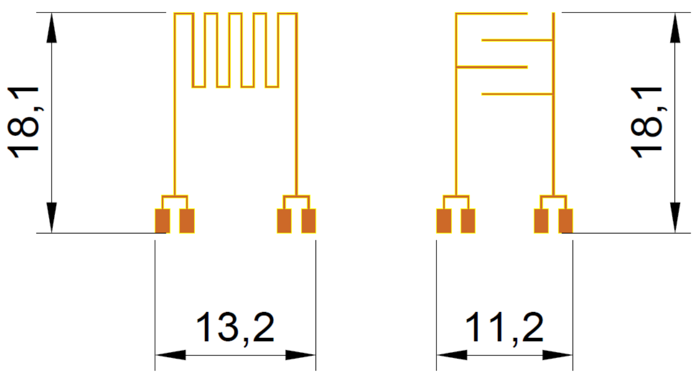


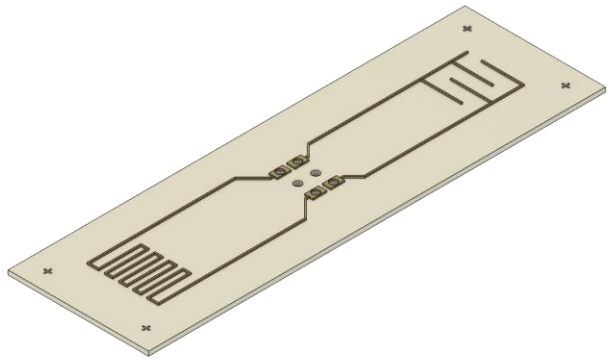
Initial Sensor – Carbon Pedot: PSS Sensing Layer



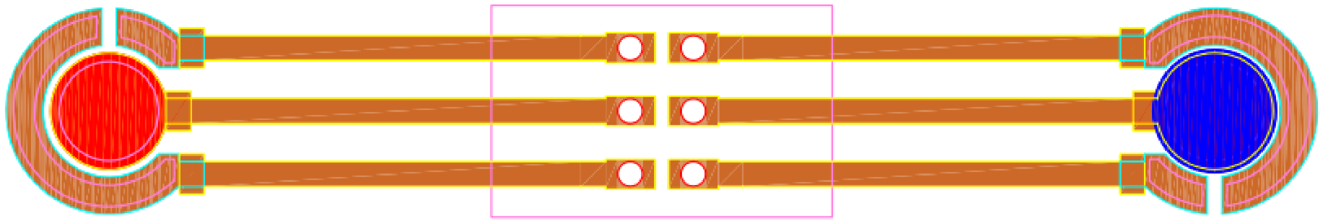
COVID!

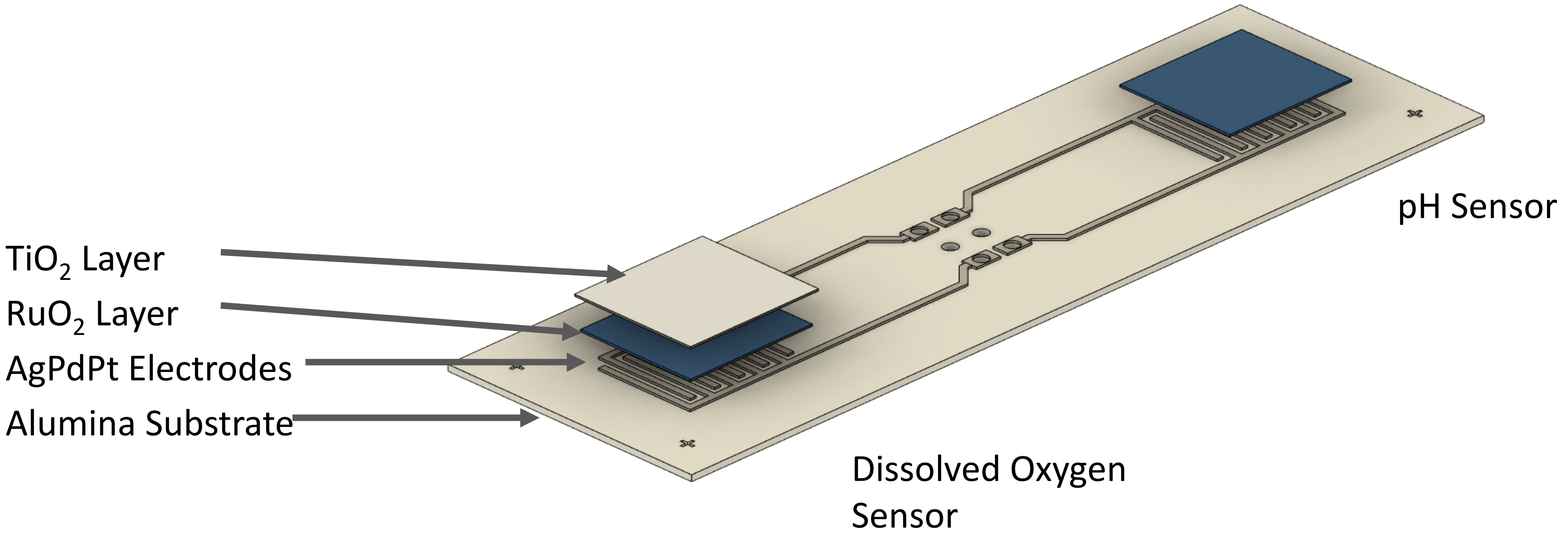
Aerosol Printed Gold Sensor Architecture





Screen Printed pH and DO Sensor





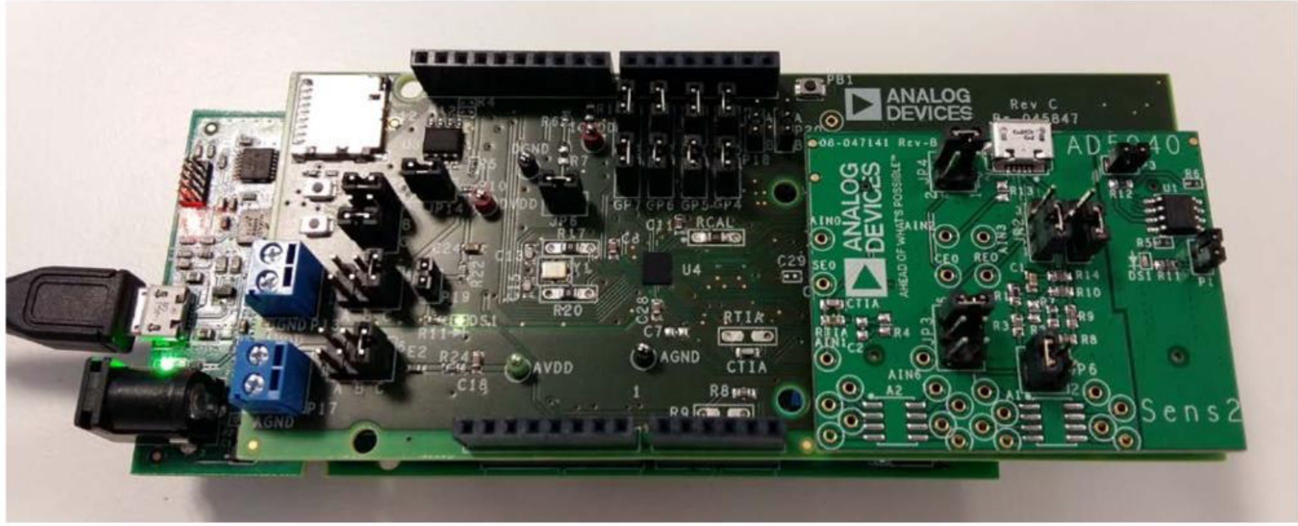
Measurement Electronics

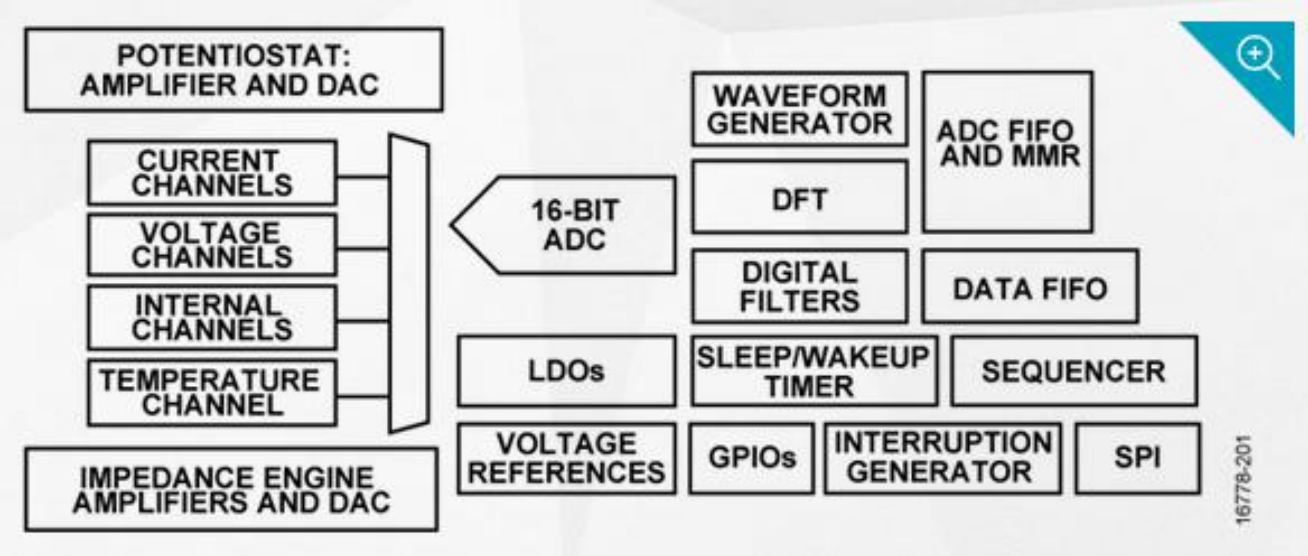
Measurement of the printed sensors can be performed via a AD5941 Analogue Front End Chip (AFE) capable of voltage, current and impedance measurement. Allowing Amperometric, Cyclic Voltammetry and Electrochemical Impedance Spectroscopy(EIS) measurements

Impedance measurements can be performed on the conductivity sensor at a wide range of frequencies.

An impedance measurement or DC resistance measurement can be used for temperature measurements.

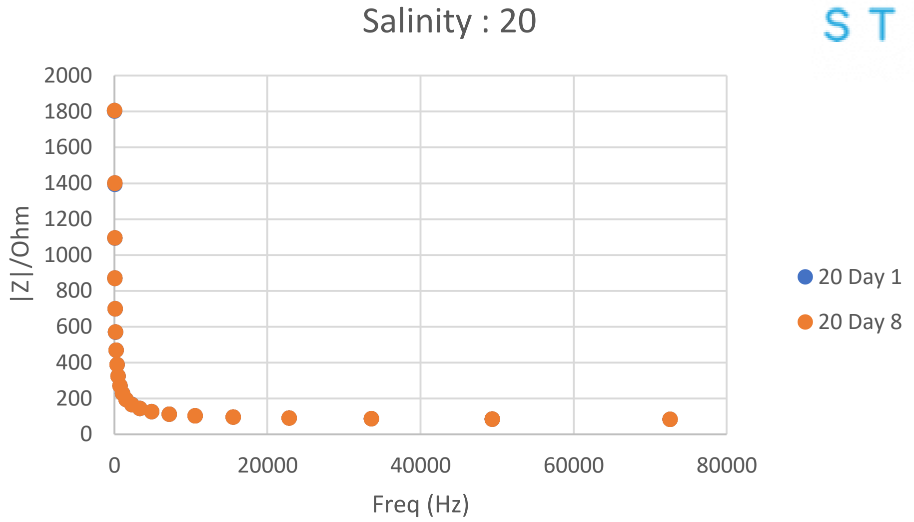
The pH and DO sensors can be measured using amperometric, impedance or EIS depending on configuration.

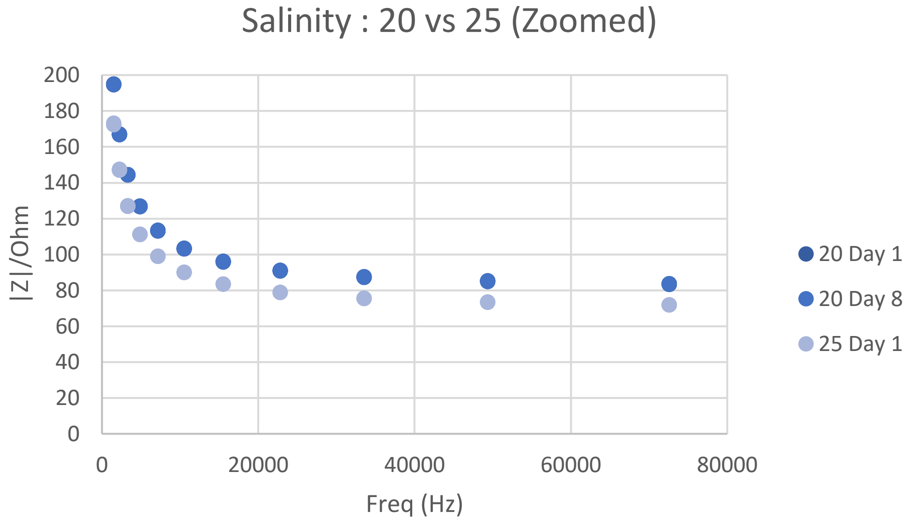


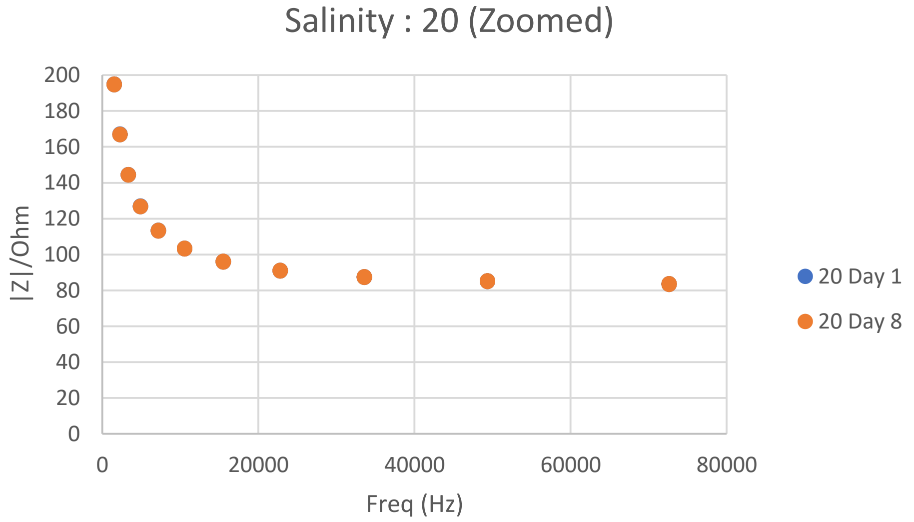


Conductivity Sensors

- 1Hz - 500kHz
- Freq (Hz) vs |Z| (Ohm)
- Overcome Redox problem vs Ag sensor
- Improved drift vs Carbon sensor
- Still requires calibration?
- Dynamic Change?







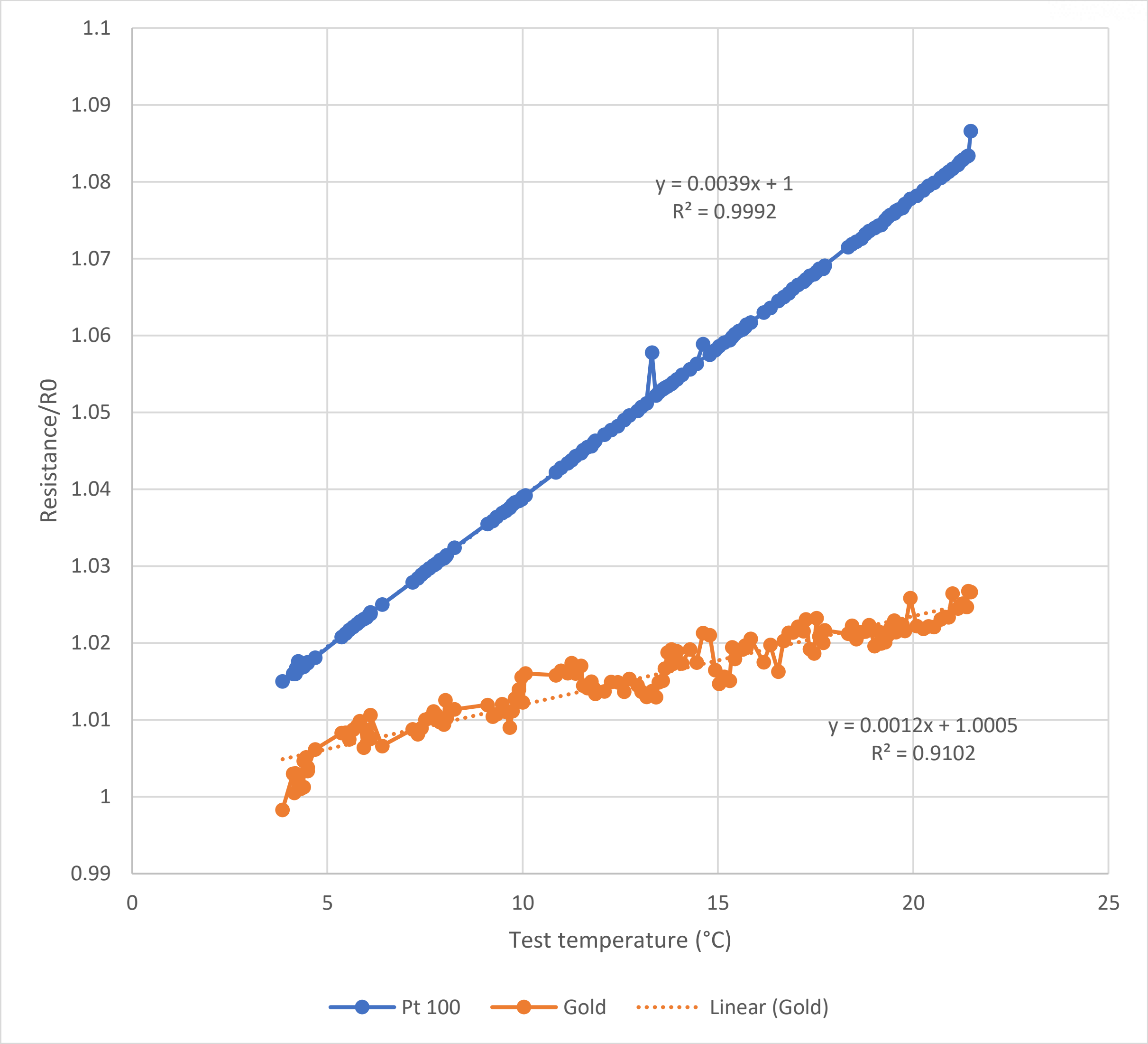
Results Temperature

Printed Gold Temperature Sensor vs Industry Standard PT100

Broadly speaking, the gold shows a similar increase in absolute resistance with temperature (Ohms/°C) but when normalised against it's "base" resistance (R_0), it appears to be ~3 times less sensitive than the PT100 and similarly less sensitive to what we would expect from a pure gold material.

There is clear noise as well which can be eliminated by electronics and processing but shows a clear positive temperature coefficient.

Platinum: 3.92×10^{-3}
Gold: 3.4×10^{-3}
Printed Gold: 1.2×10^{-3}



Sensor Head Design

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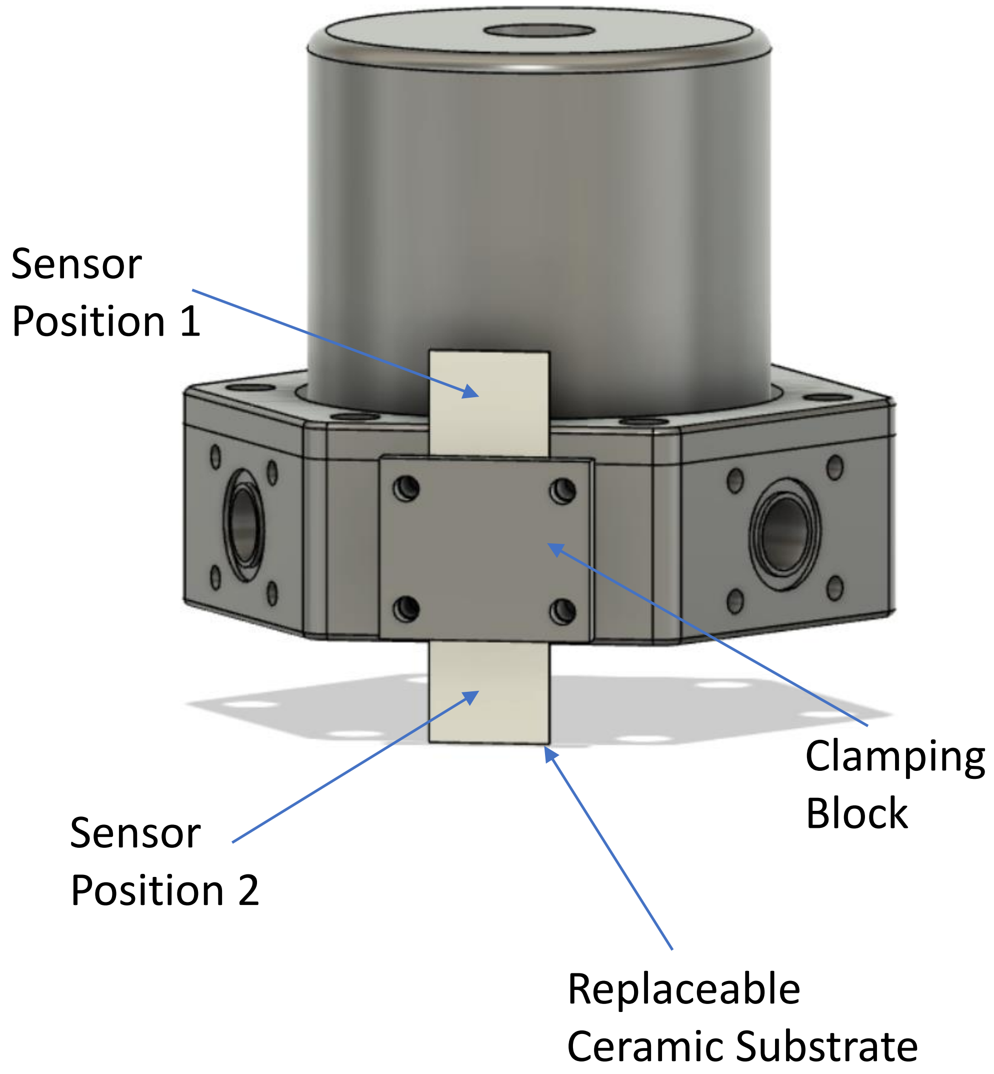
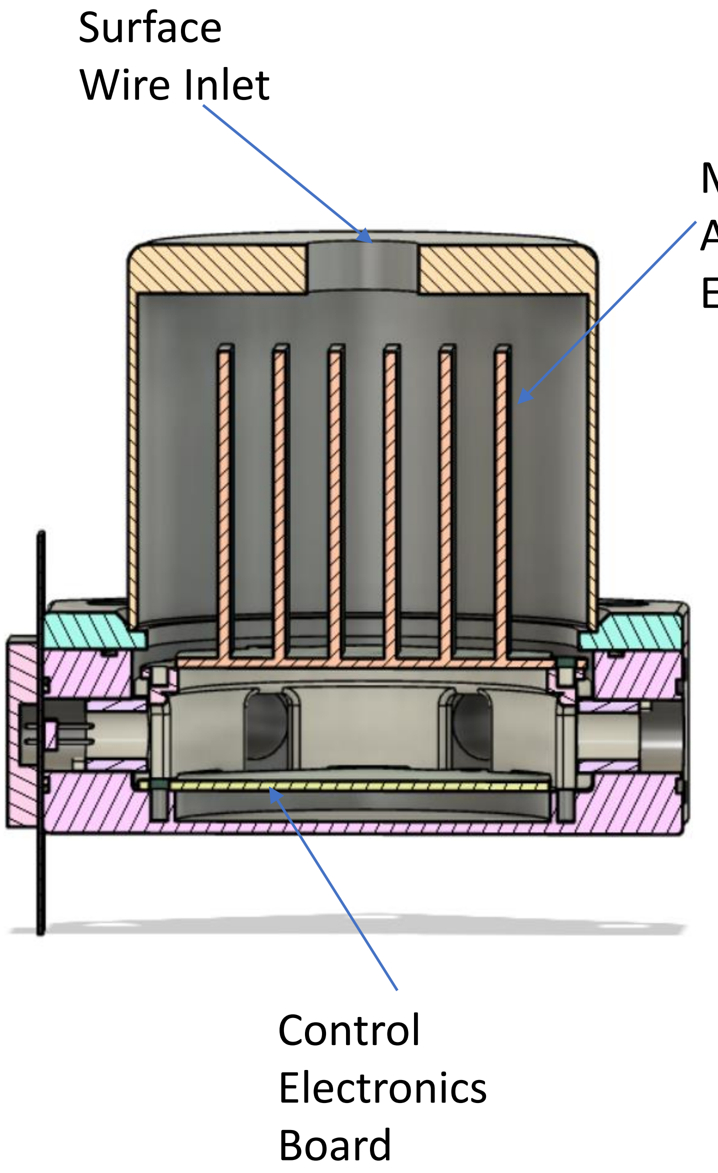
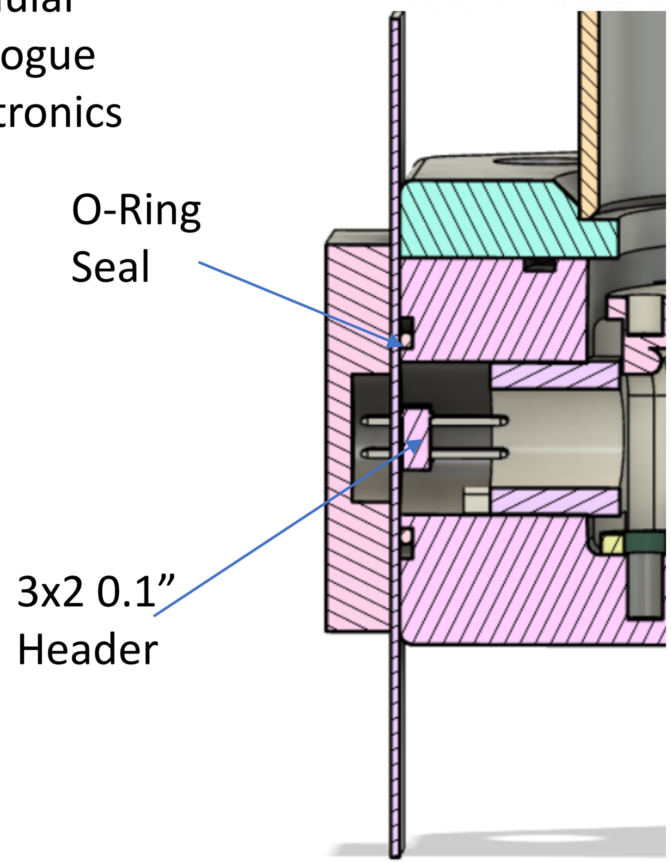






Sensor Cost Projection

Sensors are created on easily replaceable ceramic substrates with 6 mounting points available.

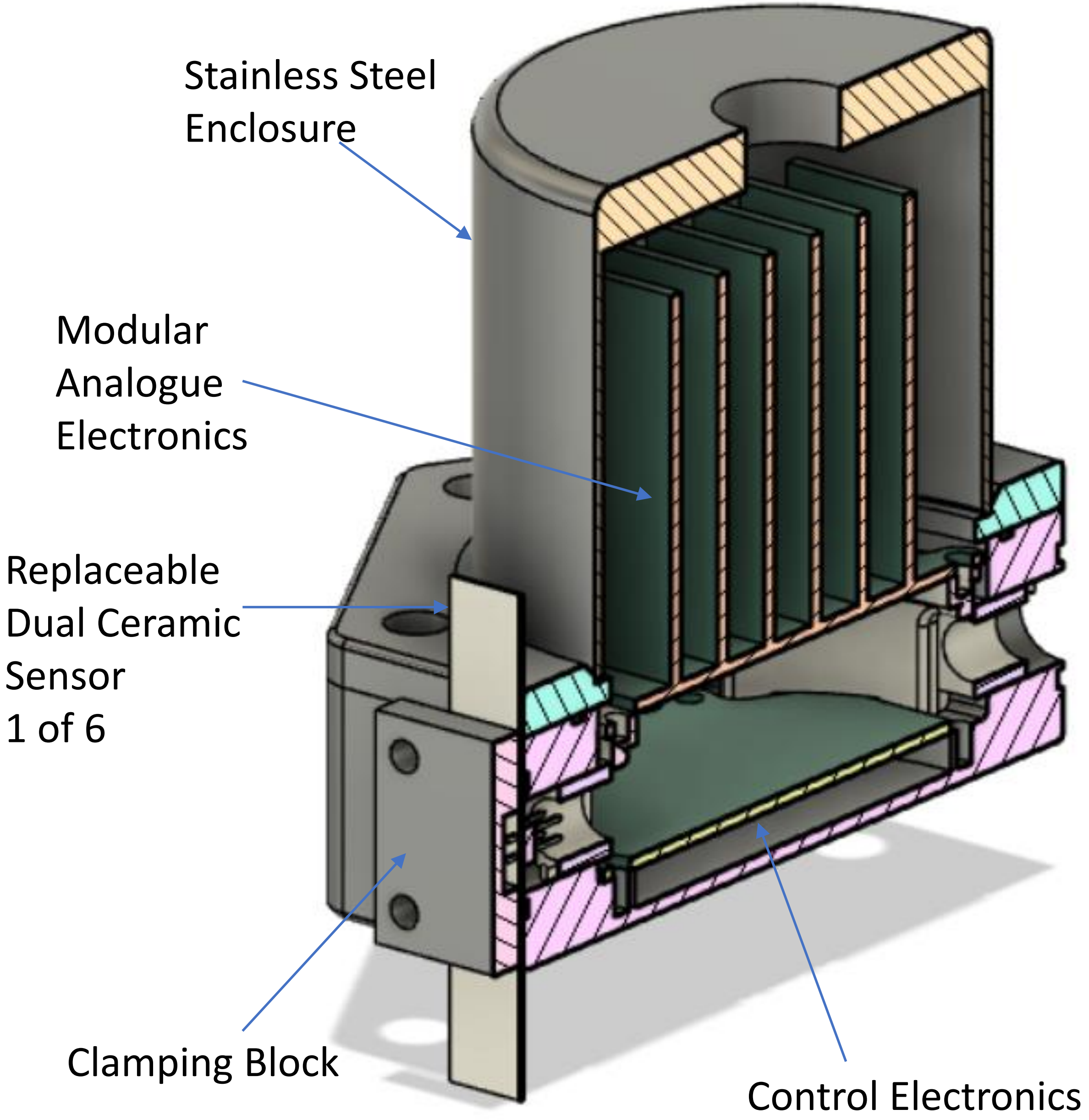
Up to 2 sensor types can be combined on a single substrate and between 2 and 3 sensor of the available positions need to be filled.

Additional ports allow new sensors to overlap in deployment with an existing sensors for data continuity.

Small batch production leads to high materials costs which could be up to £15/substrate.

Enclosure costs are low due to in house machining (Materials + Tooling) Approximately £200

Reusable electronics costs, control electronics <£50, modular electronics <£50 per port.

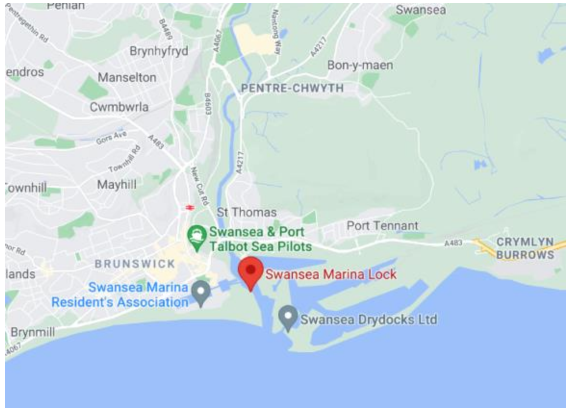


Cost Projection Summary

- Based on research scale manufacturing

• Head enclosure	£200
• Reusable electronics (3 channels)	£150
• Sensor (3 ceramic units)	£45
• Control	£50
• Module Total	£445
• Connection (local or remote)	£TBC
• Local – datalogger connection	
• Remote – self powering network	

Sonde Deployment - Swansea



(Image: Google 2022)

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Weather Radar Deployment - Swansea

Radar Location

Conclusion

- Screen printed temperature and conductivity sensors were found to be unstable when immersed in water for an extended period.
- Aerosol printed temperature and conductivity sensors using gold are stable in water and are being taken forward to the first deployment.
- Screen printable pH and DO sensors have been specified in terms of material and design.
- Housing design for deployment has been completed, including a feasible solution for water tight connections
- Data capture electronics from each sensor type has been selected
- Module target cost (3 sensor ceramics) £445
- Sondes have been deployed at two sites in Swansea
- Weather radar location and installation plans are in place

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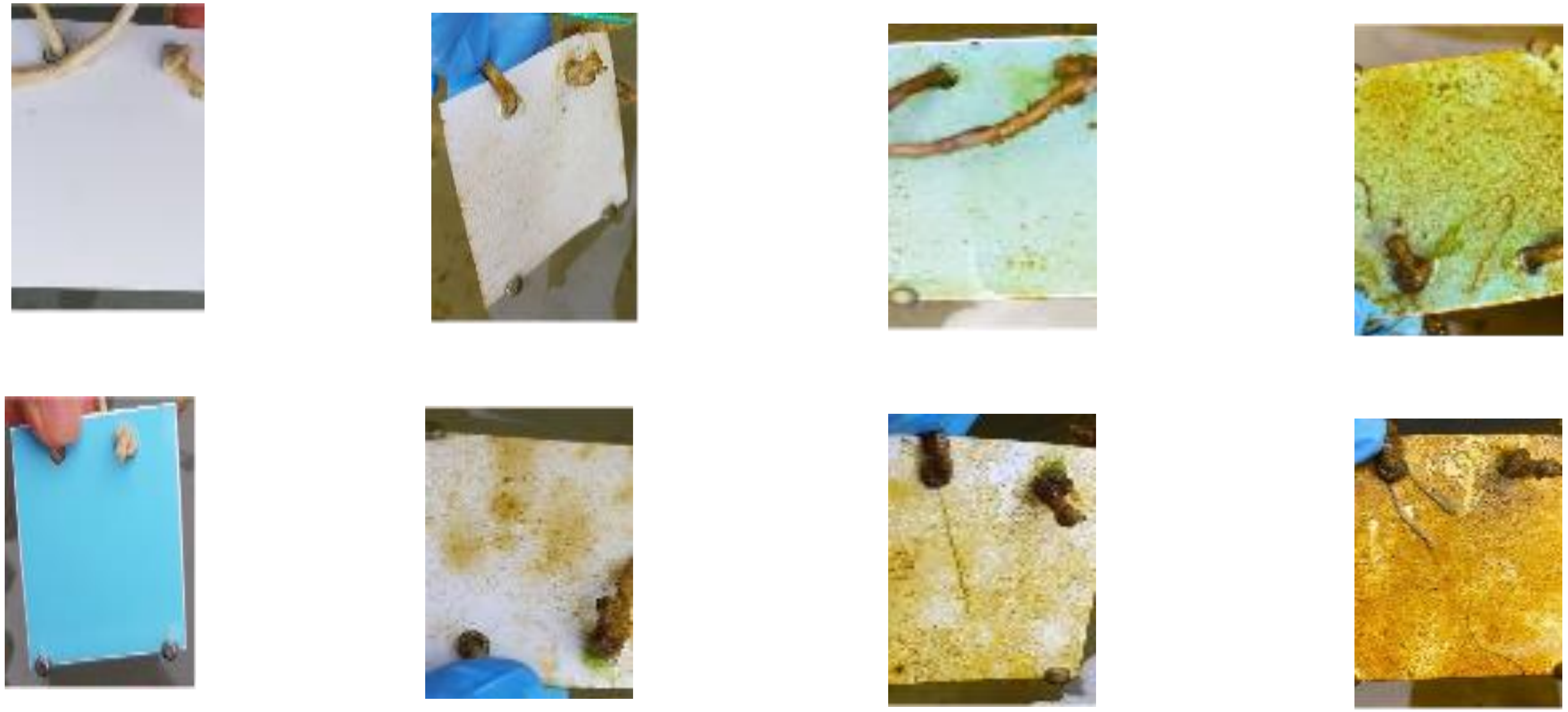
Fouling – Polymer Substrates - PET



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