Impedance Measurements of Biofilm Development by Polypyrrole Enhanced Flexible Sensors

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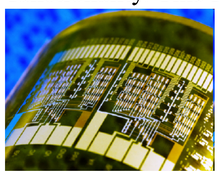
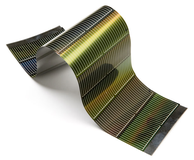
FlexEBio IGERT Program of Binghamton University and Cornell University

1 Flexible Electronics

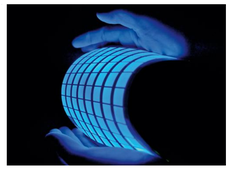
Flexible electronics provide a substrate which can be bent, flexed, rolled, or otherwise conformed without losing functionality. This feature allows for various applications.



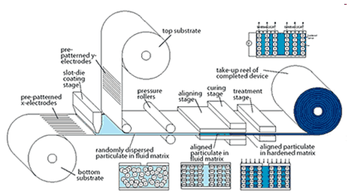
Beckman Institute



Global Solar



General Electric

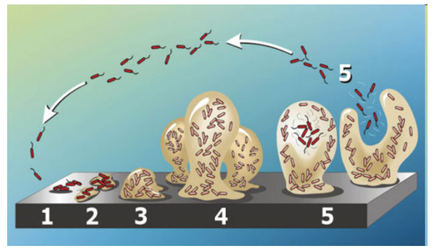


OLAMco Solar

A primary appeal of flexible electronics is the possibility to deliver **ultra-low cost** products for existing and new applications as a result of efficient mass manufacturing utilizing roll-to-roll processing.

2 Biofilms

Biofilms are invasive and in order to quickly remediate their effect, fast and efficient detection is needed



Formation of a bacterial biofilm

Image: Dr. David Davies, Binghamton University

Void formation in a mature biofilm between the biofilm and surface of attachment

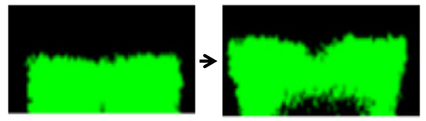
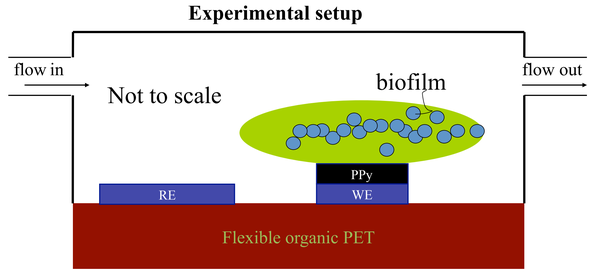


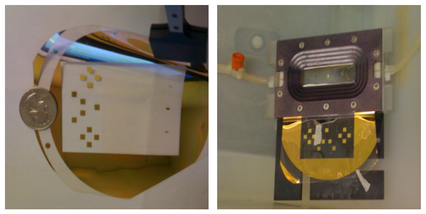
Image: Magnus G. Fagerlind et al., Journal of Theoretical Biology, 295 (2012)

3 Electric Impedance Spectroscopy (EIS) of biofilm development using flexible sensors

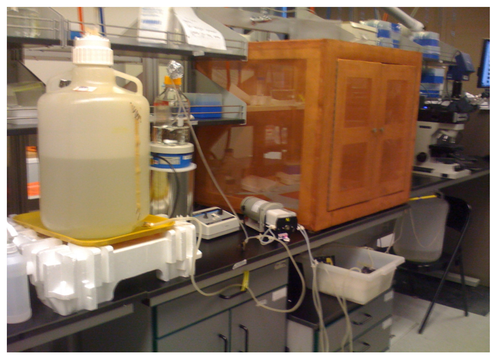


Approach: Using a polypyrrole (PPy) enhanced flexible substrate, a biofilm sensor was developed to monitor the growth of *Pseudomonas aeruginosa (PA01 gfp::GM)* biofilms and correlate the EIS measurements with the biofilm growth via fluorescence microscopy

The flexible sensors are fabricated in our Nanofab lab using photolithography

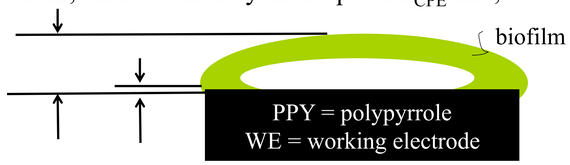


A biofilm reactor with a PET flexible sensor.

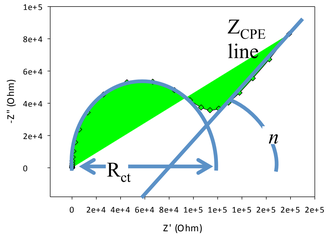


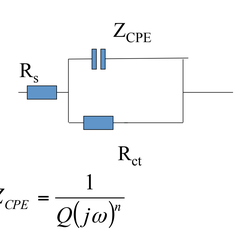
The peristaltic pump drives broth from the carboy through the biofilm reactor and across the PET flexible sensors. Bacteria were inoculated into the reactor. EIS measurements were carried out inside the copper wire Faraday cage. A Leica microscope equipped with CCD camera and FITC filter cube was used for optical recording of the biofilm development on the electrodes.

Distal interface: at low frequency, ions need to diffuse through the biofilm to the electrode to have redox reactions, characterized by the slope of Z_{CPE} line, *n*.



Proximal interface: charge transfer resistance, R_{ct}, changes due to biomass fouling and is calculated from the semicircle of the Nyquist plot.



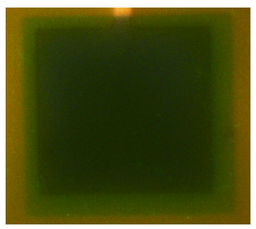


$$Z_{CPE} = \frac{1}{Q(j\omega)^n}$$

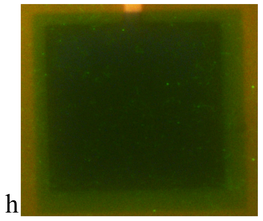
Equivalent circuit and Nyquist plot for EIS data: where Q is the charge per area, j is the imaginary number, ω is the frequency, and R_s is the resistance of the solution. Z_{CPE} is a constant phase element.

4 Results

Fluorescent images of biofilm development

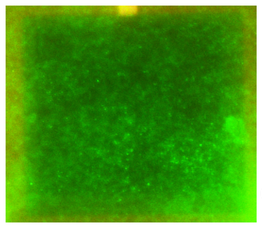


34 h

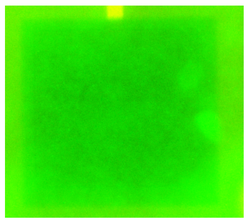


43 h

Maximum biofilm coverage is achieved in 64 hours

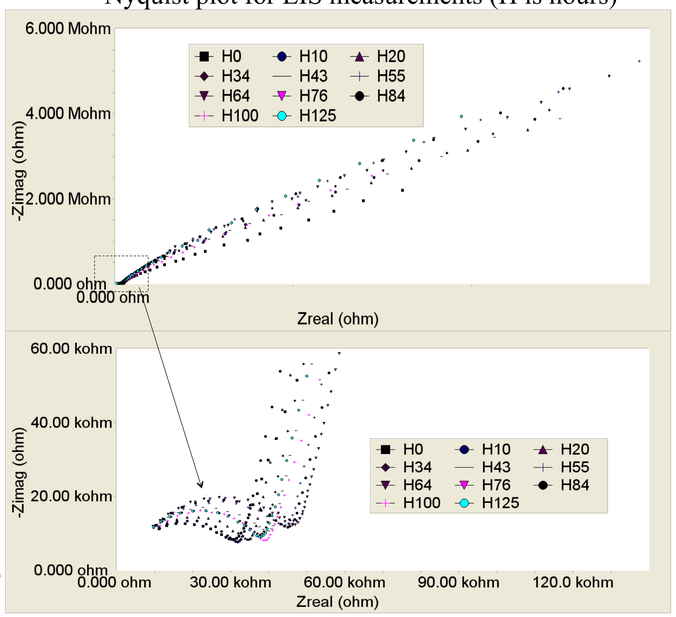


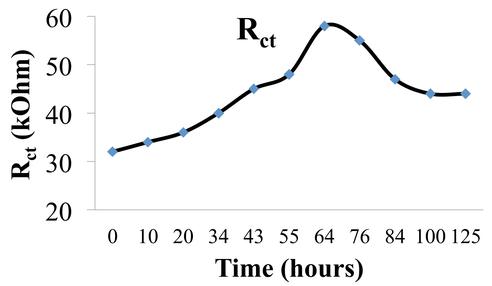
55 h

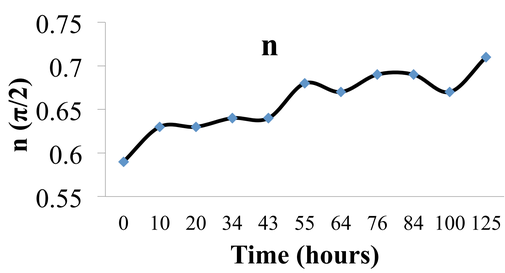


64 h

Nyquist plot for EIS measurements (H is hours)







R_{ct} increases as biofilm coverage increases. The R_{ct} peak occurs when the biofilm reaches maximum coverage. The drop of R_{ct} in late maturing stages is believed to be due to the void formation at the biofilm/electrode interface. The slope of the Z_{CPE} line increases as the biofilm fouling on the electrode increases.

5 Conclusion

The flexible biofilm sensors successfully demonstrated monitoring the maturing development of *P. aeruginosa* biofilms by measuring the charge transfer resistance and the slope of the CPE line. This work allows for real time monitoring of the formation of biofilms.

Acknowledgments

Flex-E-Bio of IGERT program of National Science Foundation under Grant No. DGE-0654112;
ADL, Nanofab and S3IP of Binghamton University