Application of RLGC Models in Addressing Hospital Acquired Infections

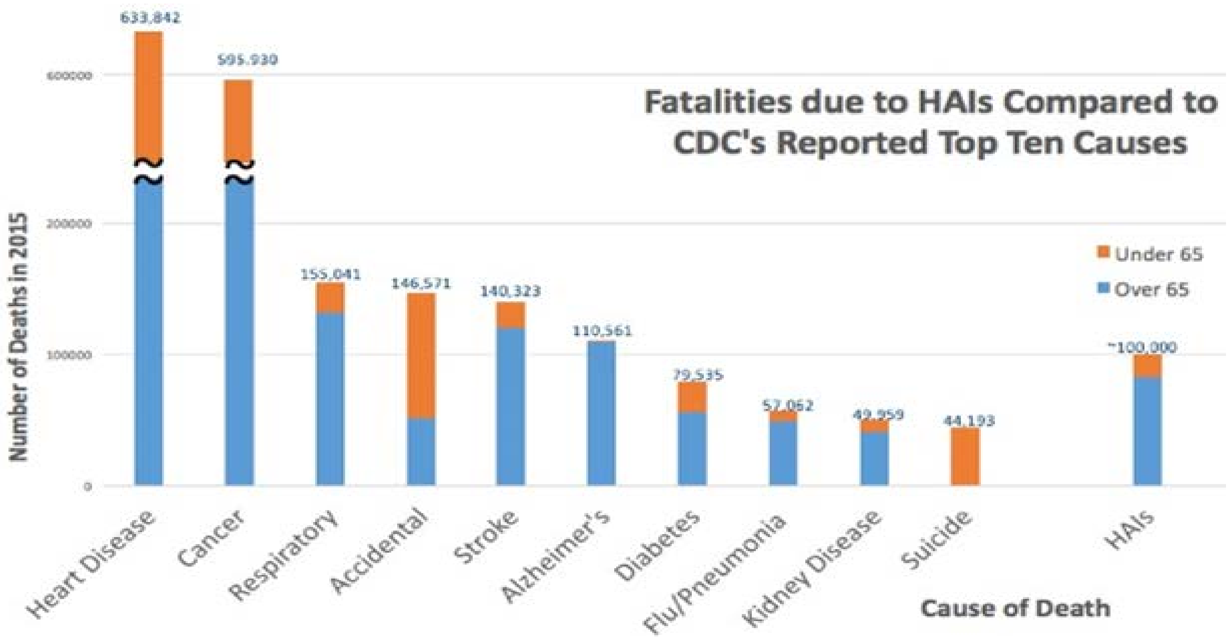
Jesus Perez
Mentors: Yaw Obeng & Joseph Kopanski
SPS Summer Internship 2018

Healthcare facilities are complex

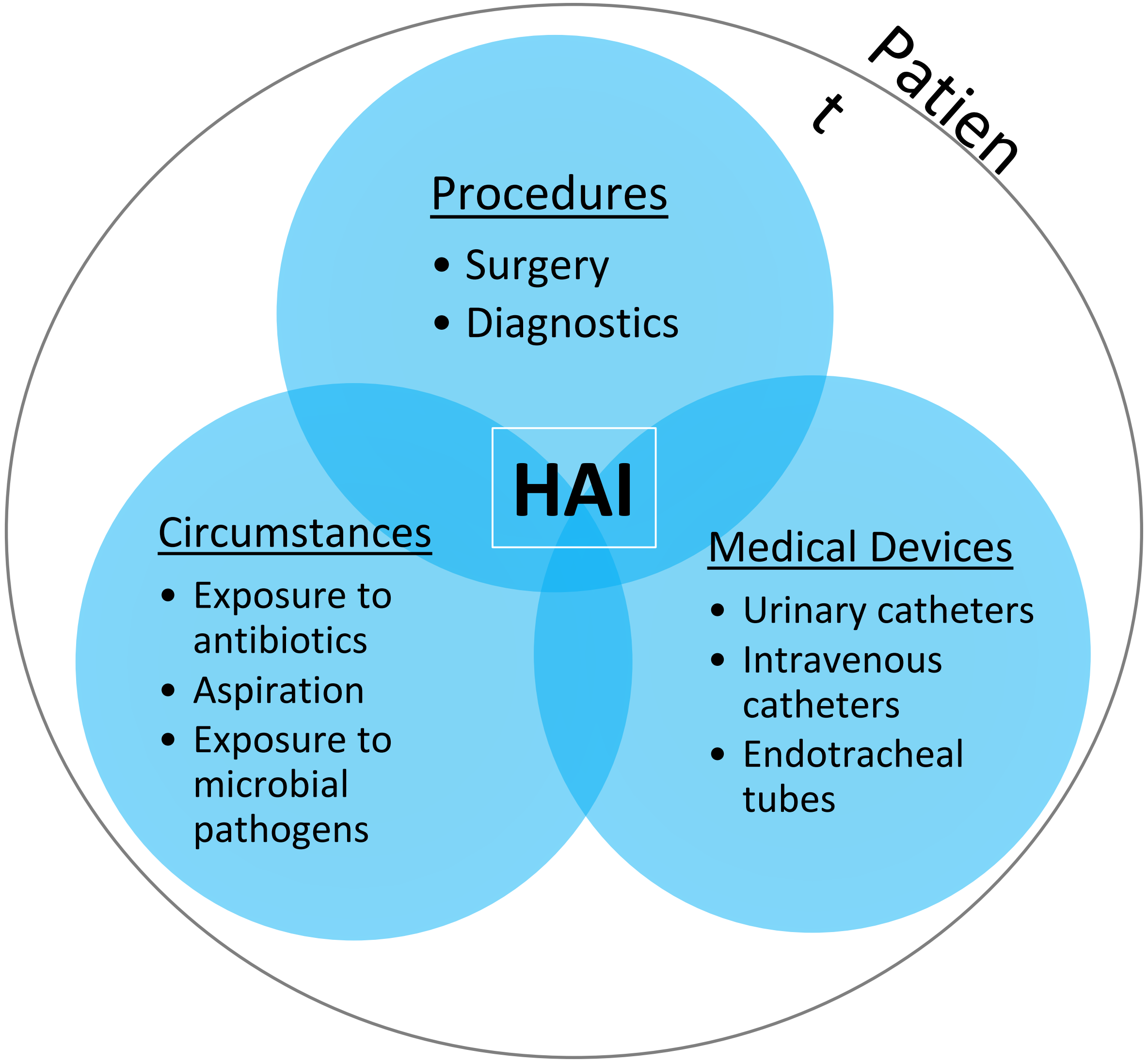
Hospitals in operation 24/7

Environment often crowded and variable

- Medical equipment
- Variety of surfaces and materials

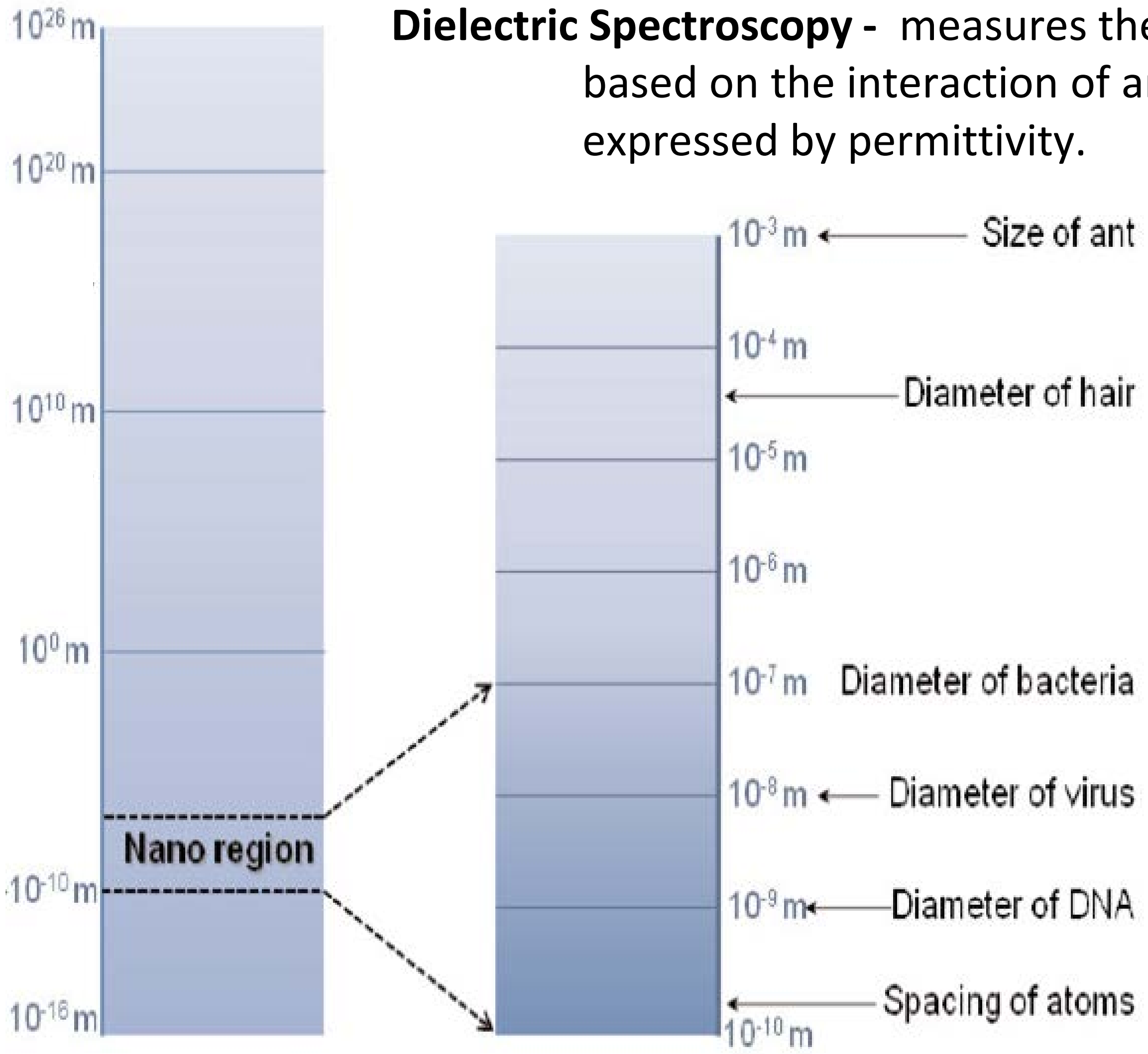


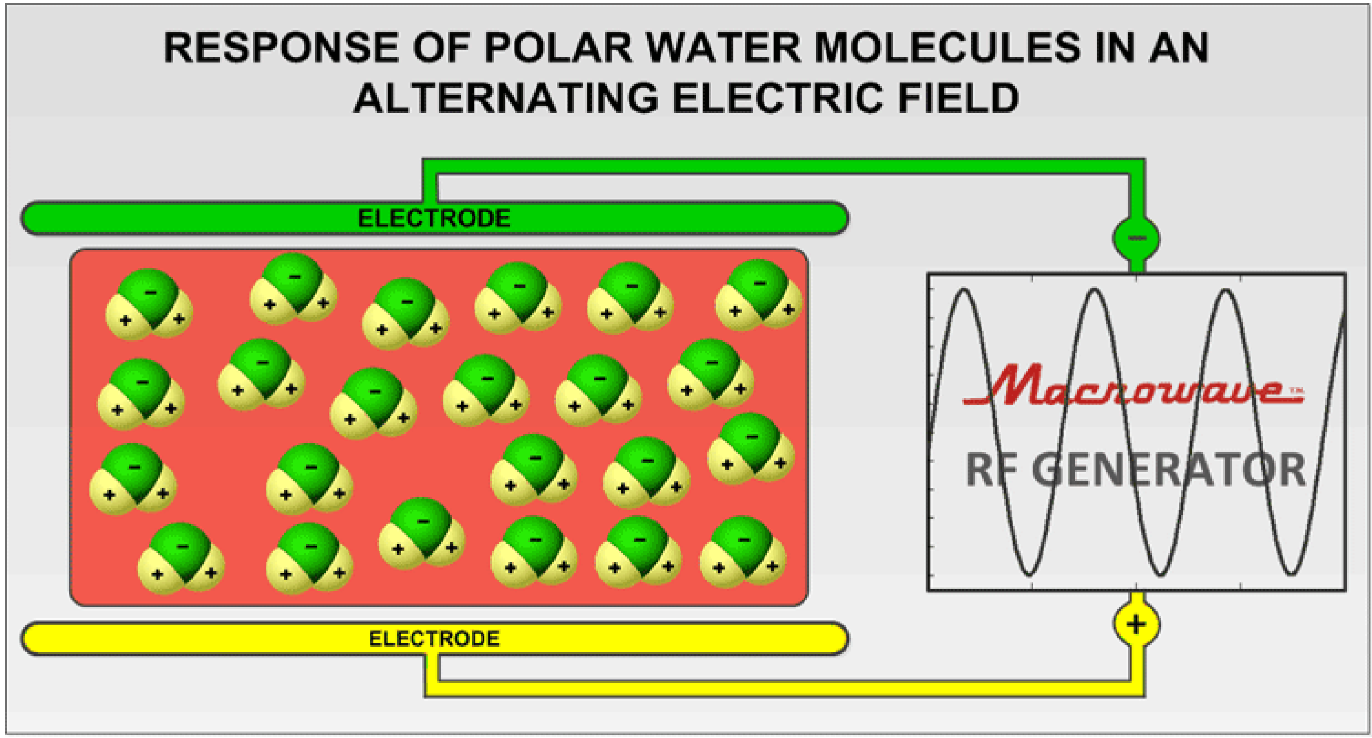
Brooks B, et al. *Nature Communications* 2017;18:1814.
National Academy of Sciences. *Microbiomes of the Built Environment*. 2017



Utilizing Radio Frequencies

Dielectric Spectroscopy - measures the dielectric properties of a medium as a function of frequency. It is based on the interaction of an external field with the electric dipole moment of the sample, often expressed by permittivity.



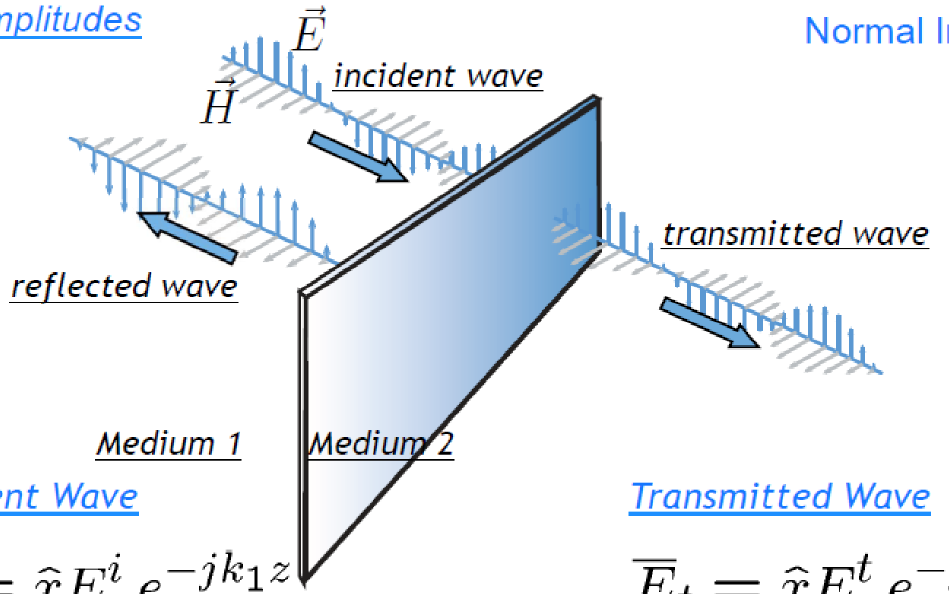


Background: Scattering parameters (S-parameters)

Incident and Transmitted Waves

same amplitudes

Normal Incidence



Incident Wave

$$\overline{E}_i = \hat{x} E_o^i e^{-jk_1 z}$$

$$k_1 = \omega\sqrt{\epsilon_1 \mu_1}$$

$$\eta_1 = \sqrt{\frac{\mu_1}{\epsilon_1}}$$

Transmitted Wave

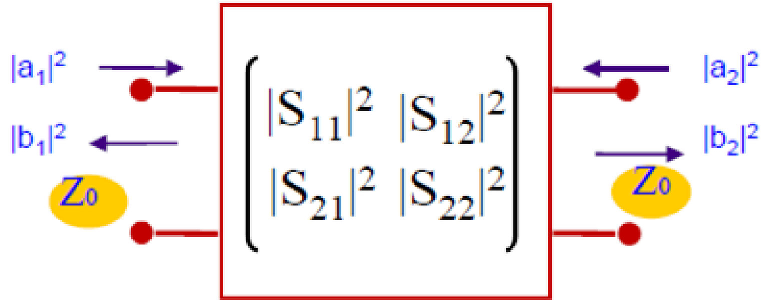
$$\overline{E}_t = \hat{x} E_o^t e^{-jk_2 z}$$

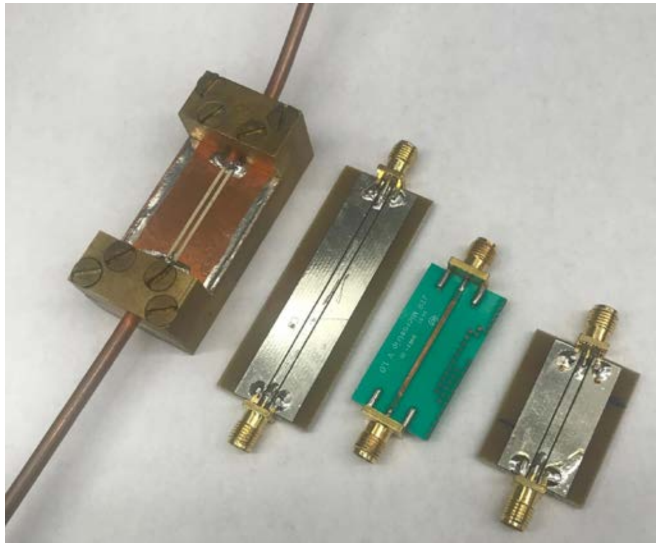
$$k_2 = \omega\sqrt{\epsilon_2 \mu_2}$$

$$\eta_2 = \sqrt{\frac{\mu_2}{\epsilon_2}}$$

4

S-Parameters and Characteristic Impedance Z0



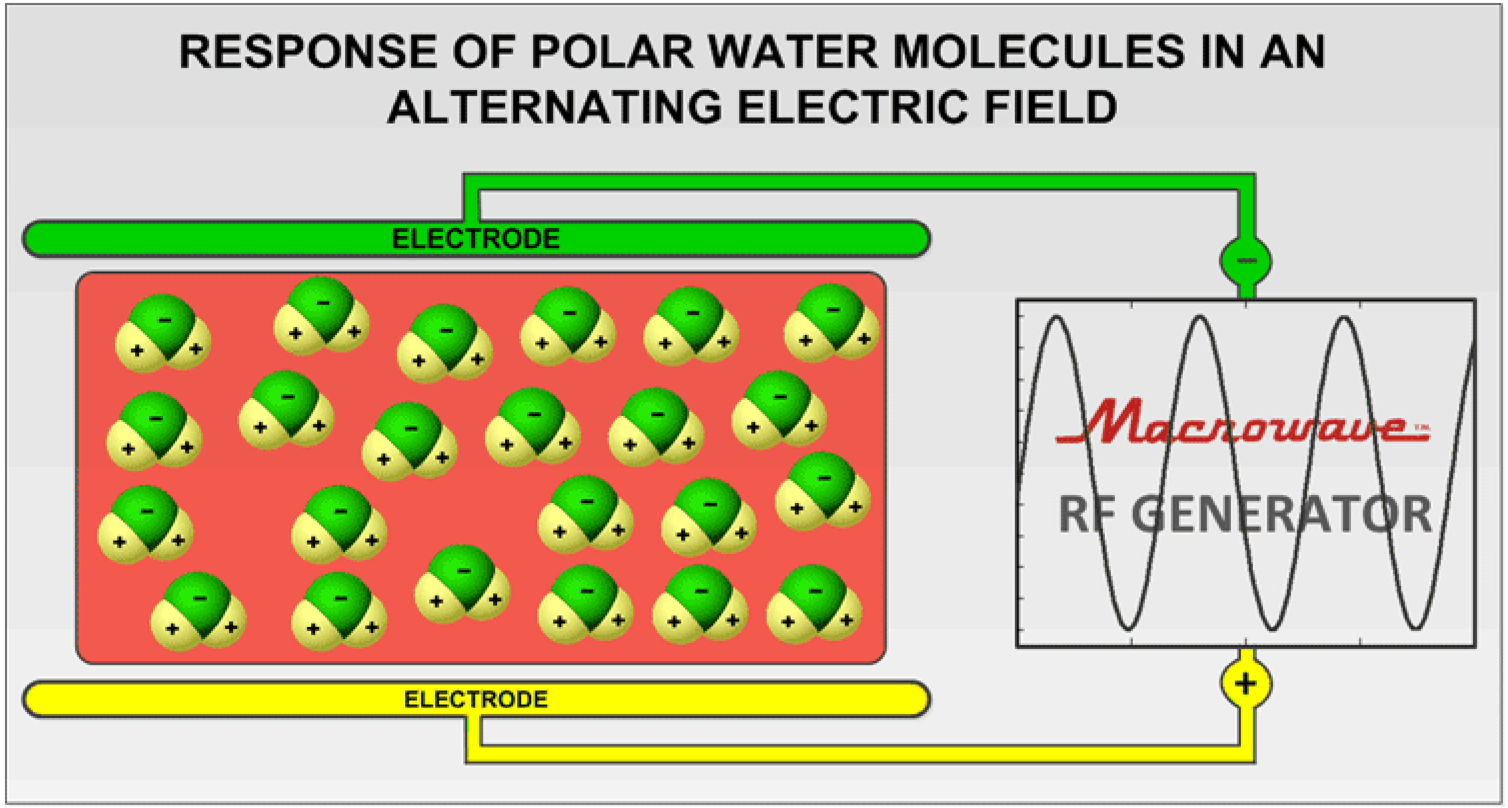


Waveguides

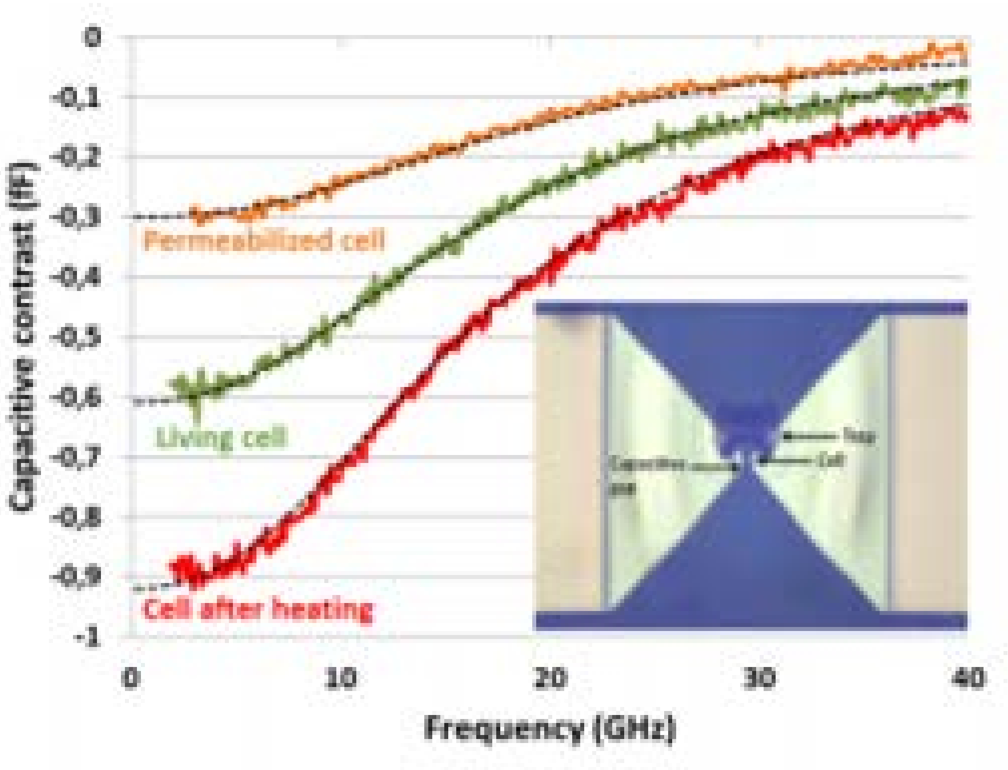
Applications of using Radio Frequencies

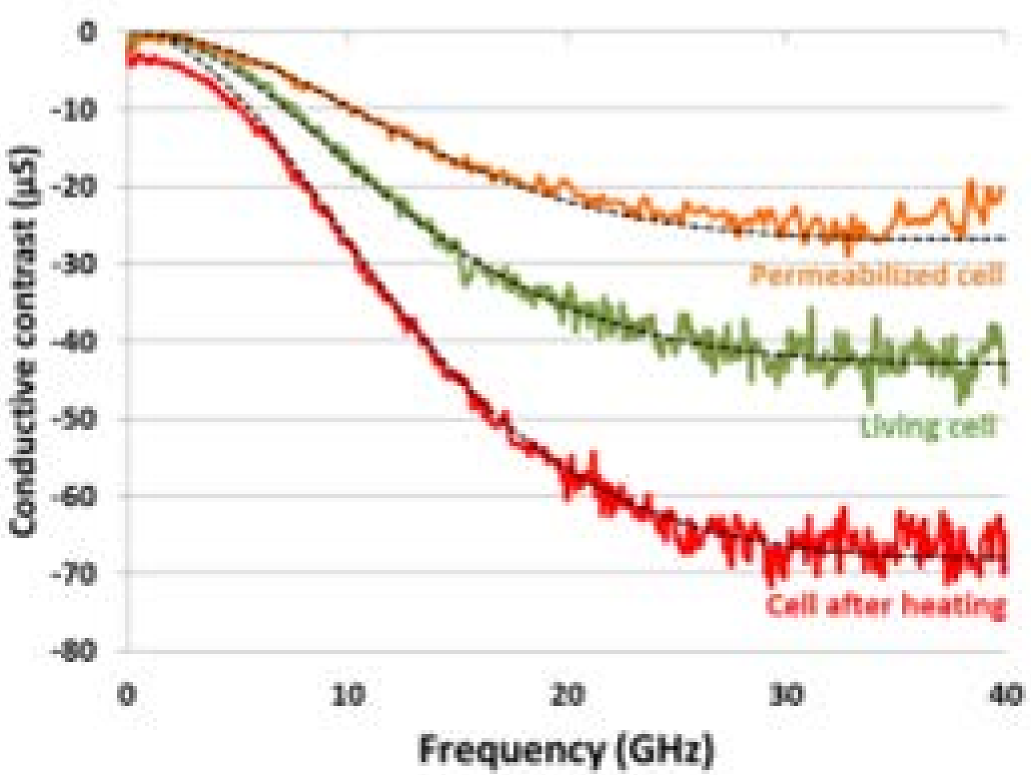
Dielectric Spectroscopy - measures the dielectric properties of a medium as a function of frequency. It is based on the interaction of an external field with the electric dipole moment of the sample, often expressed by permittivity.

- Acquire electrical data
  - fuel cell testing
  - Powerline transmission
- Medical applications
  - Measure bacterial concentration
  - Detect dangerous pathogen)
  - ***Prevent Hospital Acquired Infections***
- Determine body composition
  - Fat, muscle, water



Electrical Response of Individual Biological Cells Submitted to Different Stimuli

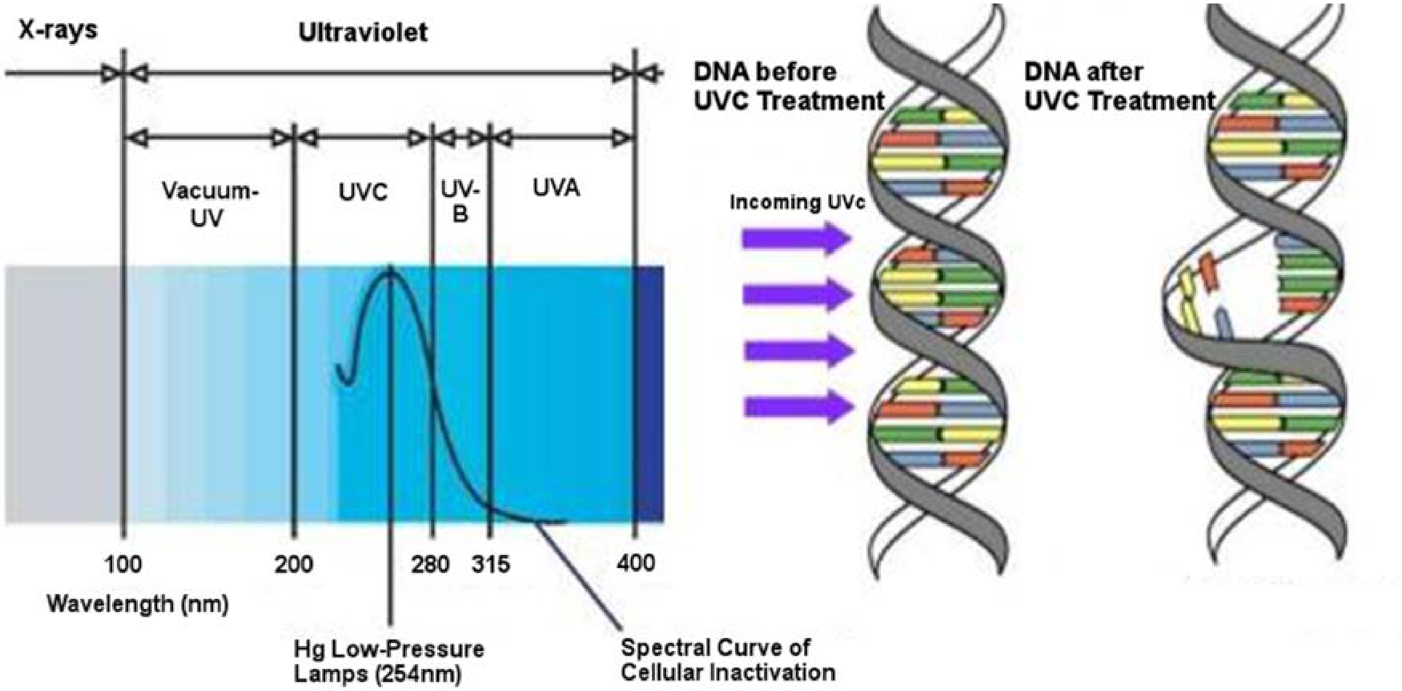




Electrical response (capacitive and conductive contrasts) of individual cell in their culture medium submitted to:

- no stress,
- thermal stress (50 °C 10 min),
- chemo-induced permeabilization (membrane or cell wall rendered permeable)

Reducing HAIs with UV light



UV-C known to disrupt the DNA chain

CDC's 2016 Study "Benefits of Enhanced Terminal Room Disinfection…" concluded –

- *"A contaminated health-care environment is an important source for acquisition of pathogens; enhanced terminal room disinfection decreases this risk."*
- *"The incidence of target organisms* ***<u>among exposed patients was significantly lower after adding UV to standard cleaning strategies</u>****"*

(33.9 cases/10,000 exposure days with UV vs. 51.3/10,000 exposure days without – 35% reduction)

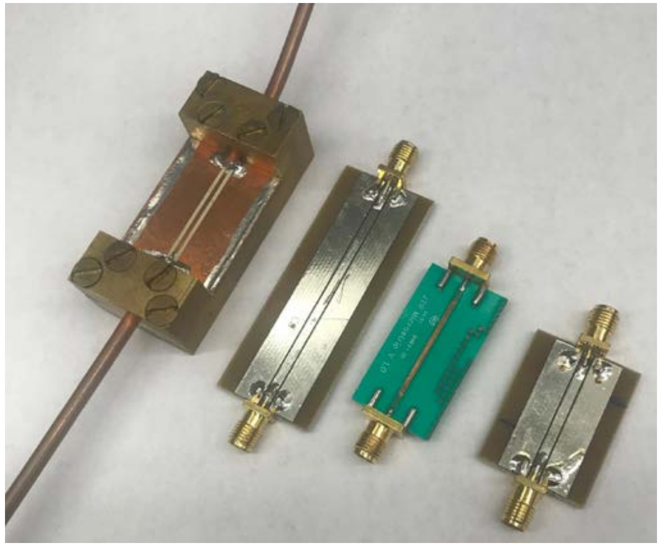
Goals

End goal: convert raw s-parameter data into electrical (RLGC) data

Tasks:

- Review existing modules
- Write, calibrate and validate new module if needed
- Apply the optimized RLGC module to existing IC corrosion / electromigration data.
- Apply module to collected data

Waveguide connected to VNA

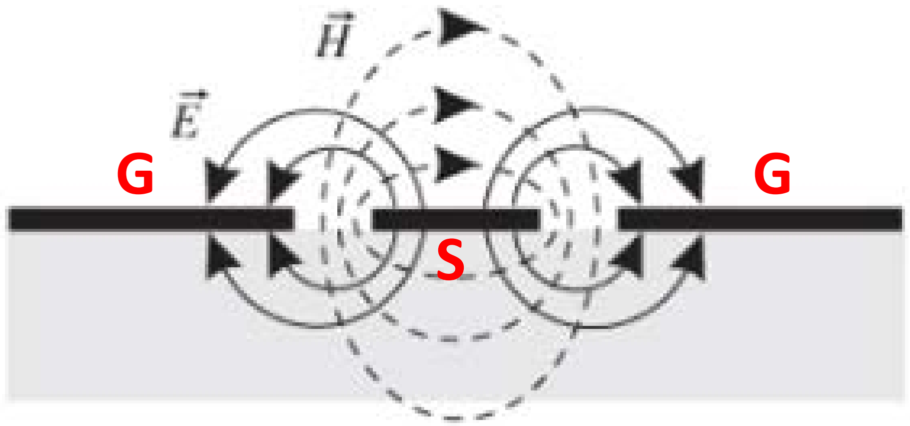


Waveguides

Measurements

Measuring a waveguide's dielectrics properties using the 2 port VNA and running the raw data thought our module produces the following information:

- Resistance (R)
- Inductance (L)
- Capacitance (C)
- Characteristic impedance (Zc)
- Propagation constant (ϒ)



Modeled E-Fields

Tasks:

- Review existing modules ✔
- Write, calibrate and validate new module if needed ✔
- Apply the optimized RLGC module to existing data.
- Apply module to collected data

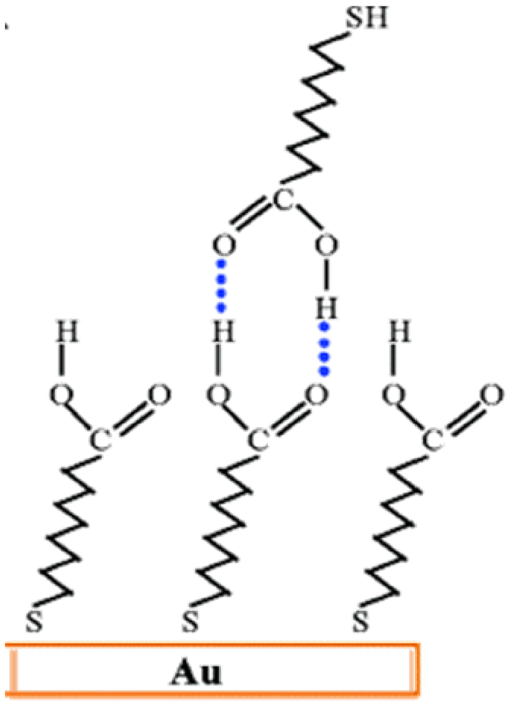
Experimental details

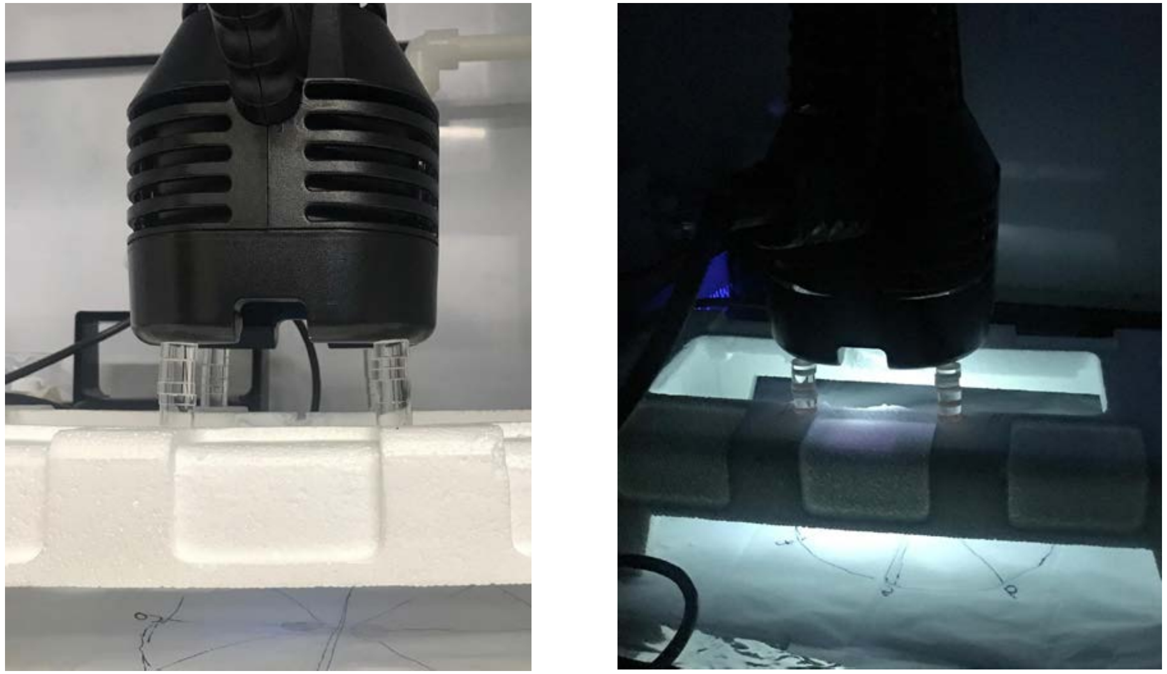
Tasks:

- Review existing modules
- Write, calibrate and validate new module if needed
- Apply the optimized RLGC module to existing data.
- Apply module to collected data

Mini experiments:

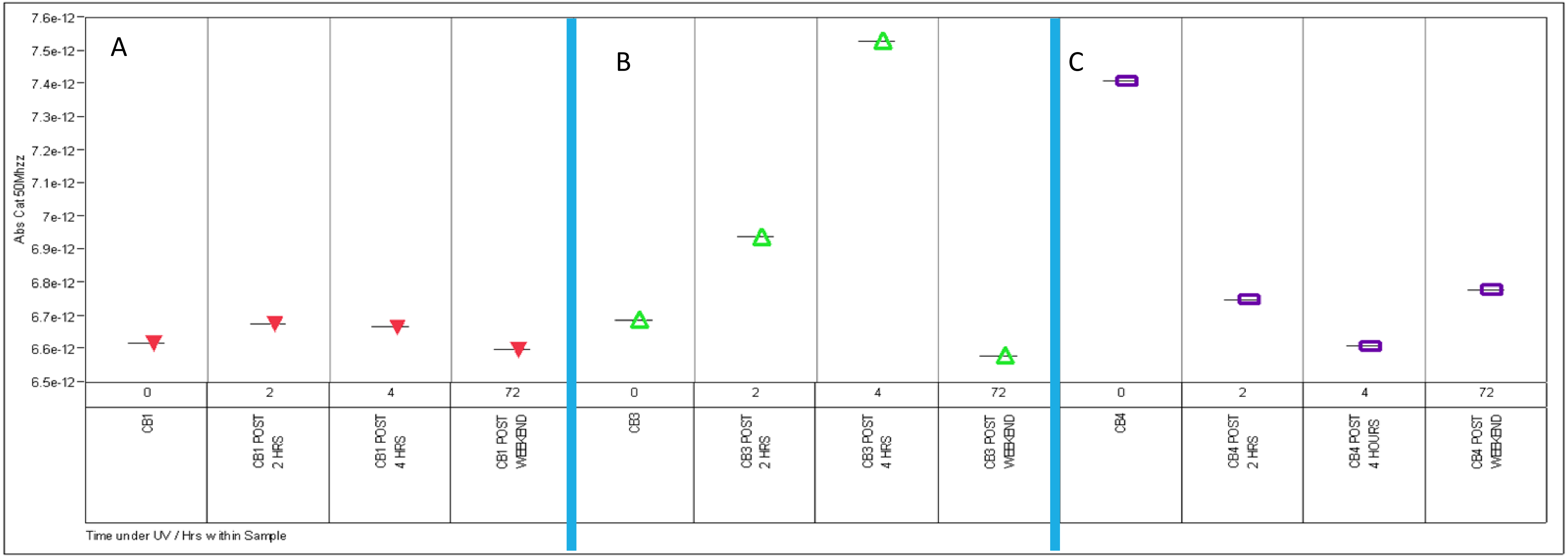
- Temporal UV Stability of $COOHC_{16}H_{32}SH/Au$
- UV-degradation of lipid Films
- UV-degradation of Yogurt Films





Samples under UV light in normal laboratory conditions

Temporal UV Stability of $COOHC_{16}H_{32}SH/Au$ in Laboratory Ambient



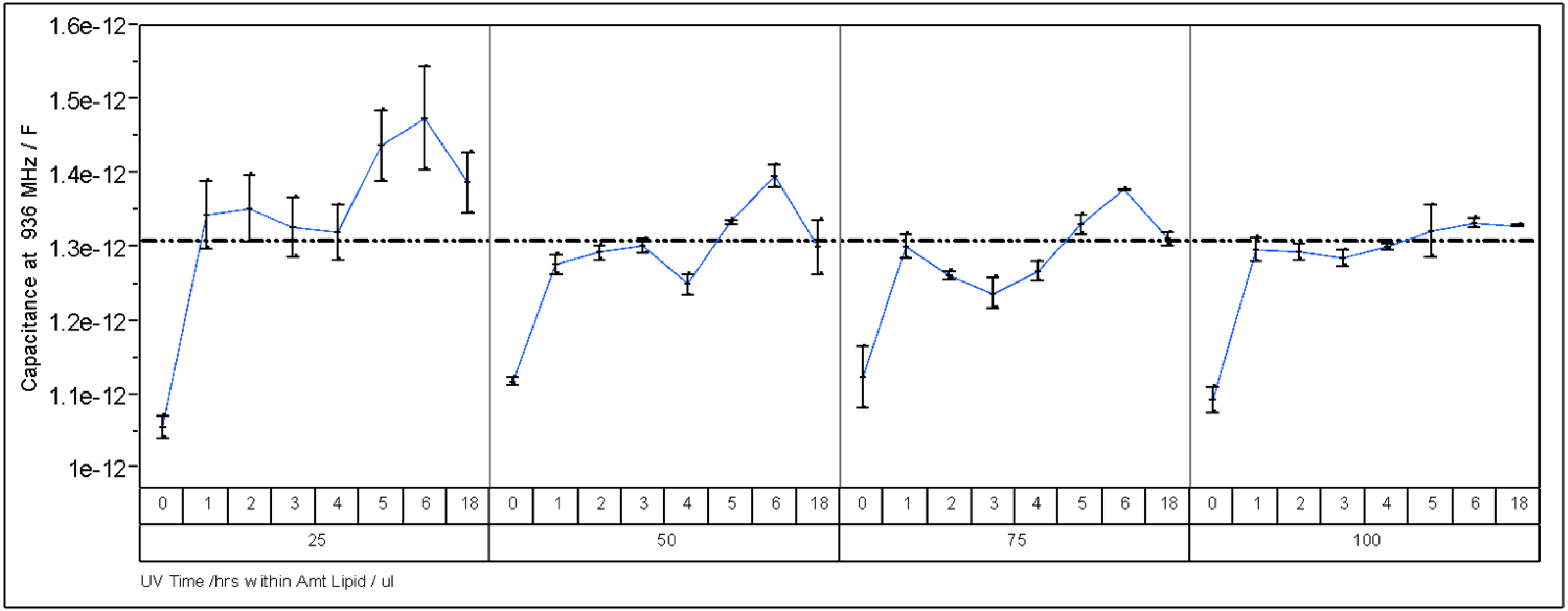
A - Bare gold on fused silica did not change over time

B - “Thick” film of alkane thiol on Gold. Film thickness decreases with UV exposure down to bare Gold

C - “Thin” film of alkane thiol on Gold. Film thickness decreases with UV exposure down to bare Gold

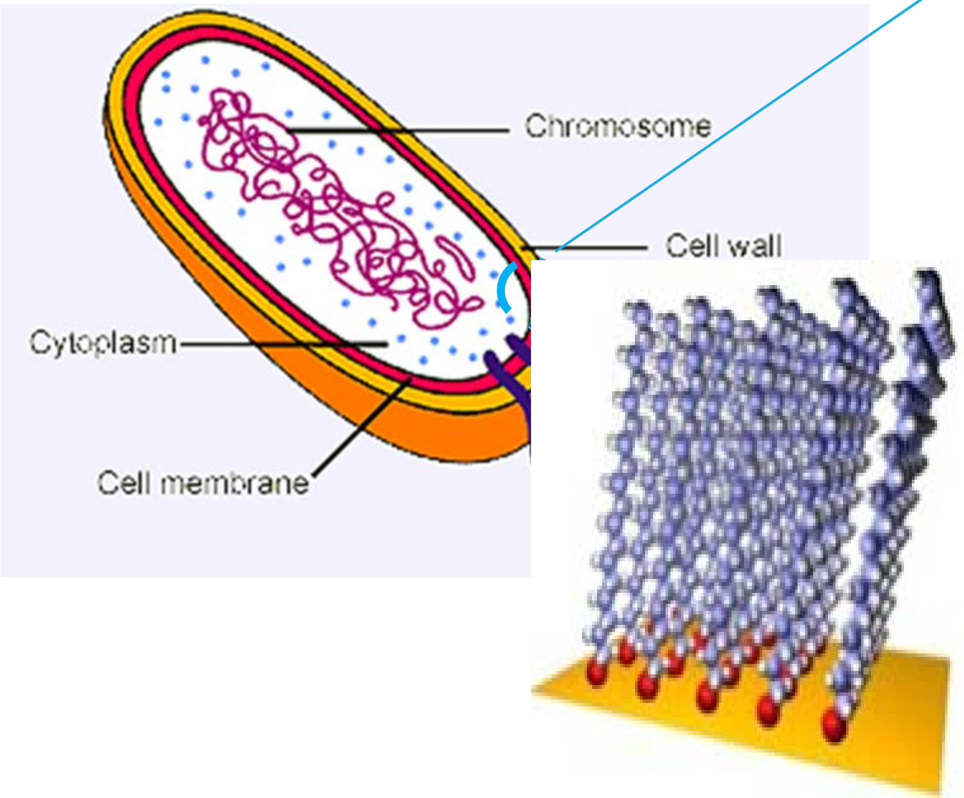
$$C = \frac{A\varepsilon}{d}$$

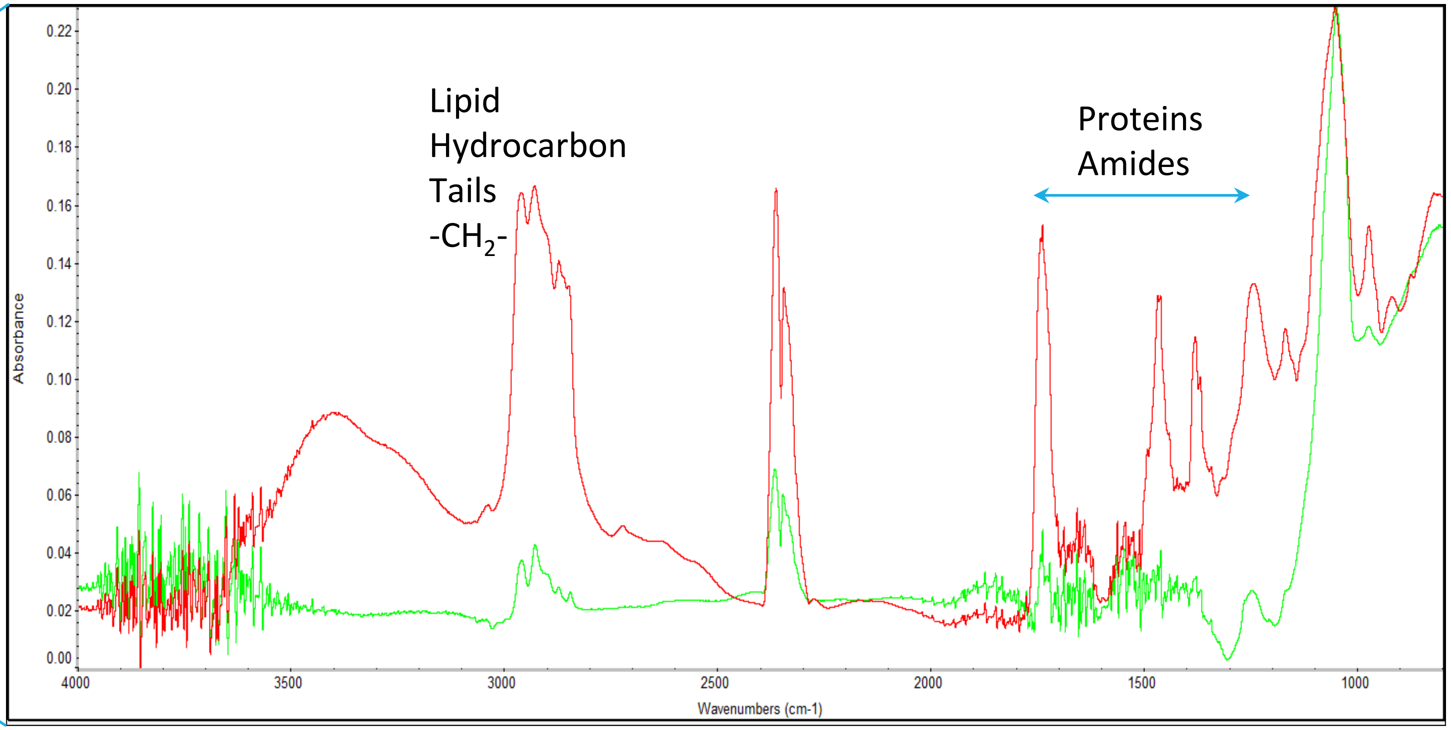
UV-degradation of Lipid Films on Glass in Air



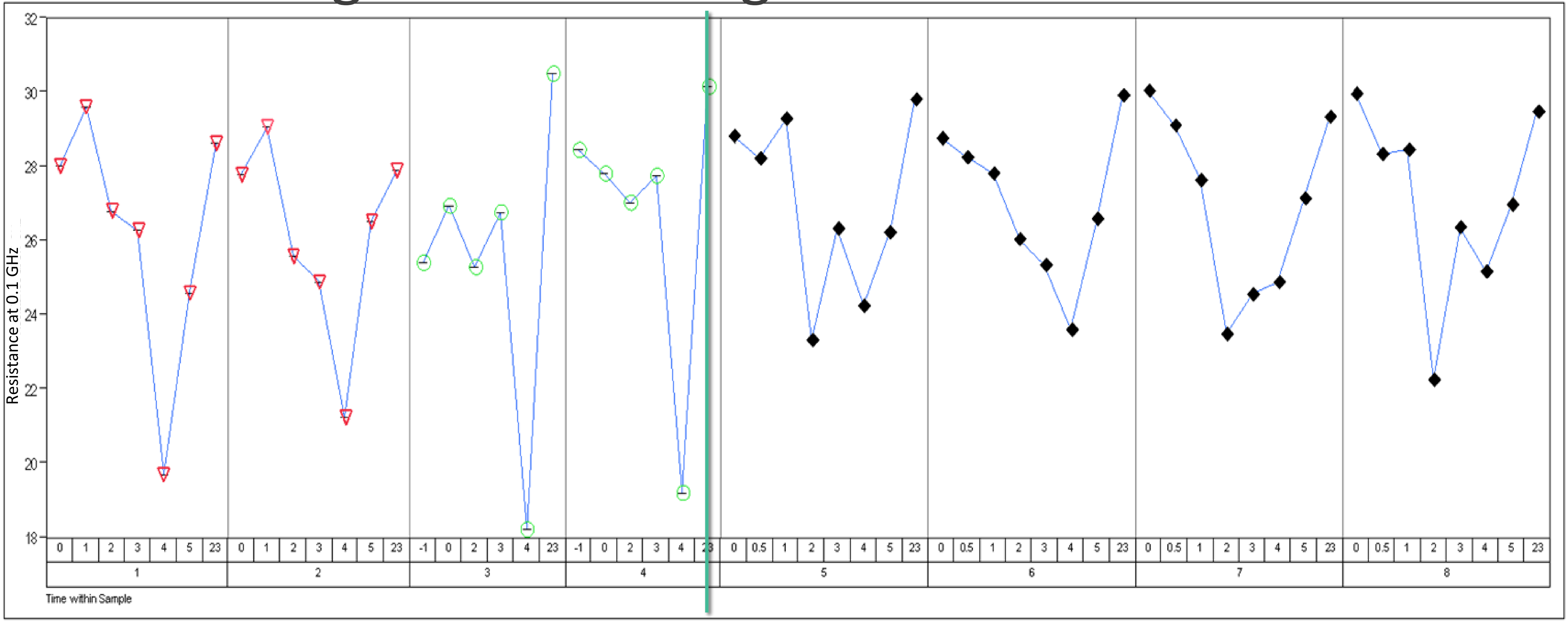
- Film capacitance is a good indicator of lipid film transformation
- Reference line represents results of 7.5 min UV-O3 treatment
- The extent of lipid film transformation appears to depend primarily on the film thickness
- We need chemical analyses (e.g. FTIR) to characterize the lipid film transformation

The FTIR Analysis of Lipid Adsorbed on C16SH-Au-Glass Substrate Pre- and Post UV-Photolysis
(Model of Cell Membrane-Cytoplasm Interface)





UV-degradation of Yogurt Films on Glass in Air



1) We can electrically detect Yogurt film transformation (i.e., cell death)
2) 10 min. under UV-Ozone (O_3) does not kill all the bacteria in the Yogurt Film
3) Cells die by (i) starvation (out of substrate in about 4 hrs.) or (ii) by photolysis (in about 2 hours)
4) Cell death is accelerated by UV-photolysis from 4hrs to 2 hrs.
5) Cells that survive UV-irradiation eventually die by starvation.

Discussion

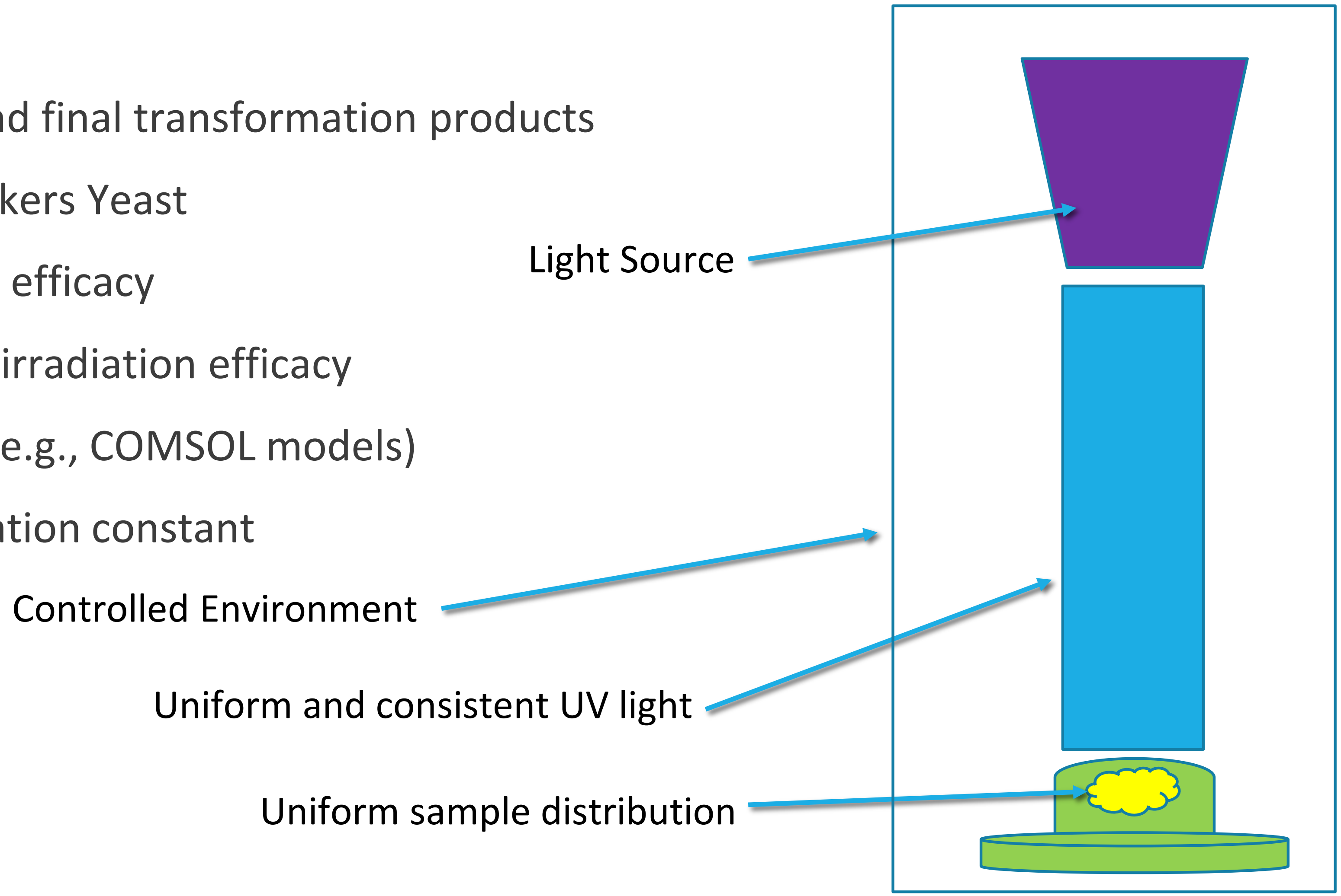
Accomplishments :

- Review existing modules
- Write, calibrate and validate new module if needed
- Apply the optimized RLGC module to existing data.
- Apply module to collected data
  - ✓ Epi on doped silicon
  - ✓ Electromigration / interconnect corrosion
  - ✓ ***Biomaterial degradation / transformation***
  - ✓ Etc.

The current model shows consistent and sensible results.

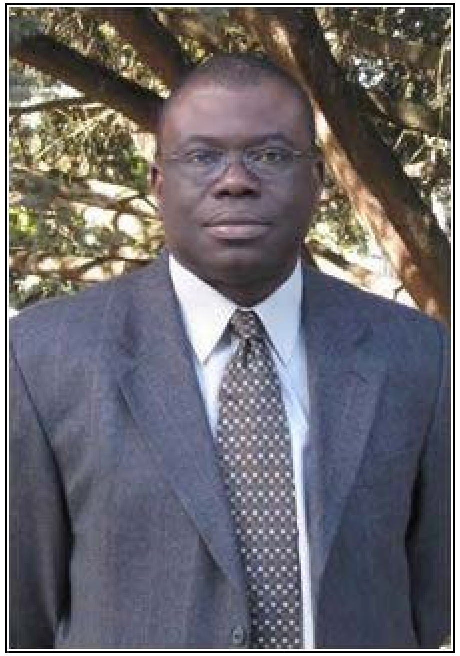
Future work

- ➢ Chemical analyses of intermediate and final transformation products
- ➢ Test theory and concepts on with Bakers Yeast
- ➢ Define parameters for HAI mitigation efficacy
- ➢ Distance and angular dependence of irradiation efficacy
- ➢ Predictive models for UV-photolysis (e.g., COMSOL models)
- ➢ Investigate the nature of the propagation constant



Acknowledgements

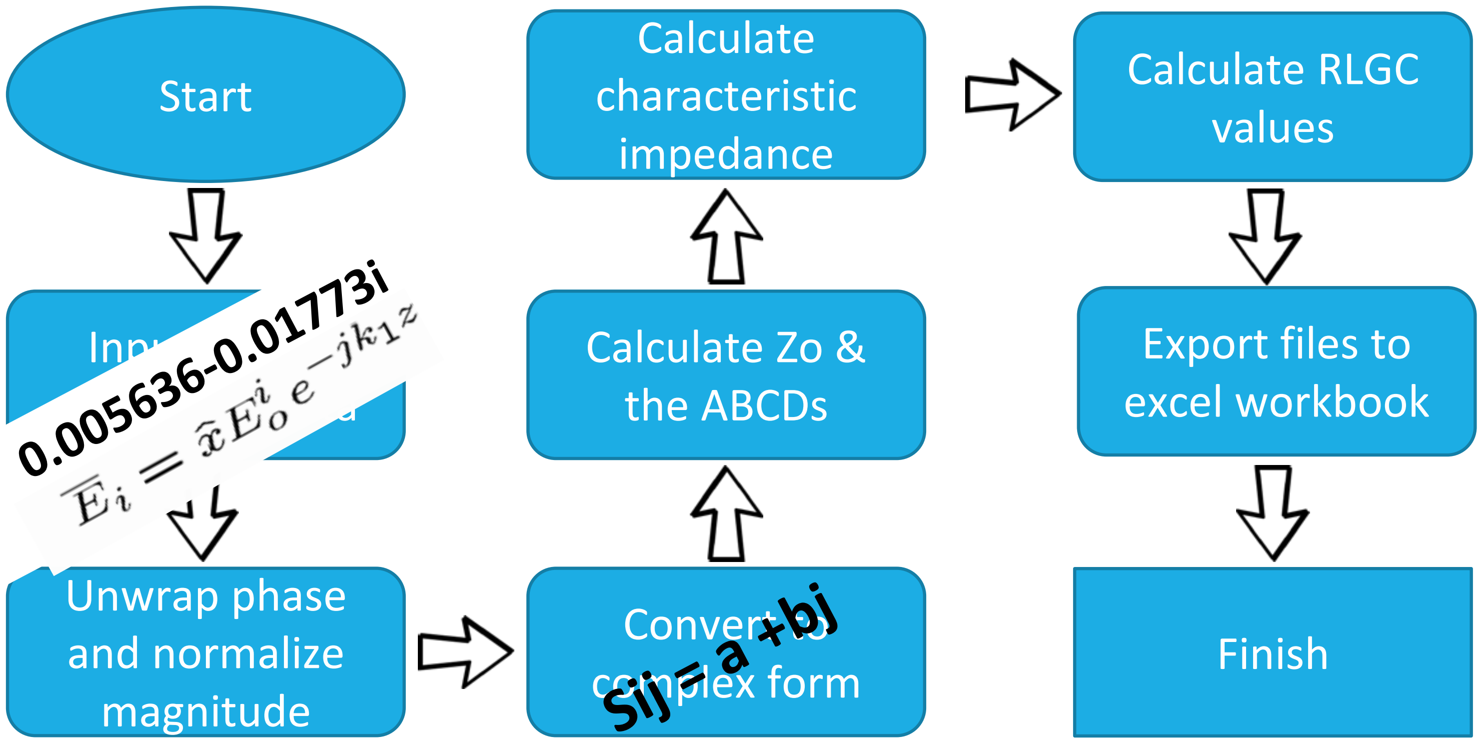
- Dr. Yaw Obeng
- Joseph Kopanski
- NIST staff
- Society of Physics Students
- California State University of San Marcos
  - Grant GM-08807



Yaw Obeng

Joseph Kopanski

S–parameters to RLGC values



$$A = \frac{(1 + S11 - S22 - ((S11)(S22) - (S21)(S12))}{2 * (S21)}$$

$$B = \text{Zo}\frac{(1 + S11 + S22 + ((S11)(S22) - (S21)(S12))}{2 * (S21)}$$

$$C = \frac{(1 - S11 - S22 + ((S11)(S22) - (S21)(S12))}{(\text{Zo}) * 2 * (S21)}$$

$$D = \frac{(1 - S11 + S22 - ((S11)(S22) - (S21)(S12))}{2 * (S21)}$$

$$\text{Zc} = Zo * \sqrt{\frac{(1+S11)\text{^}2 - (S21)\text{^}2}{(1-S11)\text{^}2 - (S21)\text{^}2}}$$

$$\Upsilon = \frac{\sinh\text{^} - 1(BC)}{l}$$

R = Re{ϒ* Zc} **G** = Re{ϒ /Zc}

L =Im {ϒ * Zc}/ω **C** = Im{ϒ /Zc}/ ω