An Investigation of High Temperature Corrosion Sensing for Coal-Based Power Plant Operations

Brian Jordan[a]
Kevin Tennant[a]
Noah Strader[b]
Dr. Edward M. Sabolsky[a]
Dr. Daryl Reynolds[b]

[a] Department of Mechanical and Aerospace Engineering
[b] Lane Department of Computer Science and Electrical Engineering
West Virginia University

MS+T 2022 October 11th
Advanced materials for harsh environments session IV
David L. Lawrence convention center 334
10:40 am – 11:00 am
Pittsburgh PA.

Initial Acknowledgments:

Acknowledgment: "This material is based upon work supported by the Department of Energy Award Number DE-FE0031912"

Background:

- Operating profile of the existing coal-fired power plants has changed from high-capacity-factor (baseload) operation to *flexible operation*.

- Increased cycling operations with *increased thermal ramp rates, and rapid changes* in unit output have a major impact on reliability, efficiency and cost of the coal-fired power plants.

- Cycling causes increased wear-and-tear on high-temperature and high-pressure components, and shorter equipment lifespan due to thermal expansion/fatigue, increased corrosion and cracking.

- *Corrosion-related issues are emphasized as the major mechanism* for boiler tube failures under harsh-environments.

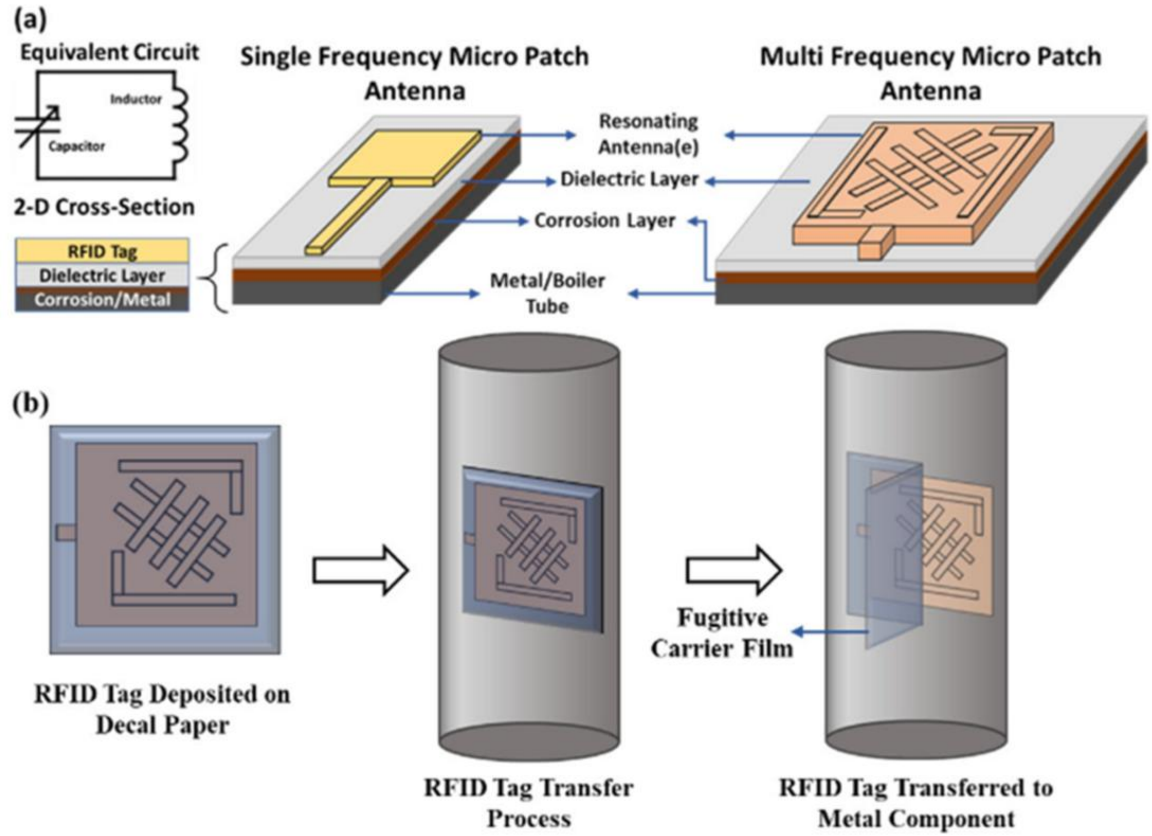
Background:

- Health and temperature monitoring of metal components and boiler tubes in the coal-fired power plants has technical challenges due to 500-1300ºC and high steam- and/or flue gas-related harsh-environments.

- *Downtime inspection* and *metal loss coupons* are common techniques being utilized to assess the corrosion and related failures in power plants.

  Limitations:
  - Slow response rate
  - Increased personnel required
  - Limited testing/inspections possible
  - Operating capability at various temperatures

The Technology:



Item (a): Schematic of proposed sensor cross-section and equivalent circuit, which includes the single and mult-frequency micro-patch RFID tag printed onto ceramic barrier layer which will insulate and bond sensor to the metal specimen.

Item (b): Representation of peel-and-stick deposition approach to transfer the chipless RFID tag sensor to metal component.

The Technology:

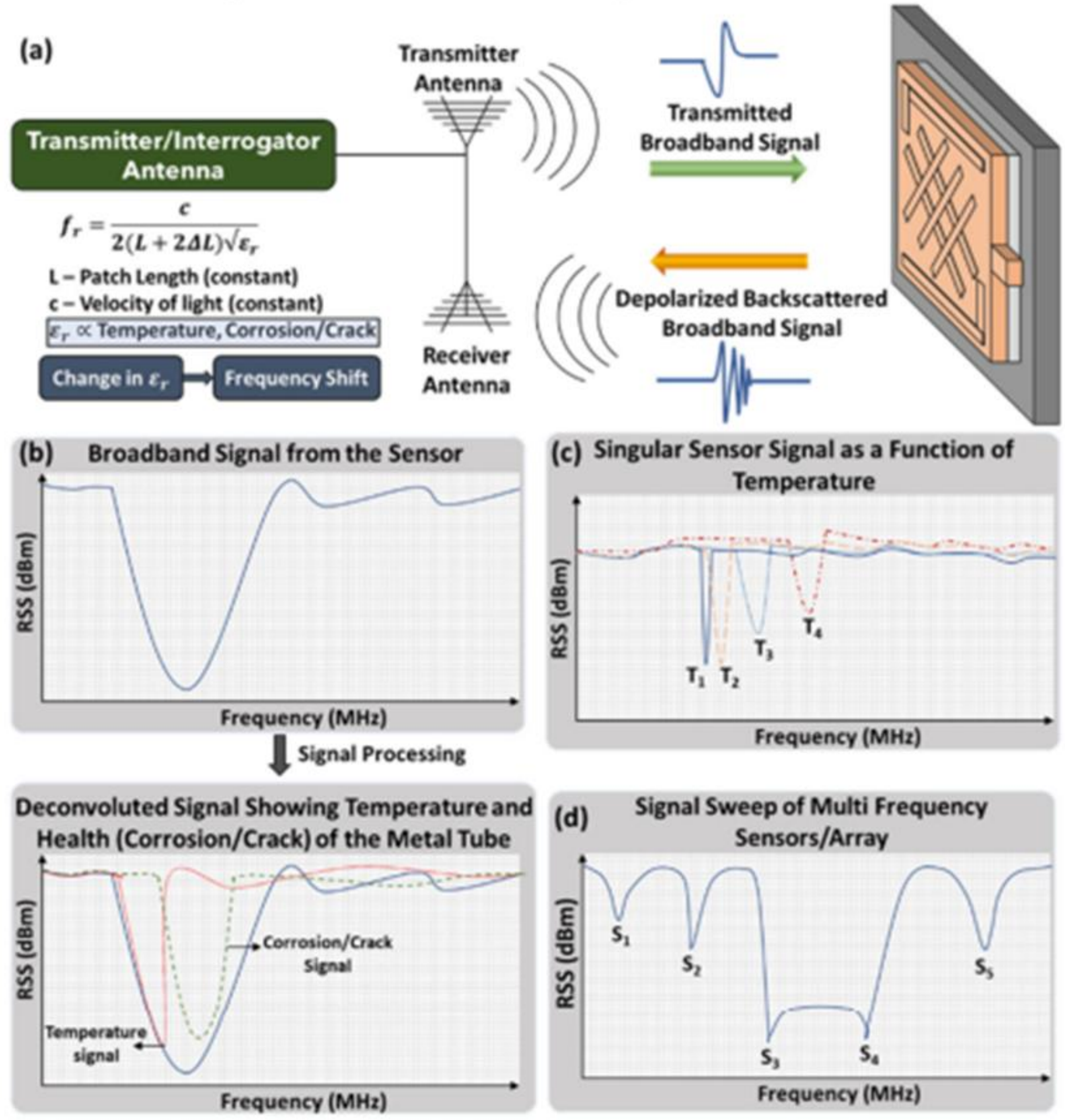
RSS= Received Signal Strength

Item (a)= *General Schematic*

Item (b)= Received broadband signal and deconvoluting step to separate temperature and corrosion/crack information.

Item (c)= Frequency shift for reflected power for singular sensor to change in sensing parameters (temperature).

Item (d)= Multi-frequency signature read for multi-sensor array measured by interrogator antennae.



Outline of Experimentation:

Corrosion kinetics of boiler grade steel

- Mass change
- Thickness growth of the oxide layer

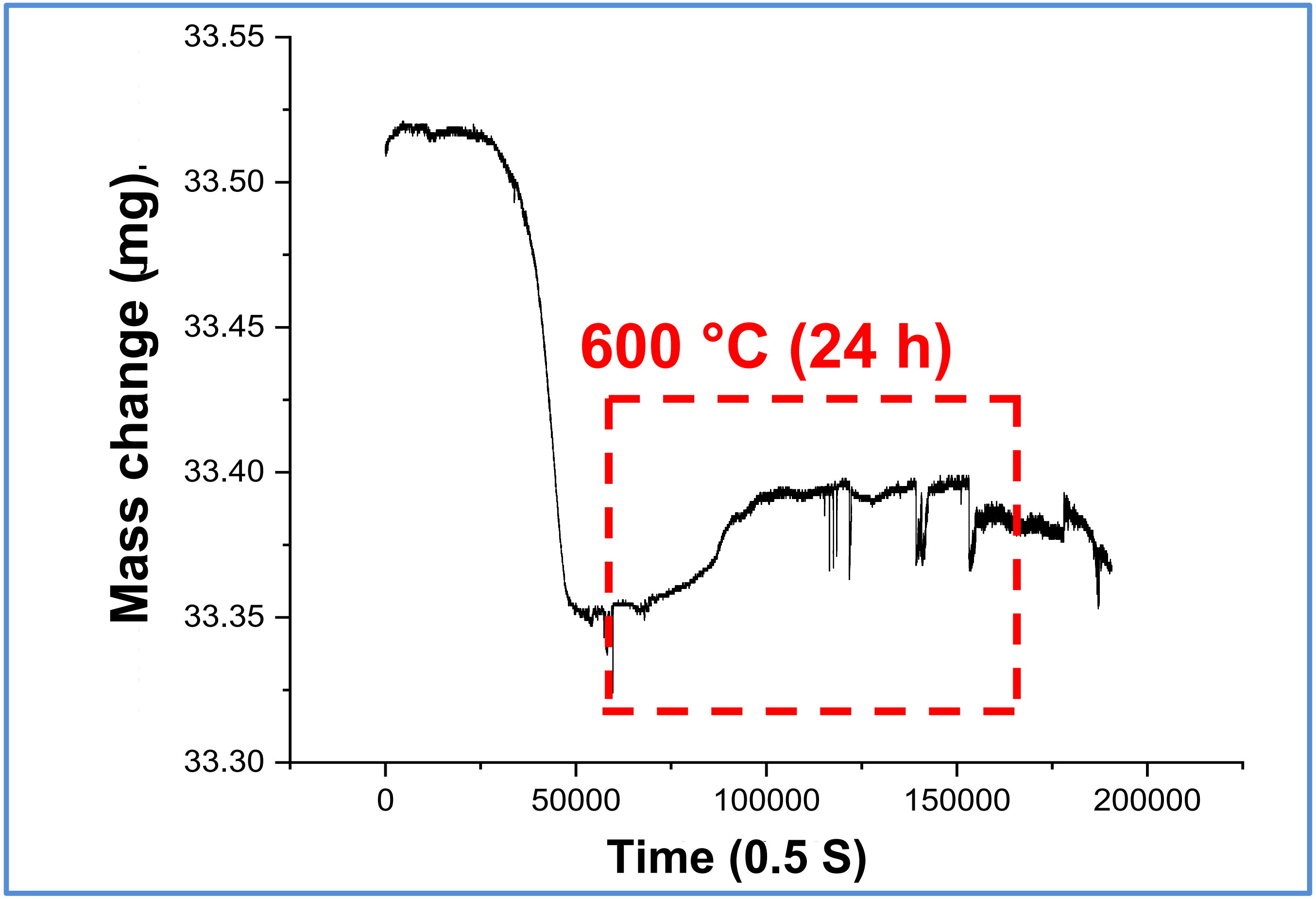
Dielectric deposition and fabrication of sensors

- Our dielectric materials investigated
- Fabrication process

Sensor interrogation

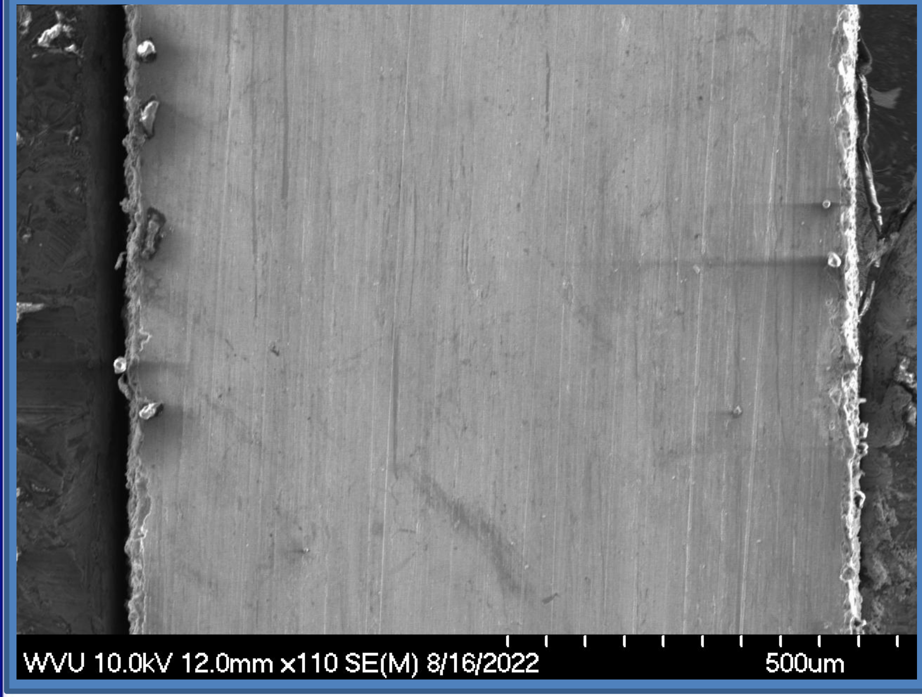
- ANSYS modelling
- Signal collection and processing

TGA Investigation of Mass Change:

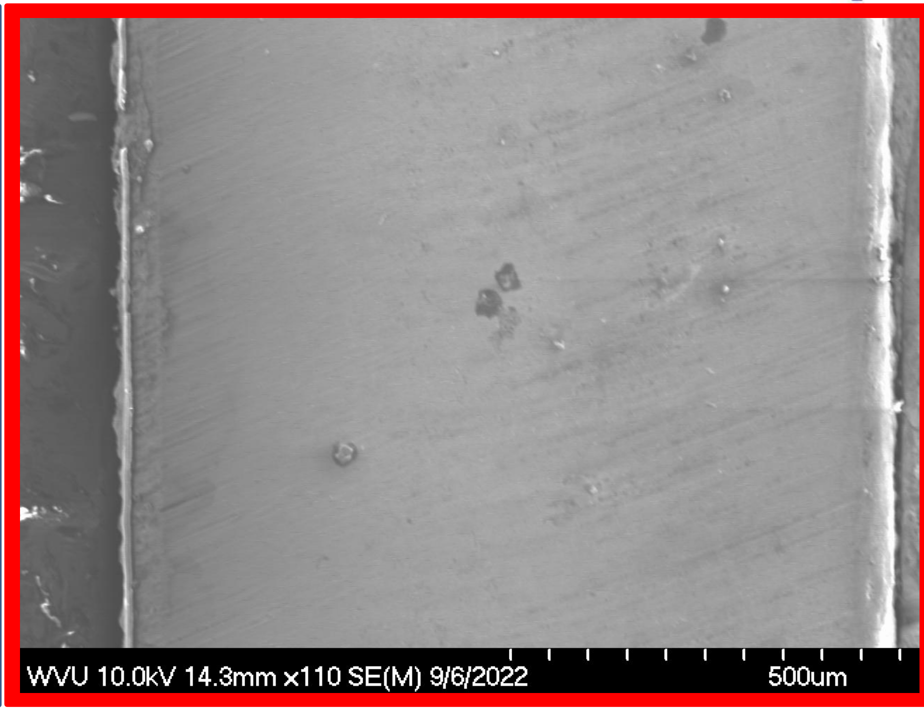


- A sample of SS 304H was heated to 600C in air and held for 24 hours
- A plateau effect on the mass change was identified at approximately 11.1 hours in the harsh environment

Thickness Change of SS 304H at 600 °C:



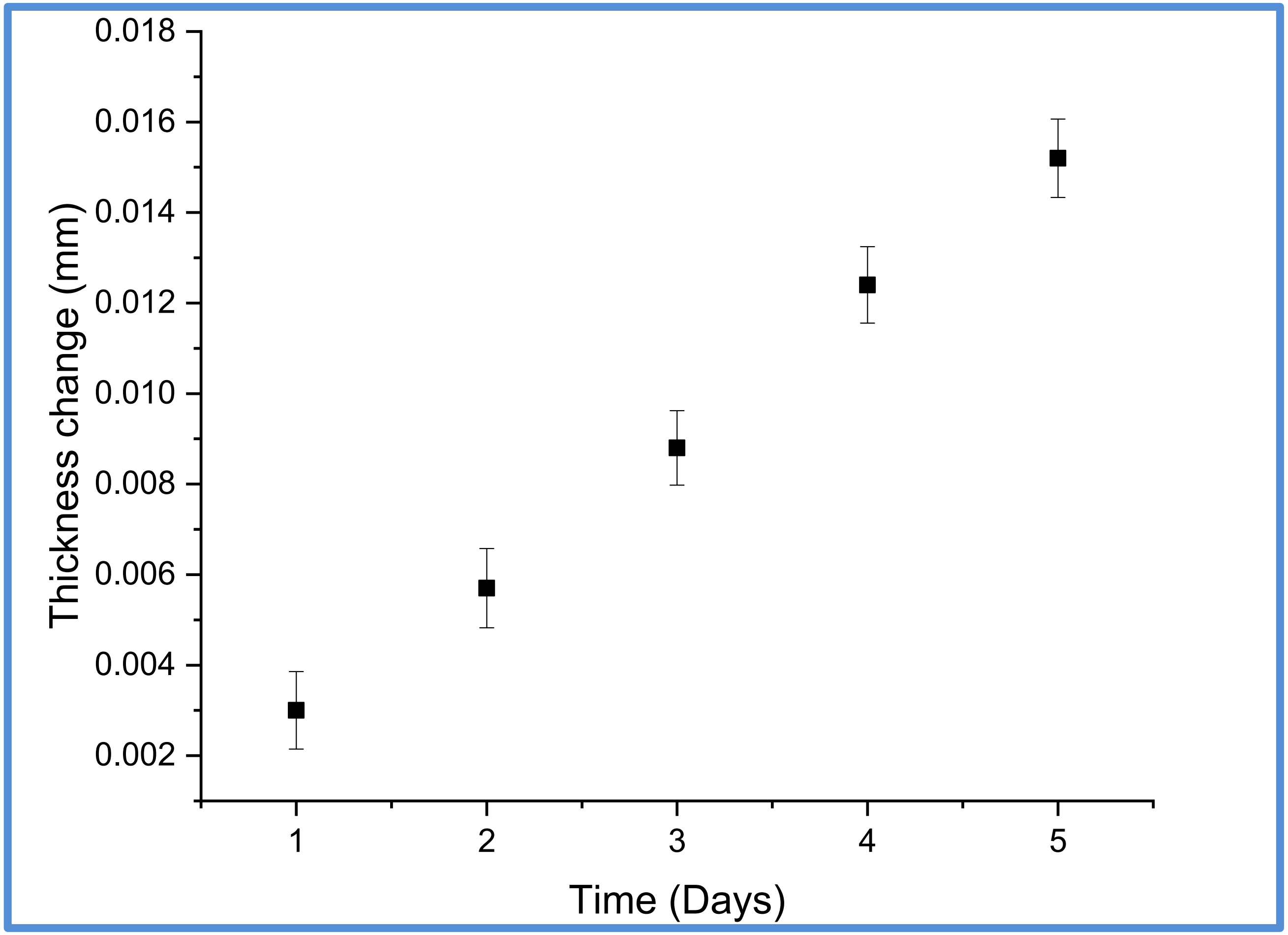
(Pre corrosion SEM image)



(Post corrosion SEM image)

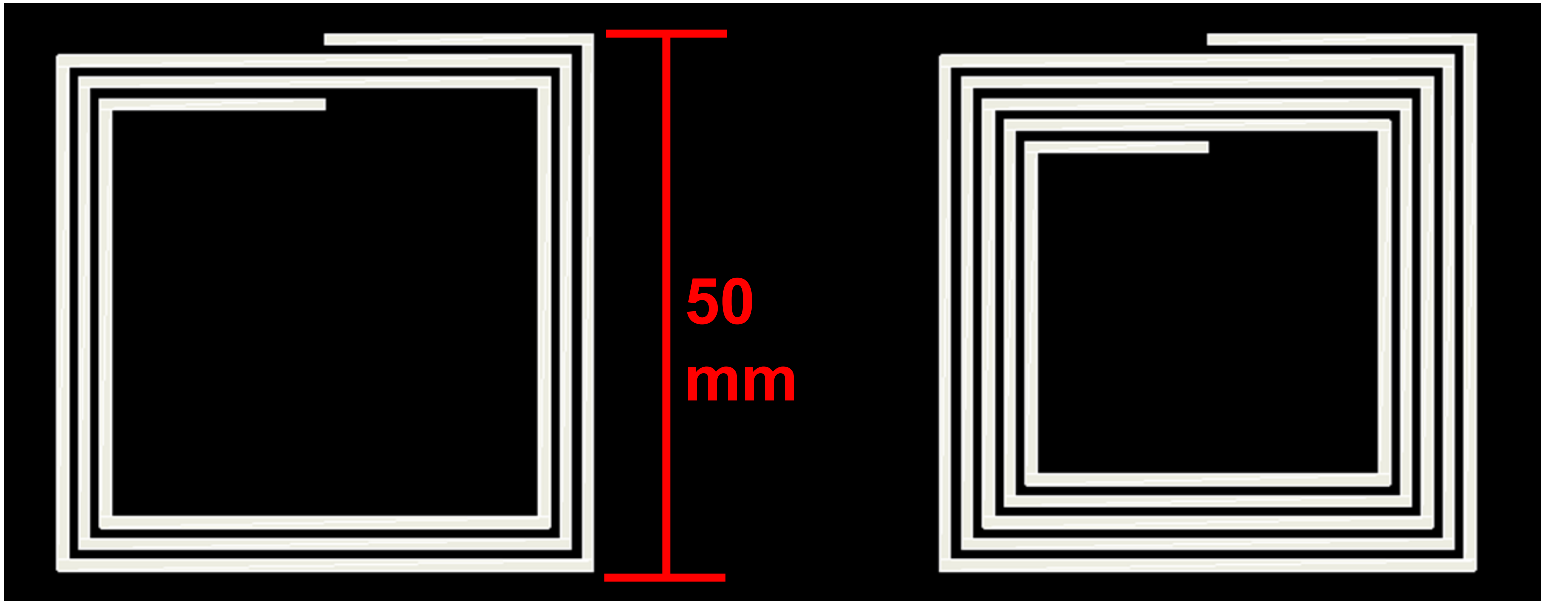
- SEM images of slivers of stainless steel before and after the corrosion process were collected
- Slivers were induced in the harsh environment for a period of 1-5 days.

Thickness Change of SS 304H at 600 °C:



- Using imageJ software the change in relative steel were calculated
- In our 600C harsh environment approximately 30 micrometres of steel were lost every 24 hours

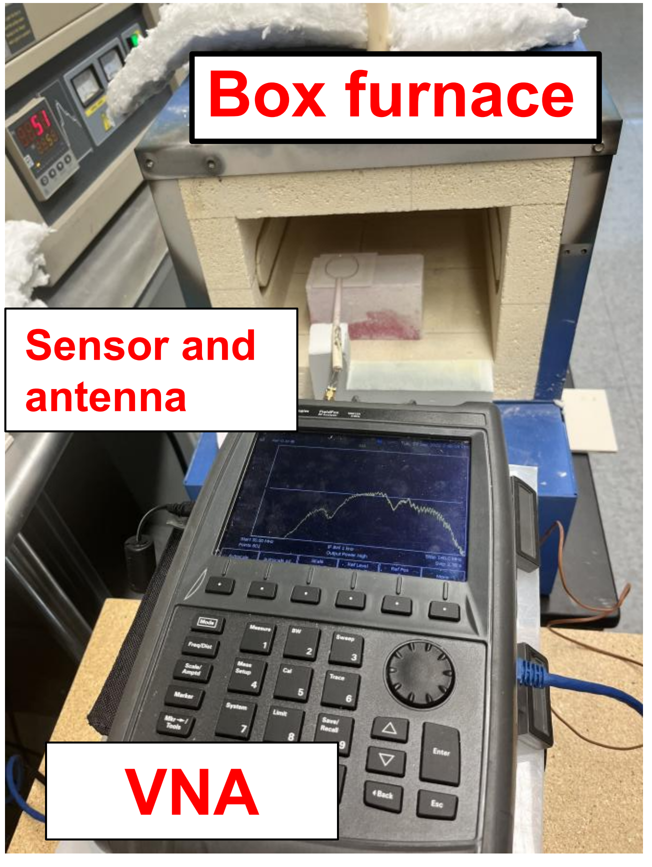
Inductor Designs:



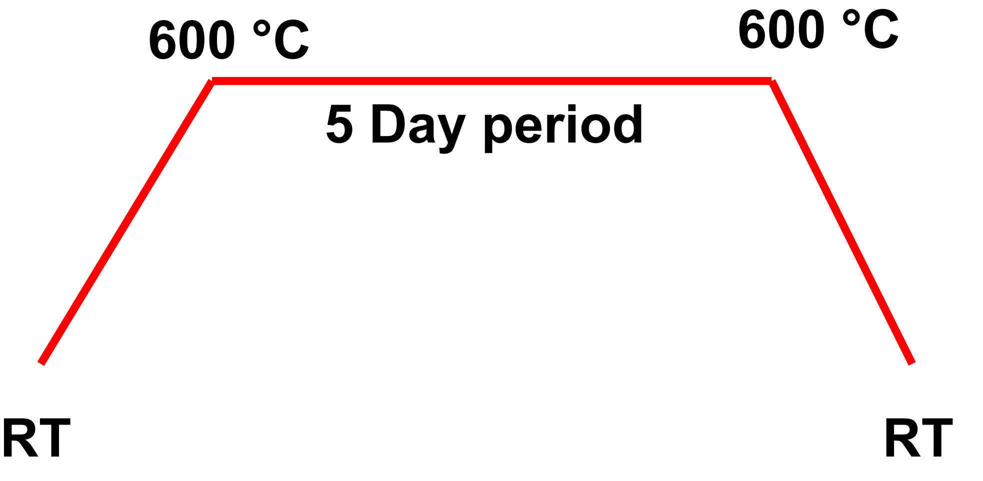
(Image of three turn and five turn inductor)

- Initial sensor will be fabricated from commercially bought low temp sealant glass via screen printing.
- Width of lines are 1 mm.
- Single resonance peaks are achieved with both designs (40 MHz-200 MHz).

Interrogation Set-up of RFID Sensor:



(Image of VNA set up for wireless interrogation)



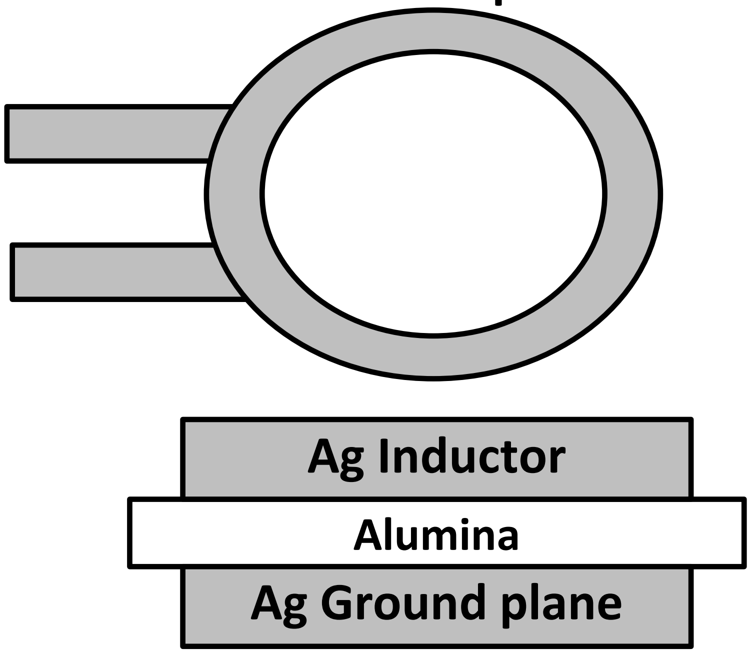
(Image simulating the cycling occurring during power plant operation)

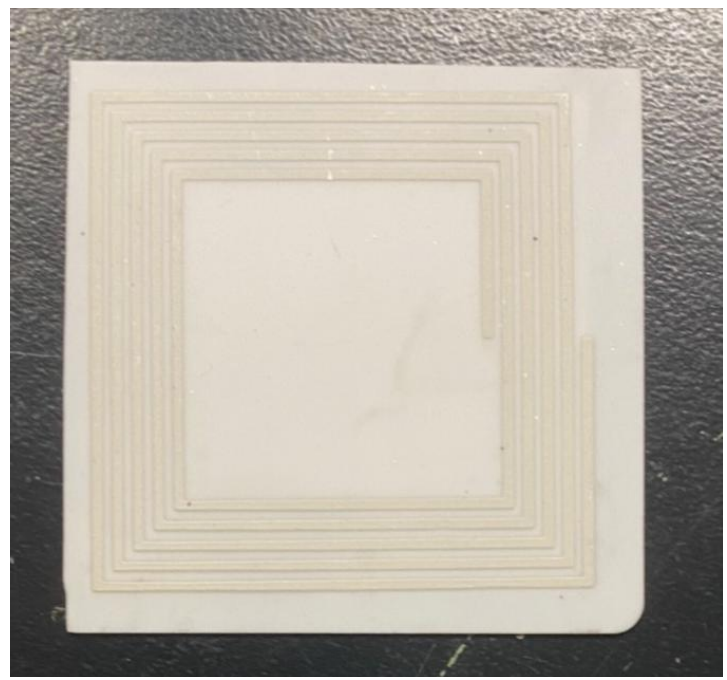
1. During the ramp up to 600C
2. During the 5 day hold at 600C
3. During the ramp down to room temperature

Fabrication of Temperature sensing RFID sensor:

- Our temperature based RFID sensor was fabricated via a screen printing process
- From our ANSYS modelling we determined a resonant frequency peak at 70 MHz
- Our sensors were then interrogated via near field loop antenna made from Pt

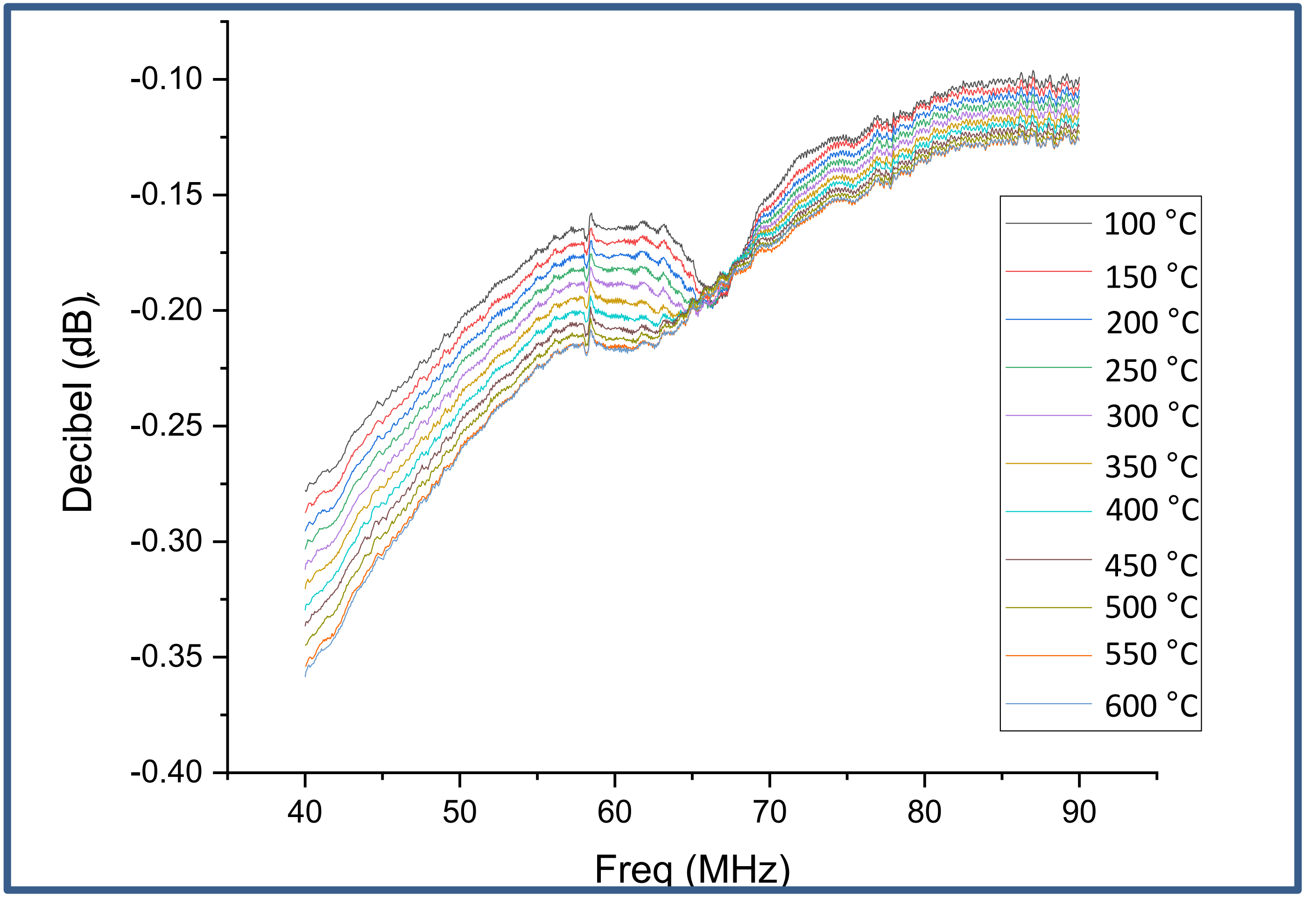
Near field Pt loop antenna





(Image of five turn temperature RFID sensor)

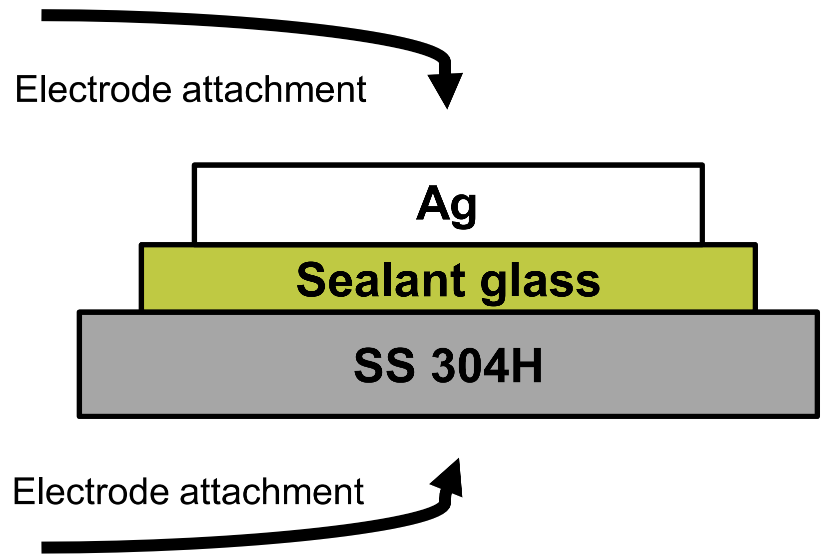
Interrogation of Temperature Sensor (Ramp up):



- Our resonant frequency peak can be clearly seen at 70 MHz.
- As the temperature increases a downward shift in frequency can be observed with a widening effect on our peak
- From our collected data we see our peak shifts around 10 KHz per 1 °C

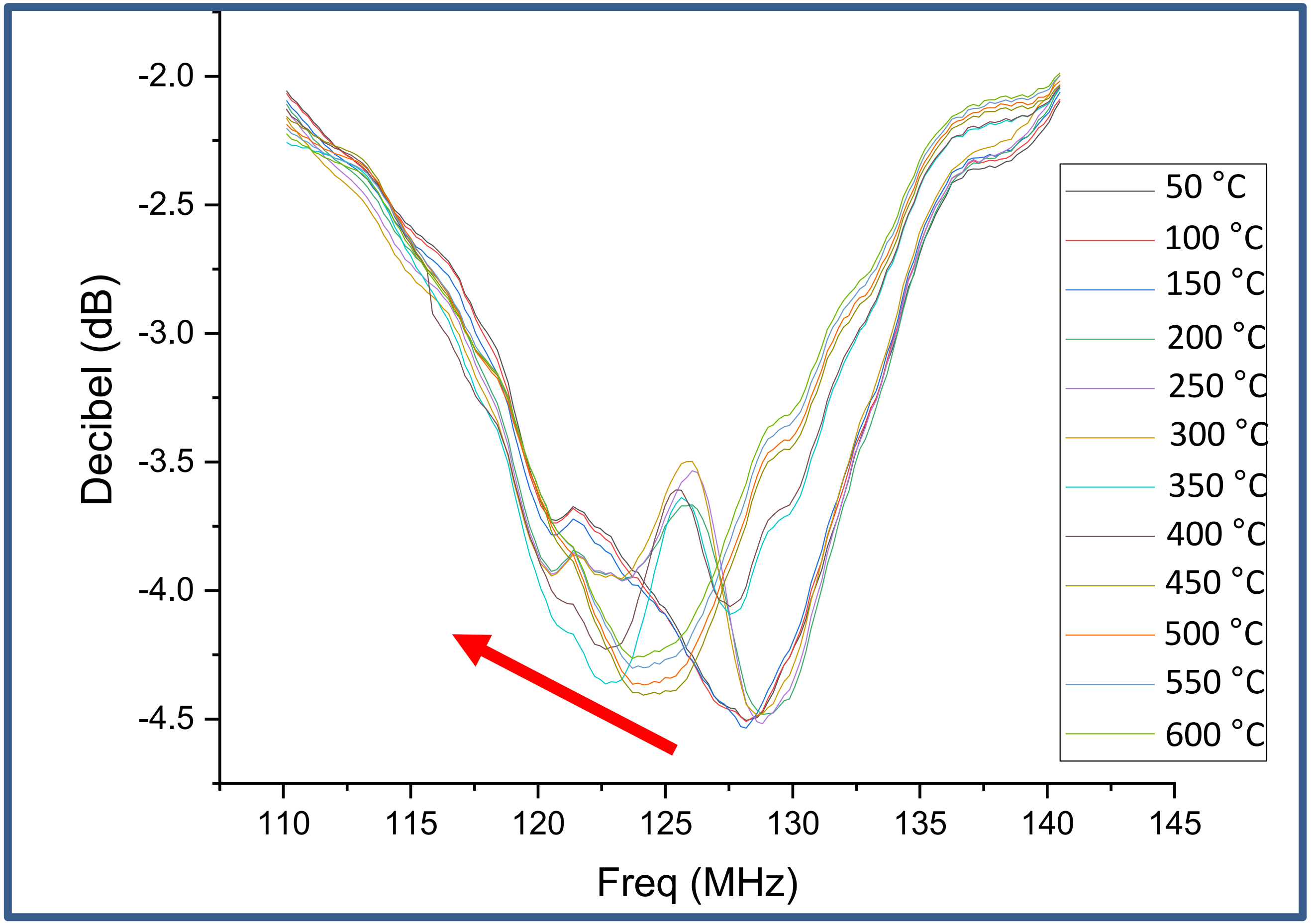
Fabrication of corrosion sensing RFID sensor:

- Both the sealant glass layer and silver inductor were fabricated onto the steel via screen printing
- Sealant glass was fired at 780 °C for 1 hour with 2 °C/min ramp up and ramp down rate
- The silver ink was sintered in a similar manner up 550 °C for 1 hour



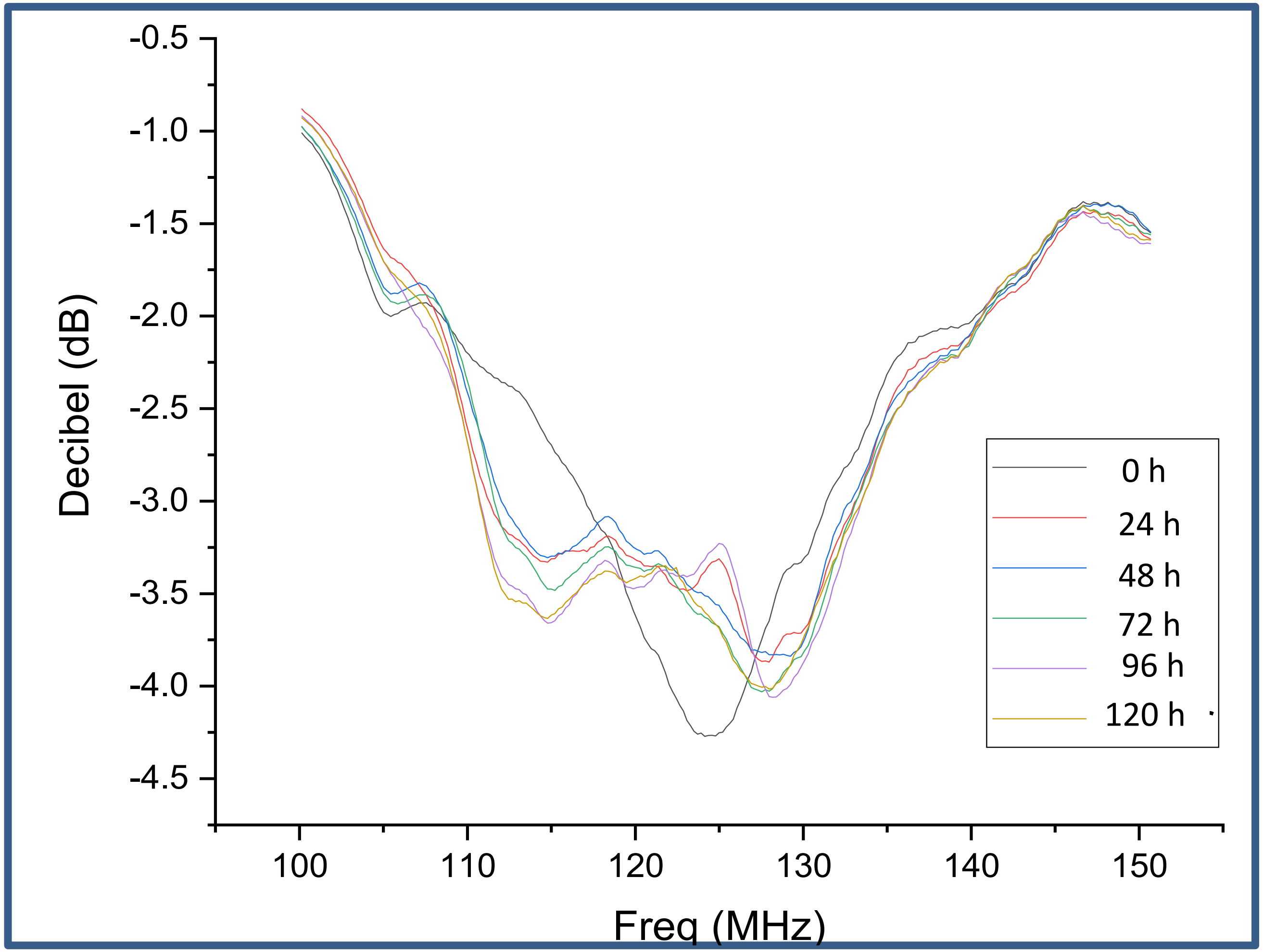
Composition	
Boron Oxide	37%
Barium Oxide	23%
Strontium oxide	5%
Silica	25%
Calcium oxide	5%
Alumina	5%

Interrogation of Corrosion Sensor (Ramp Up)



- Our resonance peak was identified at approximately 120-130 MHz
- As the temperature increases there is a downshift in frequency
- Certain geometry changes of the peak can be identified at increasing temperature due to oxide development and spallation effects

Interrogation of Corrosion Sensor (Steady Temp)



- Our resonance peak was identified at approximately 120-130 MHz
- As the oxide develops on the steel the dielectric of the ground plane changes causing a shift in our resonant frequency. Stability within the resonant frequency geometry can seen after the first day.

Conclusion

- Identified our linear trends in oxide layer growth for 600 °C in air. Paired with identifying the plateau in mass change withing boiler grade stainless steel.
- Fabricated wireless and passive RFID sensors designed to measure changes in temperature and corrosion in situ in harsh environments
- Modelled both sets of sensors on ANSYS to identify location of resonant frequency peaks
- Demonstrated in situ interrogation of both our temperature RFID sensor and also our steel back corrosion RFID sensor to mimic cycling within coal based power plants

Future Work

- Investigate thin film development of sensors directly onto stainless steel

- Investigate different sensors designs in the far field
- Model our sensors on ANSYS software at high temperatures to simulate our experimentation
- Interrogate our sensors at higher temperatures and harsher environments simulating those in a coal based power plant.

Thank you!

Questions

Dr. Edward Sabolsky:
ed.sabolsky@mail.wvu.edu

Dr. Daryl Reynolds:
daryl.reynolds@mail.wvu.edu

Brian Jordan:
brj00003@mix.wvu.edu