AC Resistmetry-type Corrosion Monitoring Sensor Fabricated by Screen-printing

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a. Tokyo University of Science
b. Newlong Seimitsu Kogyo, Co. Ltd.

Outline of presentation

1. **Introduction**
   Background and objectives
2. **Manufacture method of the AC resistmetry-type sensor**
   The sensor fabricated by screen-printing method.
3. **Experimental**
   Impedance measurement of the sensor
4. **Results and Discussion**
   The sensor characteristics
5. **Conclusion**

Background of research

Corrosion factor for electronic parts:

- Water
- Corrosive gas (ex. H_2S, SO_2, NO_2)
- Salt (ex. NaCl, KCl)

Measurement of corrosion factor

Screen-printing sensor

1. Miniaturization
2. Reproducibility
3. Flexible design
4. Low cost

Screen-printing apparatus

Application for many sensors

Humidity, Toxicity, Corrosion, etc…

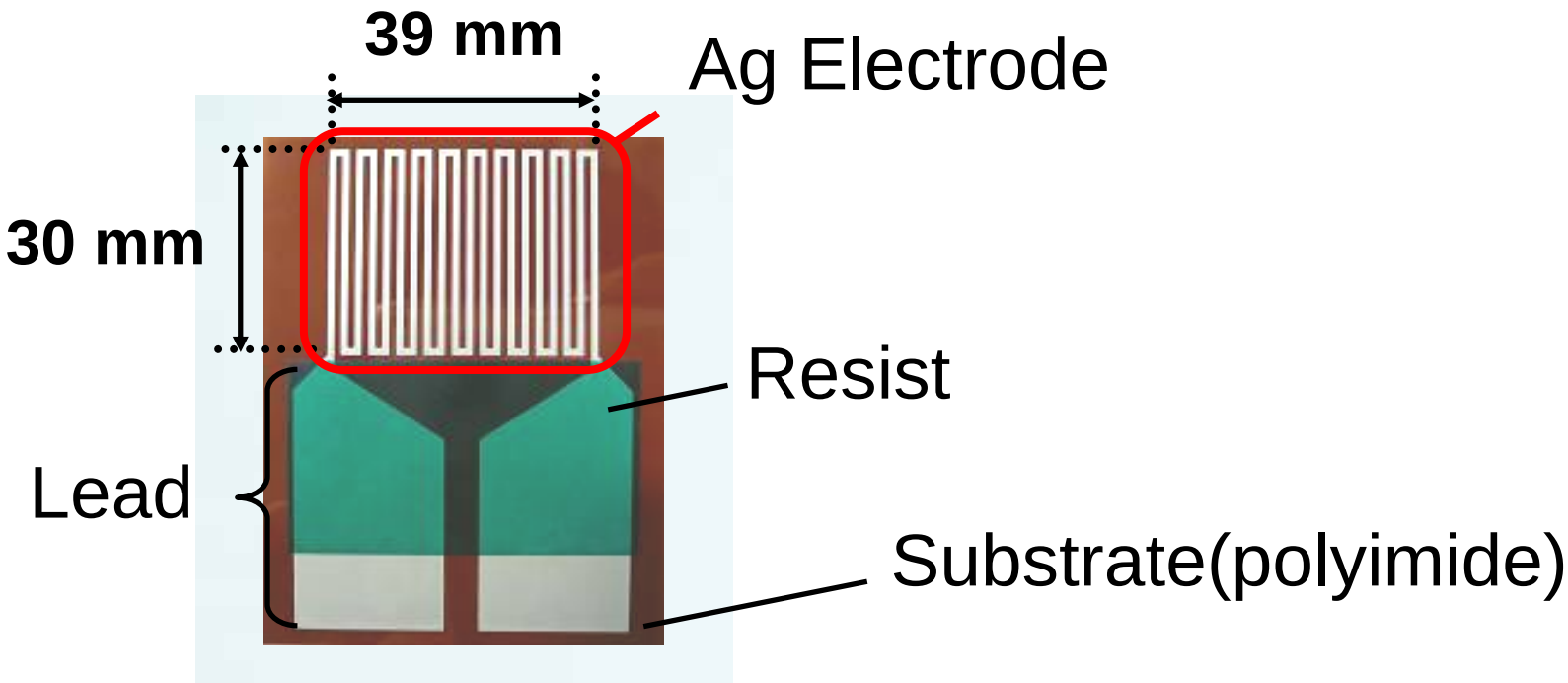
Purpose of this research

To fabricated an electrochemical impedance spectroscopy (EIS)–based *in-situ* corrosion sensor by screen-printing technique

Measurement the EIS under the following corrosion conditions.

1. Sulfur gas
2. High humidity and salt

Fabrication of the sensor

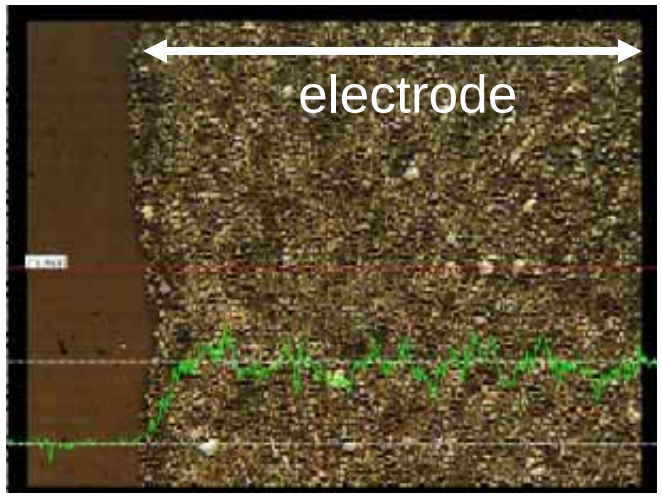


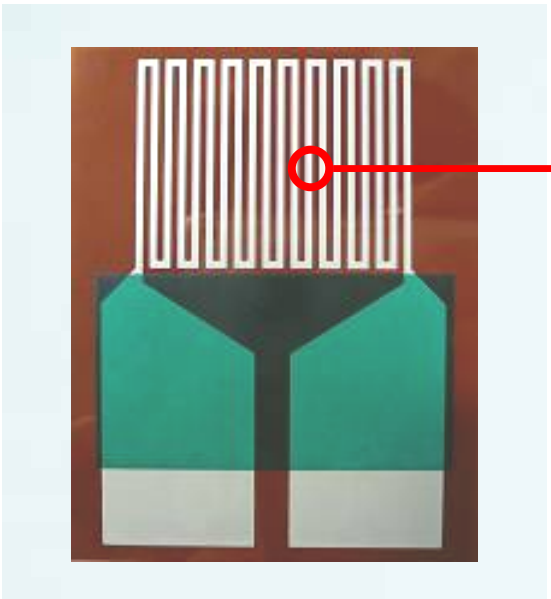
Ag electrode

- line width: 1mm
- line interval: 1mm

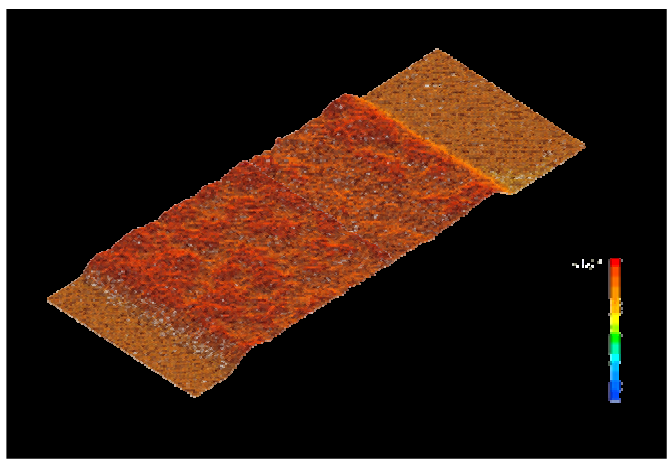
Surface observation of the sensor

Photograph of the electrode surface



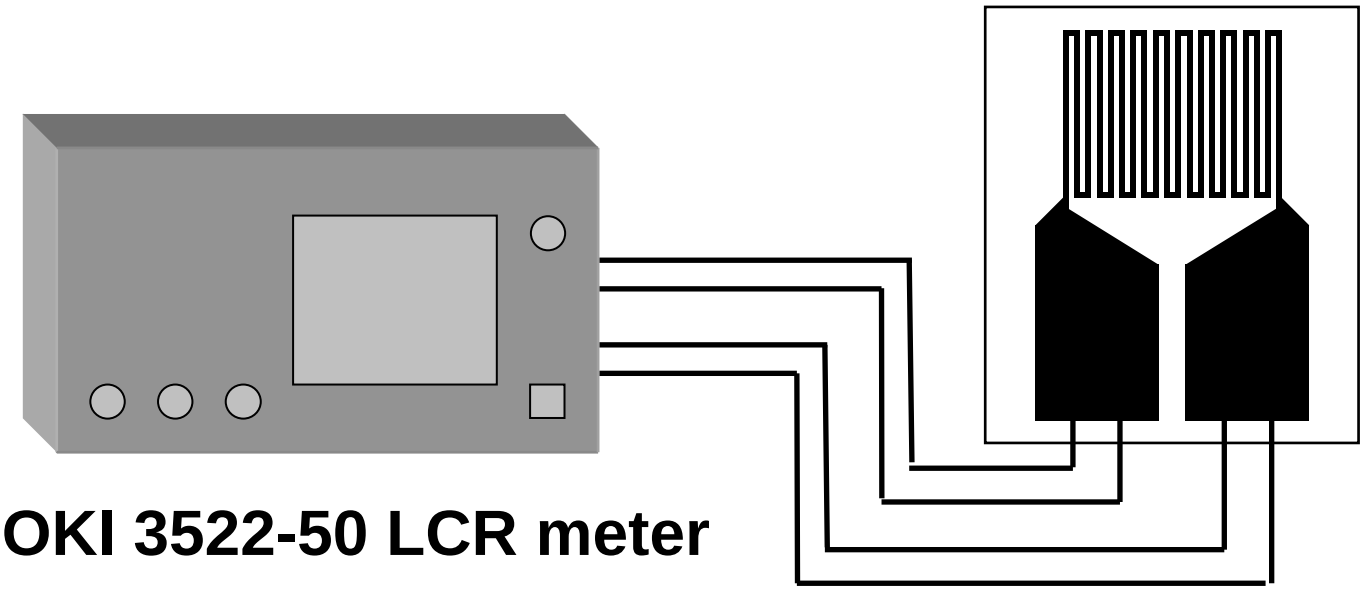


3D view of the electrode surface



Sensor surface was observed
by confocal laser microscope

Experimental set up

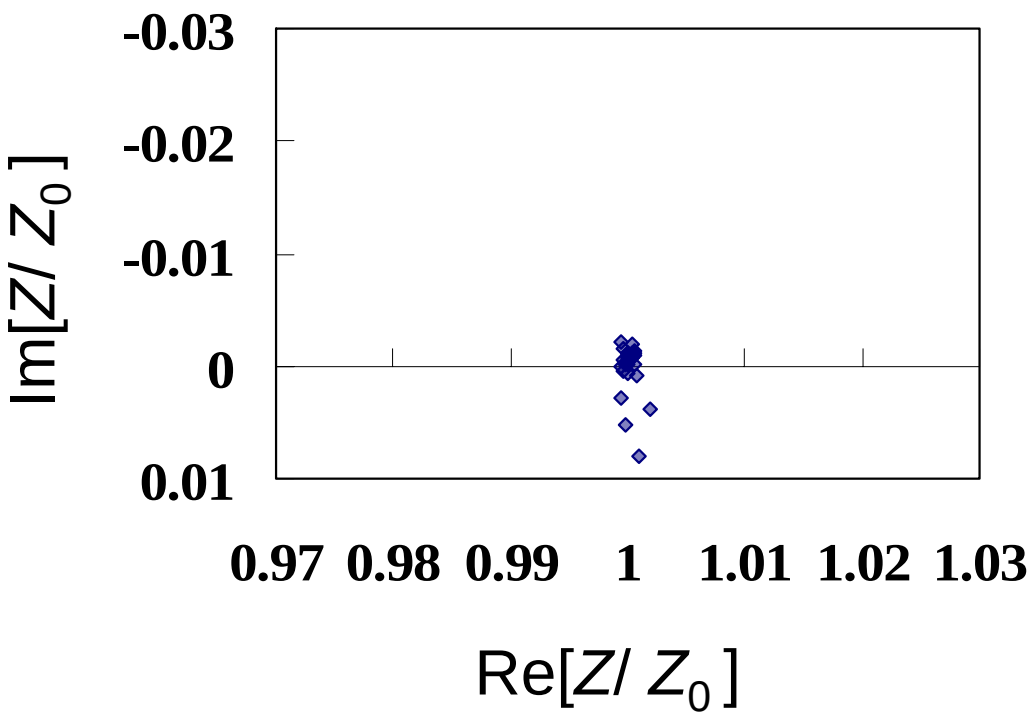


HIOKI 3522-50 LCR meter

Frequency range: 100 kHz - 100 mHz
Potential amplitude: ±10 mV

Characterization of the sensor

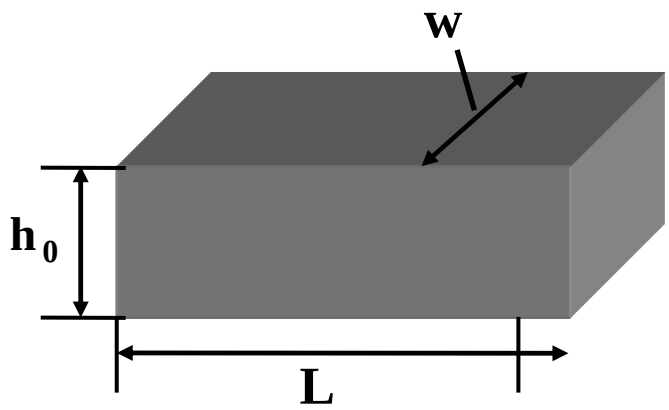
The EIS was measured immediately after fabrication in the atmospheric condition. (humidity = 30%RH, temperature = 23 °C)



Z_0: initial impedance at 1 kHz

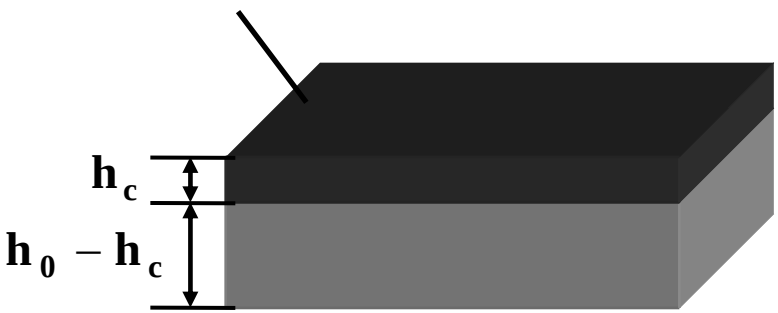
Principle of the corrosion sensor (1)

Metal thin film electrode



$$h_c = h_0 \times \left(1 - \frac{R_0}{R_c}\right) \qquad (1)$$

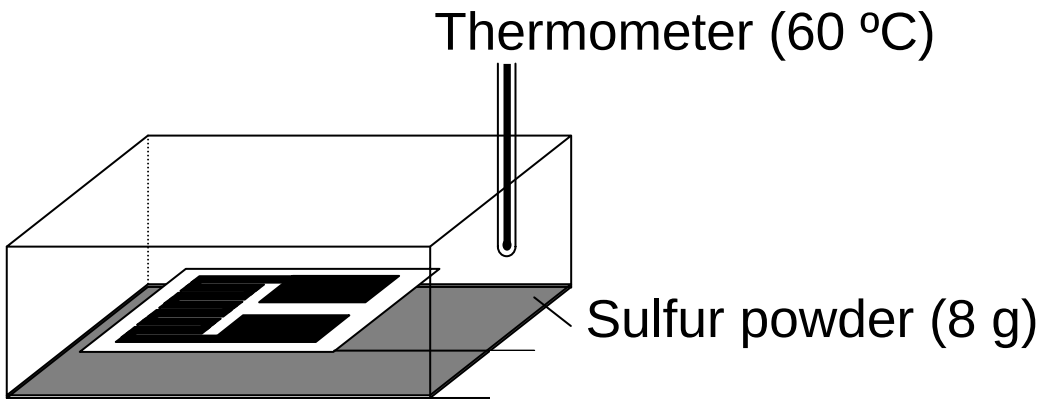
Corrosion film

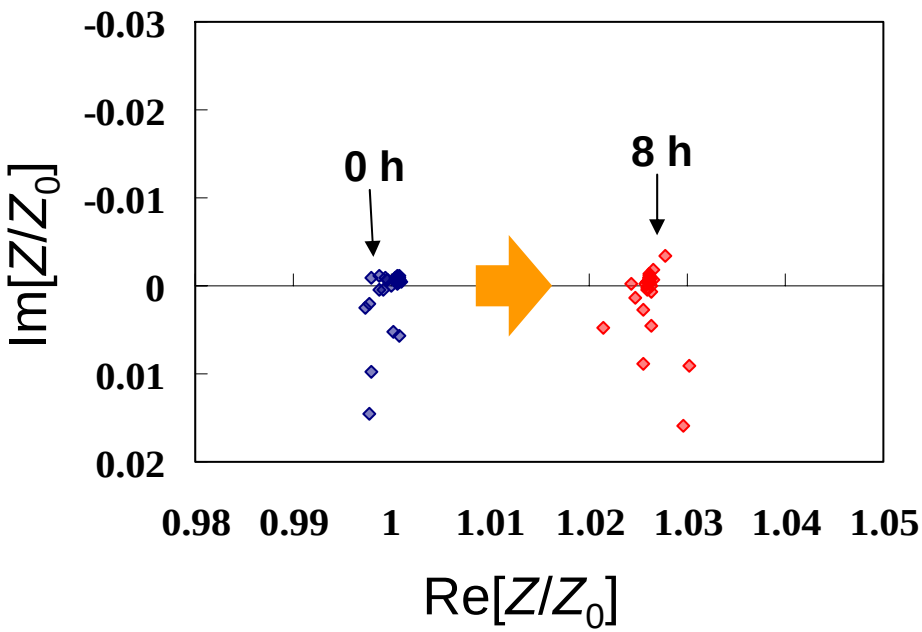


R_0: initial value of the metal thin film electrode resistance

R_c: the value of the electrode resistance after generating the corrosion film

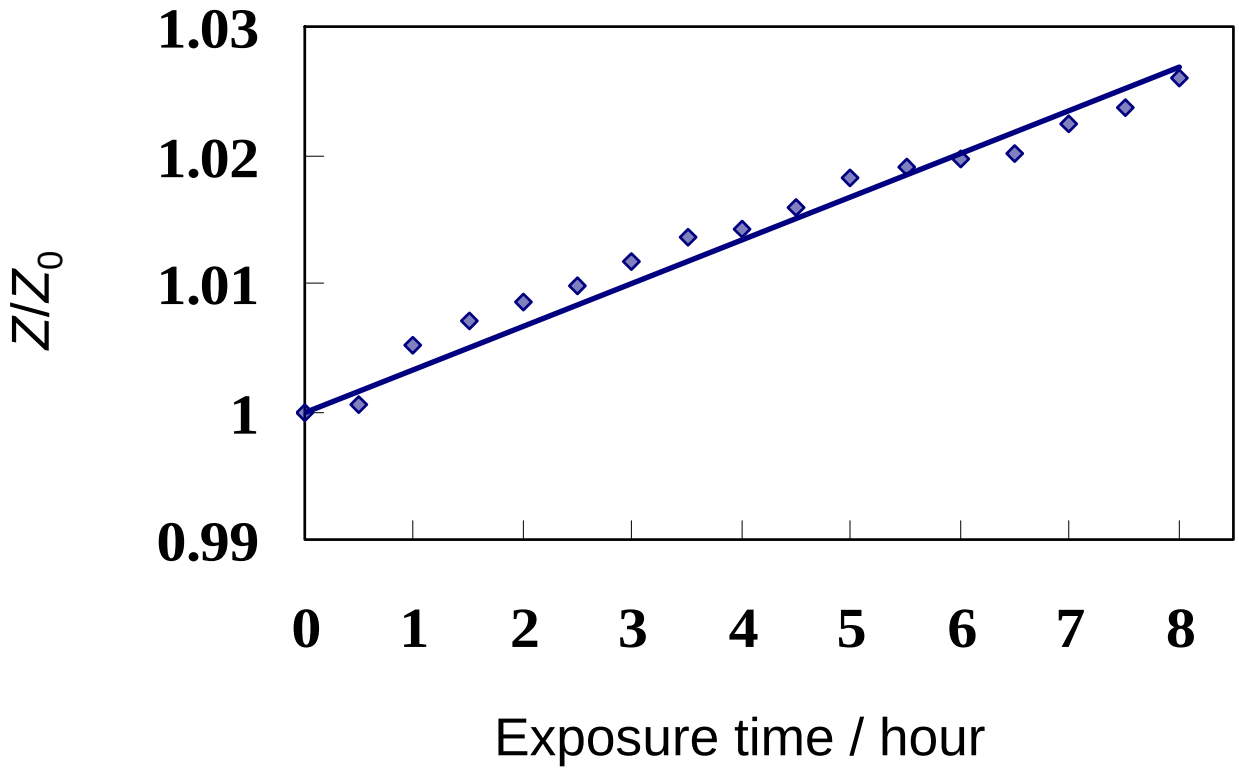
Response of the sensor under sulfur gas condition





- The *Z* increased with time.

Time-*Z* plot under sulfur gas condition



Z/Z_o was proportional to exposure time

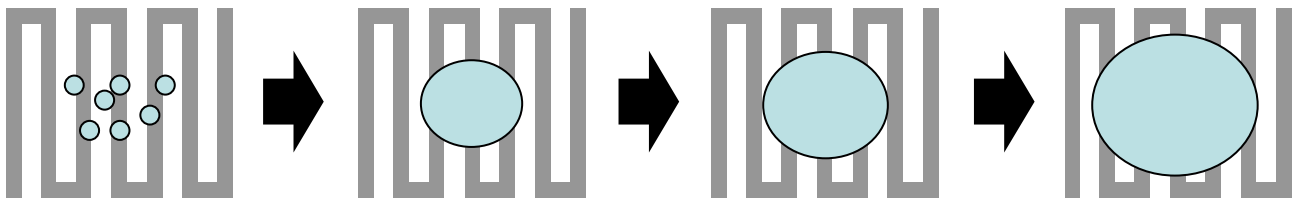
*Chemical reaction： $S_8 + 16Ag \rightarrow 8Ag_2S$

Impedance measurements under high humidity and salt

Experimental

Casting NaCl powder on the electrode surface

Placed the electrode at high humidity condition
(temperature: 23.2-24.5 ºC, humidity: 88-89%RH)

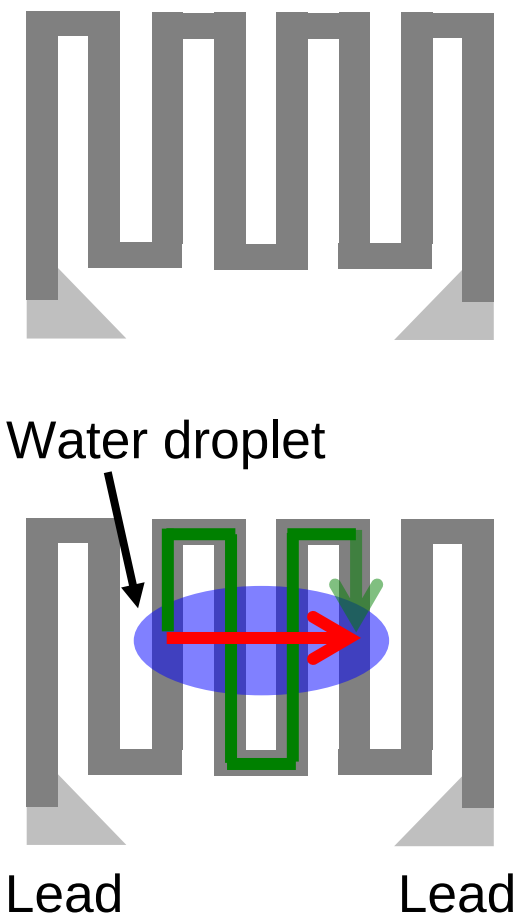


The NaCl powder has hygroscopicity

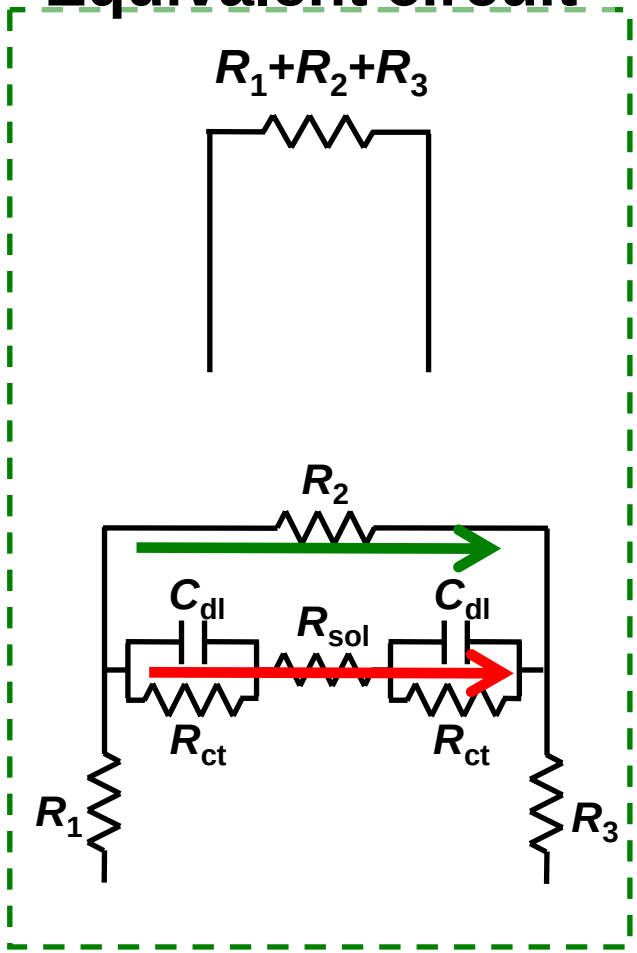
Water droplets are generated on the electrode surface

The water droplets grow and condense

Principle of the wet corrosion sensor

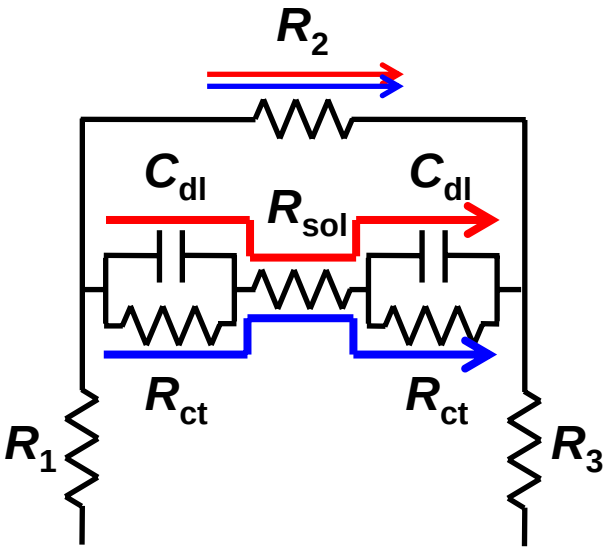


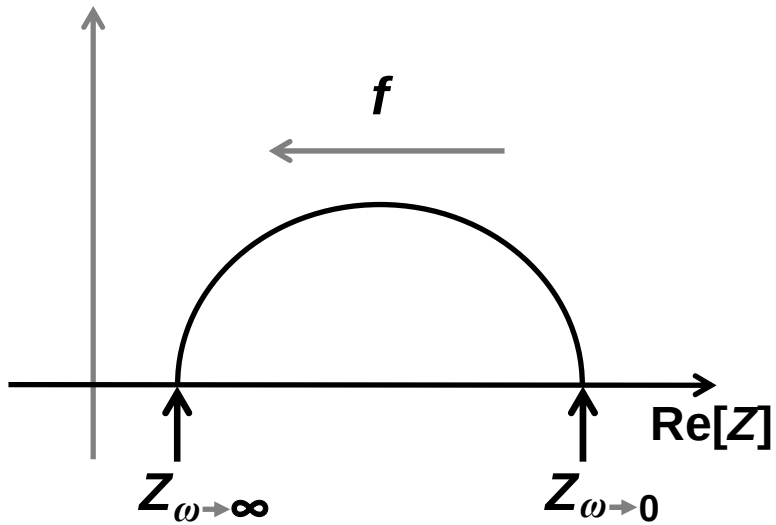
Equivalent circuit



R_1, R_3: Resistance between lead and water droplet
R_2: Resistance between water droplet
R_{ct}: Charge transfer reaction resistance, R_{sol}: Solution resistance
C_{dl}: Capacitance of electric double layer

Nyquist plot of the equivalent circuit





: Current flow at high frequency range

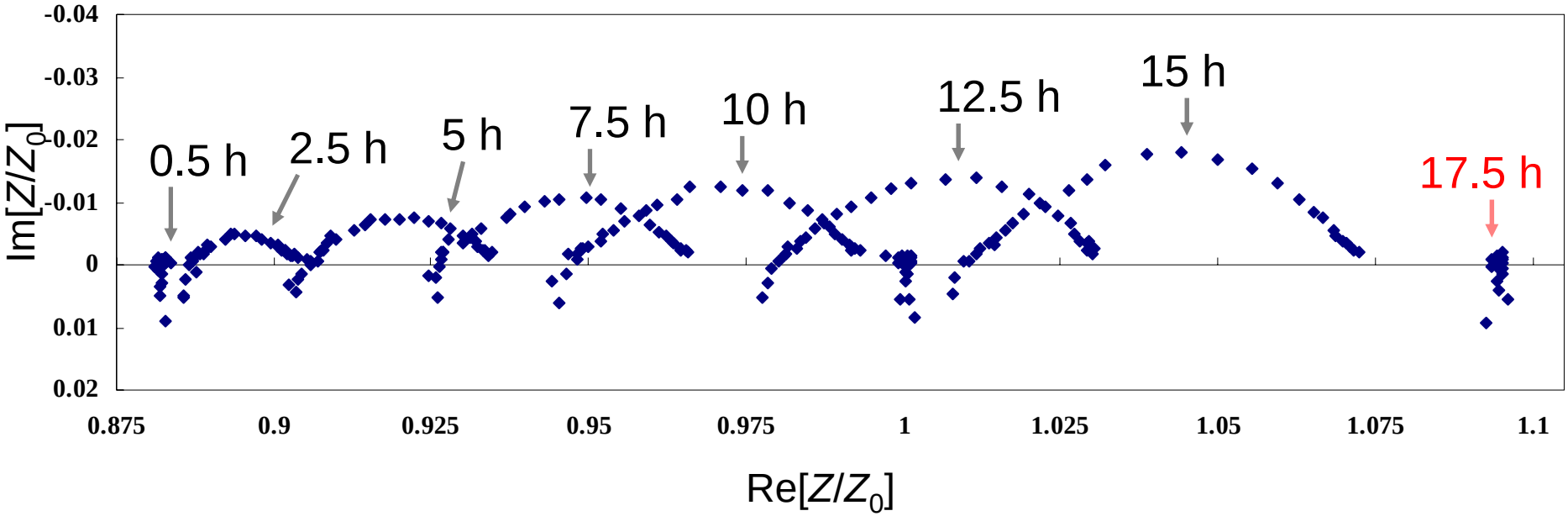
: Current flow at low frequency range

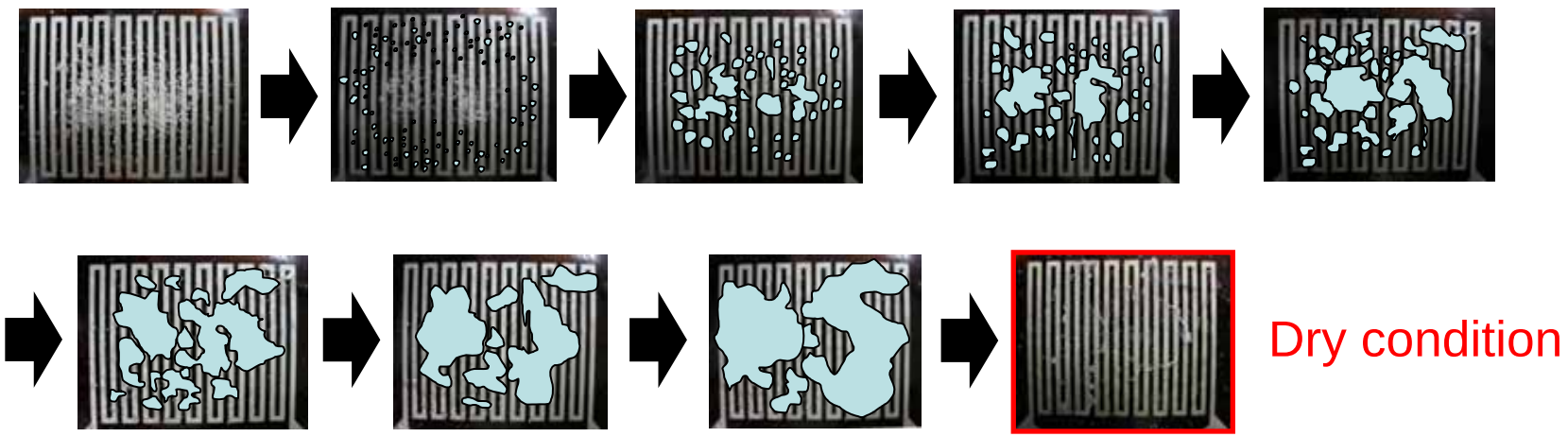
$$\begin{cases} Z_{\omega\to\infty} = (R_1 + R_2 + R_3) - \dfrac{{R_2}^2}{R_{sol} + R_2} \\ Z_{\omega\to 0} = (R_1 + R_2 + R_3) - \dfrac{{R_2}^2}{2R_{ct} + R_{sol} + R_2} \end{cases}$$

Diameter of the semicircle

$$Z_{\omega\to\infty} - Z_{\omega\to 0} = \frac{2R_{ct}R_2}{(R_{sol} + R_2)(2R_{ct} + R_{sol} + R_2)}$$

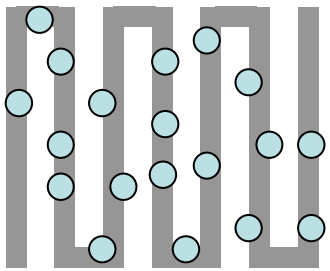
Impedance spectrum under high humidity condition (9)

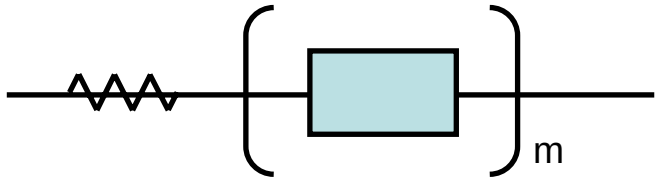




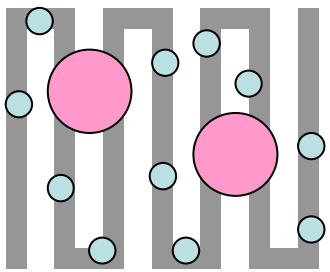
Equivalent circuit for the impedance simulation

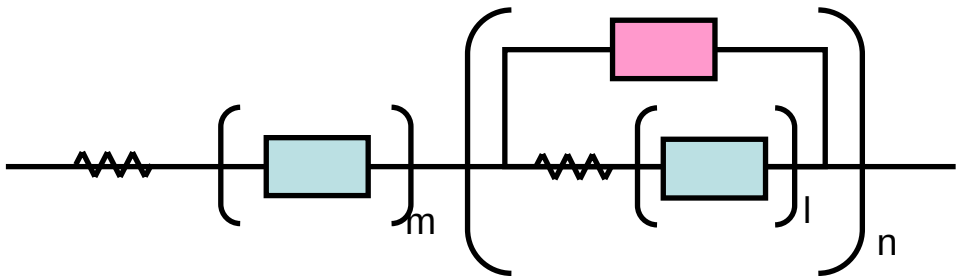
(a)

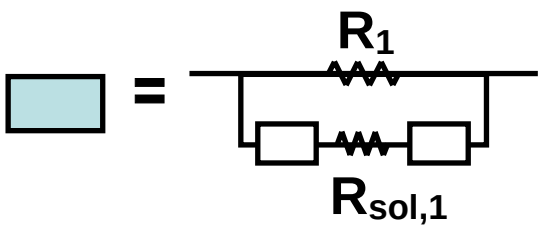


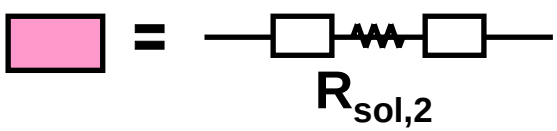


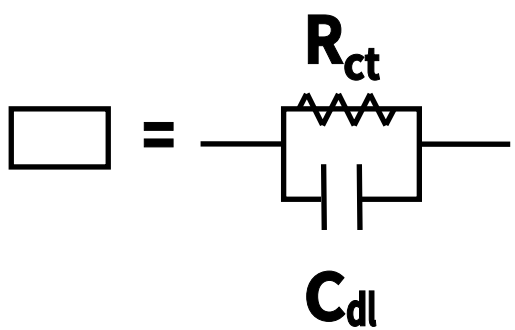
(b)



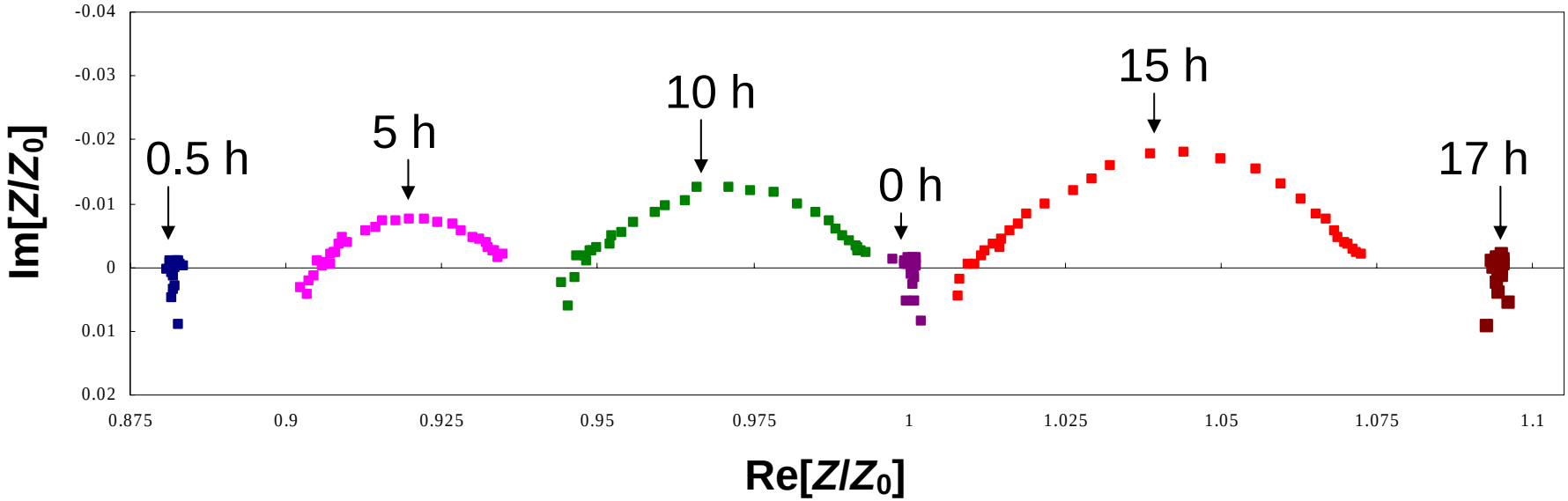


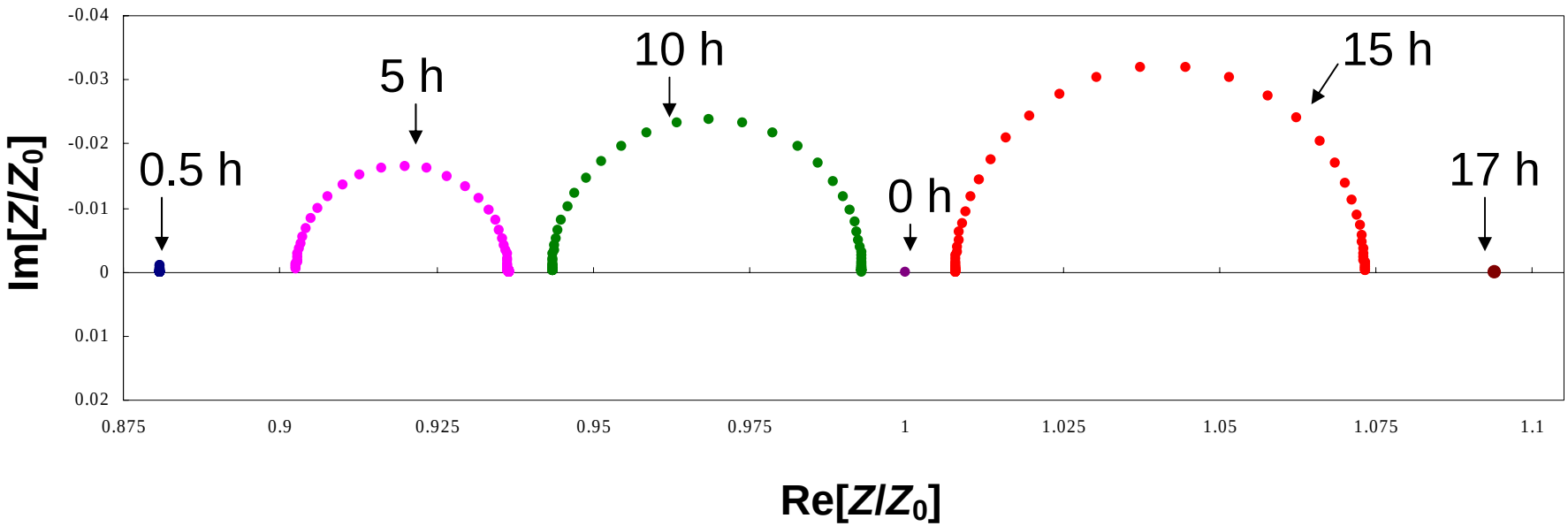






Simulation result





Fitting parameter

	0 h	0.5 h	5 h	10 h	15 h	17.5 h
R	**30**	**5**	**4.5**	**0.15**	**6.9**	**30**
R_1		**0.2**	**0.25**	**0.3**	**0.5**	
R_z			**0.6**	**1.35**	**10**	
R_{sol}		**1**	**3**	**15**	**35**	
$R_{sol}(2)$			**12**	**42**	**115**	
m	**0**	**125**	**10**	**7**	**5**	**0**
n	**0**	**0**	**15**	**9**	**2**	**0**
l	**0**	**0**	**4**	**6**	**3**	**0**
R_{ct}		**0.1**	**1.5**	**37**	**600**	
C_{dl}		**1.E-06**	**1.E-04**	**1.E-04**	**1.E-04**	

Conclusion

- The AC resistmetry-type corrosion sensor was fabricated by screen-printing technique.
- The sensor can be monitored at sulfur gas and high humidity condition.
- The nyquist plot of the experimental results can be simulated by the equivalent circuits.