Examination of Corrosion on Steel Structures by Innovative Nano Sol-Gel Sensors

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Problems of Corrosion

- Causes premature failure of steel and steel-reinforced concrete bridges.
- Threatens the integrity and safety of civil infrastructures.

American Infrastructure

- According to ASCE 2009 Infrastructure Report Card, America's infrastructure received an overall grade of D.
- Nationwide bridges have an average life of 43 years old.
- One in four bridges is either structurally deficient or functionally obsolete.
- The sudden collapse of the I-35 Bridge in 2007 is a severe warning of the safety problem of infrastructures

U.S. Bridge Statistics

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
All Bridges	582,976	585,542	589,674	589,685	590,887	591,940	593,813	595,363	597,340	599,766
Urban	128,312	130,339	133,384	133,401	135,339	135,415	137,598	142,408	146,041	151,171
Rural	454,664	455,203	456,290	456,284	455,548	456,525	456,215	452,955	451,299	448,595
Structurally Deficient Bridges, Total	93,072	88,150	86,692	83,595	81,261	79,775	77,752	75,923	73,784	72,520
Urban	14,073	12,967	NA	12,705	12,503	12,316	12,175	12,600	12,585	12,951
Rural	78,999	75,183	NA	70,890	68,758	67,459	65,577	63,323	61,199	59,569
Functionally Obsolete Bridges, Total	79,500	81,900	81,510	81,439	81,537	80,990	80,567	80,412	80,317	79,804
Urban	27,588	26,095	29,398	29,383	29,675	29,886	30,298	31,391	32,292	33,139
Rural	51,912	52,835	52,112	52,056	51,862	51,104	50,269	49,021	48,025	46,665

NA = Not Available

SOURCE Transportation Statistics Annual Report, U.S. Department of Transportation, Bureau of Transportation Statistics, 2008

I-35W Bridge Collapsed in Minneapolis

Courtesy of dailycaller.com

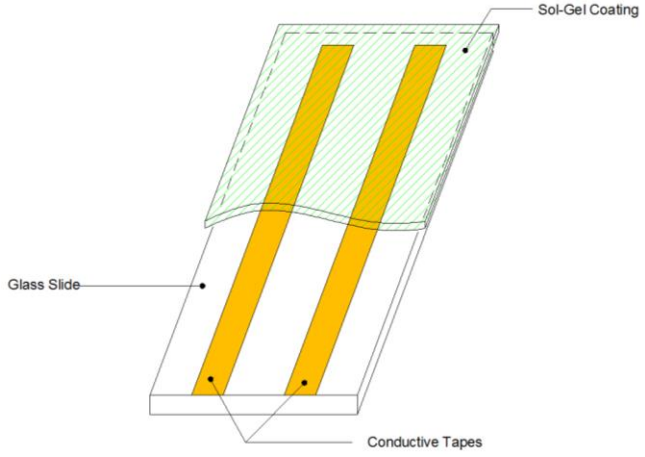
Detecting Corrosion Is Important

- Chloride is a ubiquitous and mobile ion.
- Commonly from deicing agents.
- Chloride can penetrate can weaken the passive film coating of reinforcing steel and lead to corrosion.
- Automatic monitoring is highly desirable.

What is Sol-Gel?

- Sol-gel is an amorphous, mechanically stable, inert, and porous material.
- Sol-gel changes its conductivity as a function of the amounts of chloride anions retained in its matrix structure.
- Sol-gel sensors can be produced and attached to steel structures to examine the amount of available chloride for corrosion.

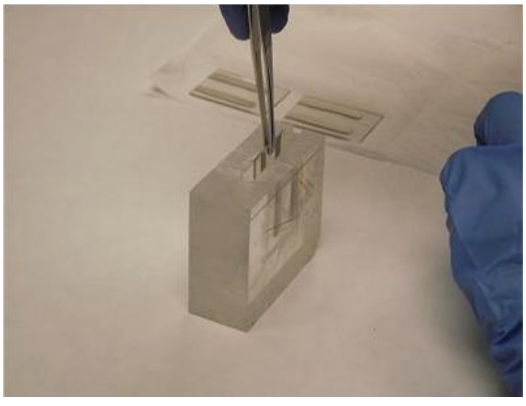
The Diagram of a Sol-Gel Coated Corrosion Sensor



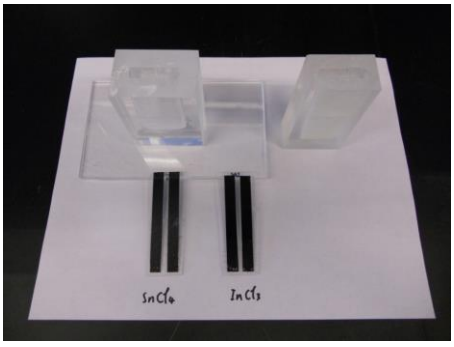
Efforts to Improve Sol-Gel Sensors

Sensor Components	Tested Materials
Electrodes of the sensor	Conductive Al, Cu, Carbon, Gold by sputter coating, and conductive fibers (i.e., XYZ tapes)
Substrate	Glass plates
Sol-gel ingredients	$SnCl_4$ or $InCl_3$

Dip Coating of a Sensor in Sol-Gel Solution

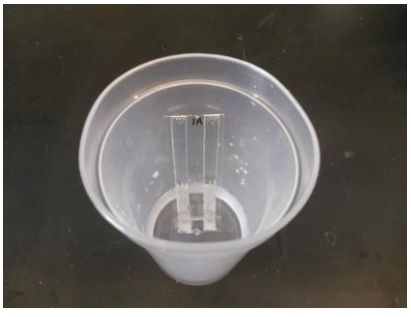


Pictures of Sol-Gel Sensors

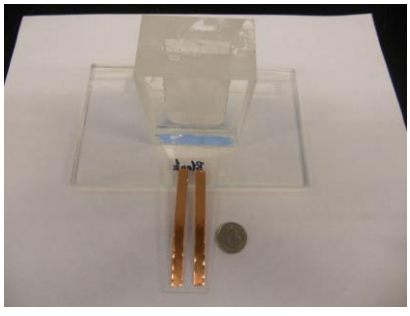


$SnCl_4$ and $InCl_3$ sol-gel coated on glass plates with carbon tapes. The carbon tape is black.

Continued



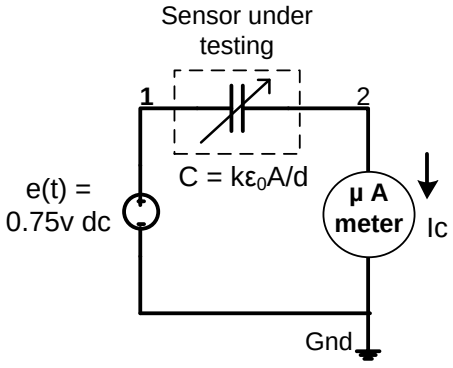
$SnCl_4$ sol-gel coated on glass plates with aluminum tapes. The sensor is soaked in NaCl solution for testing.



Blank copper sensor

Testing of the Sol-Gel Sensors

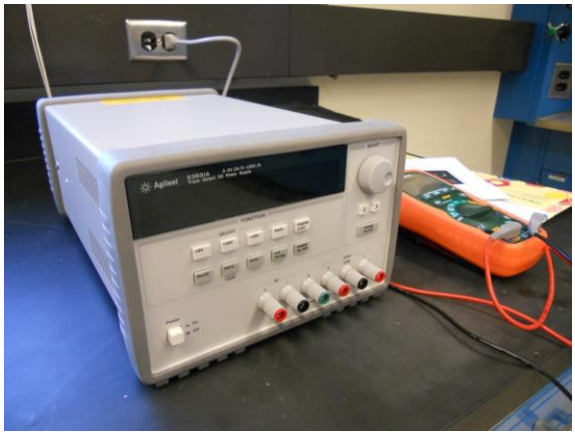
Method of DC Current Measurement



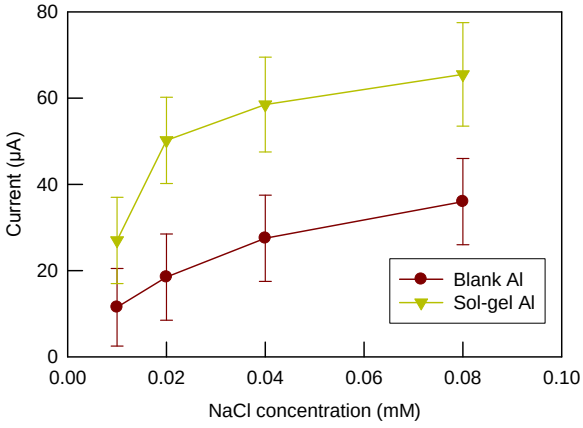
- 0.75 V DC Power

DC Current Testing System

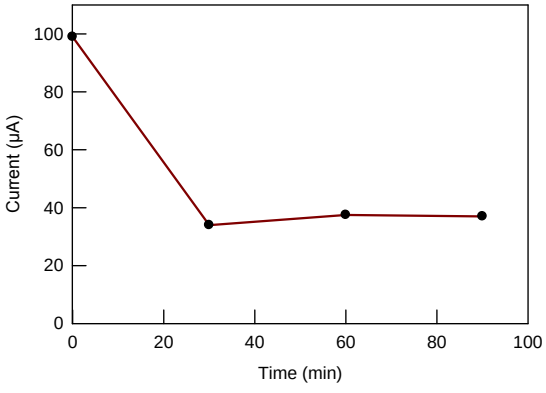
- DC power and multi-meter



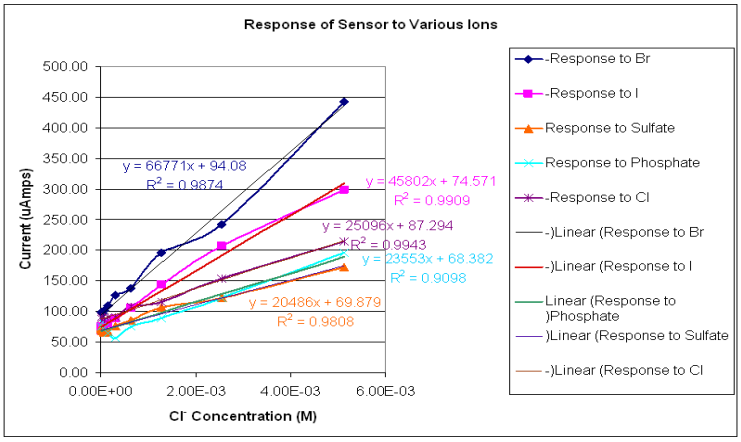
$SnCl_4$ Sol-Gel Response to Different Cl^- Concentrations by DC Method



Refresh the Sol-Gel Sensor in DI Water after Soaking in 10 mM NaCl Solution for 30 minutes



$SnCl_4$ Sol-Gel Response to Different Anions

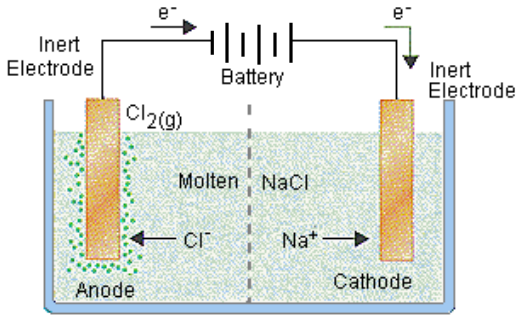


The results of testing the sensors' response to various anions.

Potential Problems of DC Current Measurement

- May cause electrolysis of NaCl solution and produce Cl_2, H_2, and NaOH.
- Electrolysis may damage Sol-Gel and the electrodes inside the sensor.
- A new method needs to be explored

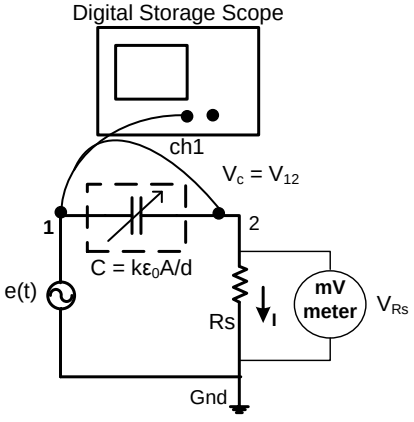
Diagram of Electrolysis of NaCl Solution



(Modified from Bodner Research Web, Purdue University)

Testing of the Sol-Gel Sensors

New Method of AC Capacitance Measurement



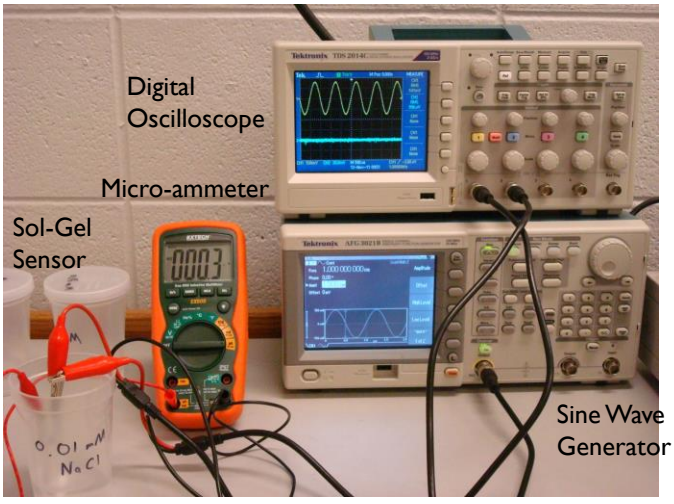
- Sine wave 1 kHz
- 1.5 V peak-to-peak

Formula of Sol-Gel Capacitance Calculation

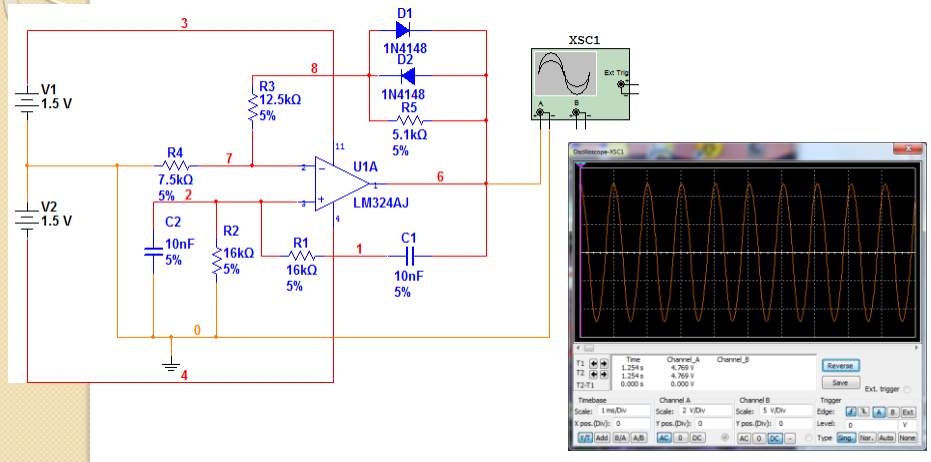
Xc = Vc/Ic -- Reactance of Sol-Gel sensor in Ohm

C = 1/(2π·F·Xc) -- Sol-Gel capacitance in farad

Sol-Gel Corrosion Sensor Testing Equipment



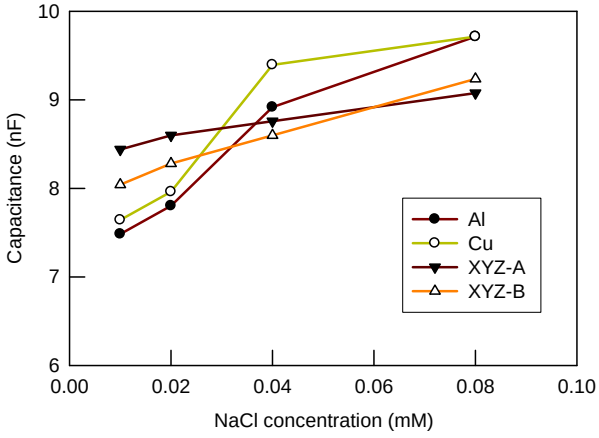
Sol-Gel Corrosion Sensor Node: AC 1 kHz Sine Wave Generator Design



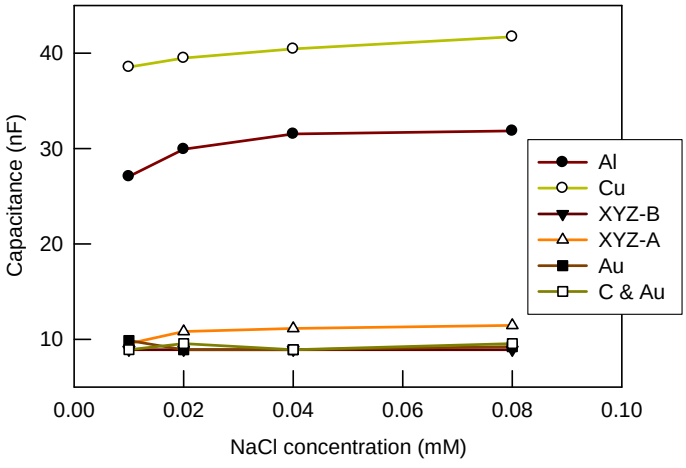
Advantages of AC-Capacitance Measurement

- Eliminate electrolysis problems.
- Improve the integrity of the sensor.

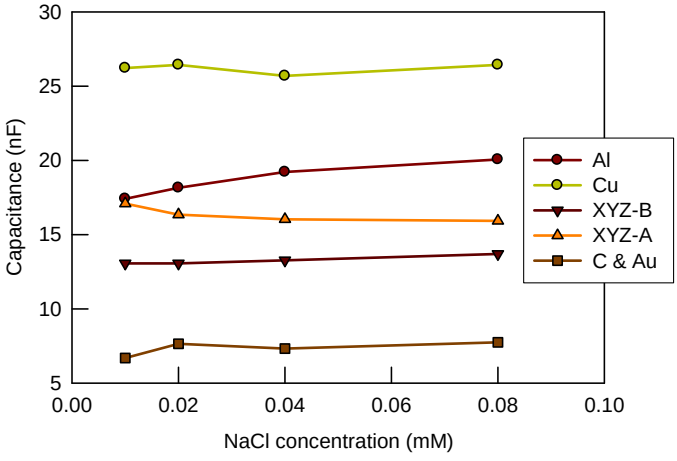
Capacitance of Blank Sensors without Sol-Gel Coating



Capacitance of $InCl_3$ Sol-Gel Coated Sensors



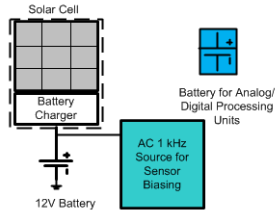
Capacitance of $SnCl_4$ Sol-Gel Coated Sensors



Wireless Corrosion Sensor Board

Remote Sol-Gel Corrosion Sensor Node (Power Source Subsystem)

- **Solar power panel and control (20 W)**
- **DC battery power source (12 V 37 AH)**
- **Power Source Requirement (~ 5 W)**
  - Sol-Gel sensor bias AC signal source (sine wave)
  - RF power source requirement estimation (1 W)
  - Sol-gel sensor power requirement (1 W)
  - Analog signal processing unit power requirement (0.5 W)
  - Digital signal processor (0.5 W)



Conclusions

- This study explored an innovative sensor made of nano sol-gel to detect NaCl strength.
- Two testing methods, i.e., DC current and AC capacitance methods have been investigated.
- Sol-gel coated sensors gave much stronger responses to NaCl concentration than uncoated sensors based on both testing methods.
- A positive trend of signal was observed with an increase in NaCl concentration and vice versa.

Conclusions (Cont'd)

- AC power-capacitance method has the advantage to avoid electrolysis of NaCl solution brought by DC power, and thus is more reliable and robust.
- Aluminum electrodes coated by $InCl_3$ or $SnCl_4$ sol-gel showed the strongest positive responses with an increase in NaCl concentration.
- Wireless automatic monitoring system is under investigation.

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Questions?