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Versatile In-Situ Engine Lubricant Health Sensor

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Abstract

The objective of this project is to study impedance behavior of degraded lubricants using portable interdigitated micro sensors via electrochemical testing. Electrochemical measurement techniques were used on both commercially available and custom built micro sensors (fabricated through electron beam lithography) to understand impedance behavior of a mixture of oil, wear and additive particles, and other impurities at different environmental conditions. The impedance response of the oil was found to increase with a decrease in wear and additive metal ion concentrations, total acid number (TAN) and temperature. Based on these results obtained, work is ongoing to improve the measurement sensitivity and create a sensor that can effectively detect the amount of degradation oil has experienced and to isolate the influence of multiple degradation mechanisms.

Introduction

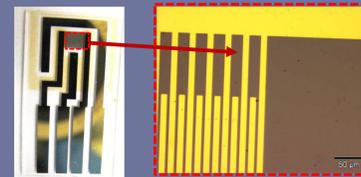
- Lubricants are used in engines to reduce friction, promote engine cooling, and prevent corrosion. These lubricants will eventually degrade with time under harsh engine operating conditions and hence need to be changed periodically.
- Degradation of oil is a result of a number of mechanisms such as; engine component wear, oil oxidation, water ingress, and combustion byproducts.
- A versatile and microscopic in-situ sensor that can sense quality of a wide variety of engine lubricant brands at various temperatures and pressures is of great need. This problem can be resolved by applying portable interdigitated micro sensors to examine the impedance behavior of degraded lubricants through electrochemical tests.



<http://www.automotivebodyspecialists.com/services/oilchange.php>

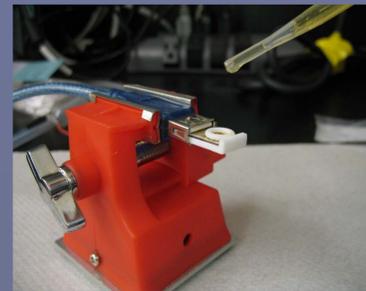
Electrodes:

- DropSense electrodes (carbon and gold) were ineffective due to their large spacing between electrodes.
- ALS commercial microelectrodes with 3 μm and 10 μm spacing were used to measure impedance on base stock oil (containing additive and wear metals).

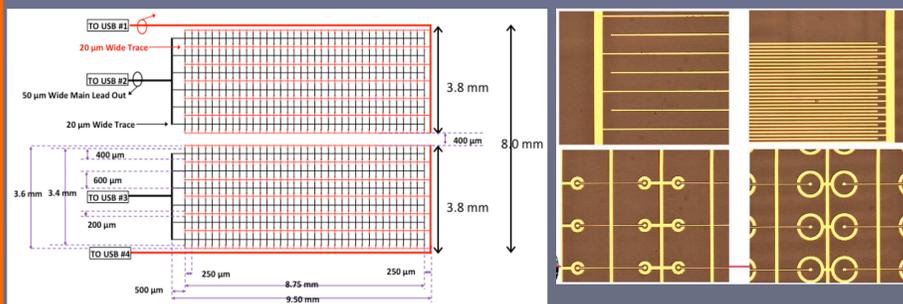


Experimental setup:

- Teflon O-ring was placed over the sensing array to contain oil and prevent it from leaking.
- Electrochemical Impedance Spectroscopy (EIS) was conducted using a Gamry Reference 600® potentiostat. Frequency range used was from 100,000 Hz to 0.25 Hz and voltage amplitude used was 500 mV.



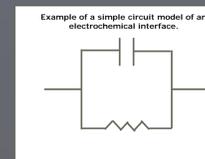
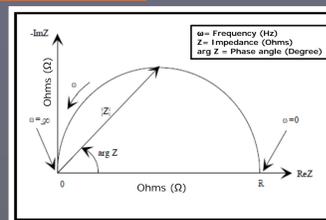
Custom Built Sensors



Custom built sensors (through electron beam lithography) with spacing of 10 μm, 50 μm and 100 μm were designed and built.

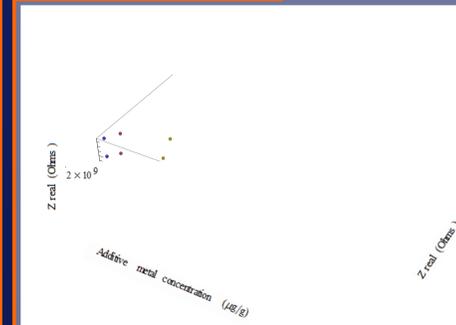
What is EIS? How does it work?

Electrochemical Impedance Spectroscopy applies sinusoidal current and voltage at wide range of frequency which gives measurement of different electrochemical reactions at different rates and also the capacitance of the electrode*. Electrochemical reactions and interfaces can be modeled as electrical circuit. A semi-circle on a Nyquist is a characteristic of a circuit with a single time constant. Impedance on a Nyquist plot can be represented by a vector with length |Z| & the angle between the vector and x-axis as arg Z.

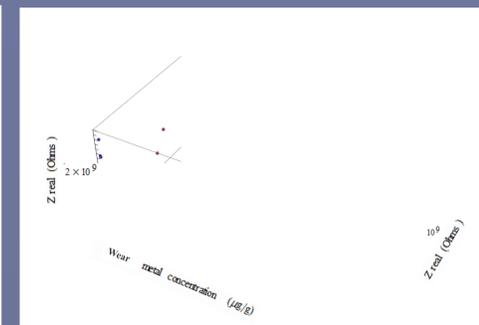


*<http://gamry.com/assets/Application-Notes/Basics-of-EIS.pdf>

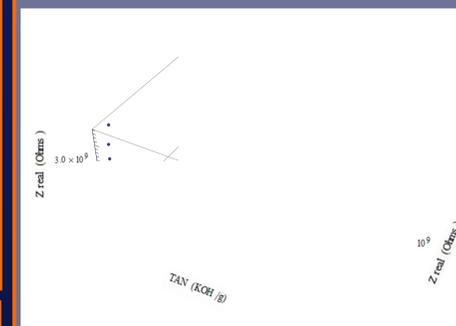
Results



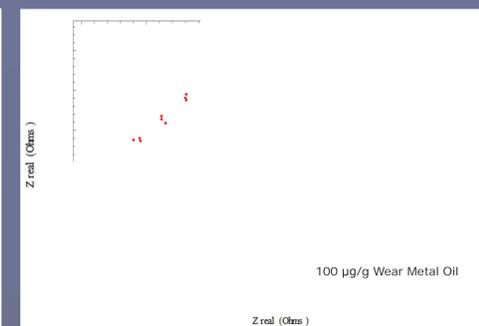
Additive Metal Composition in Oil



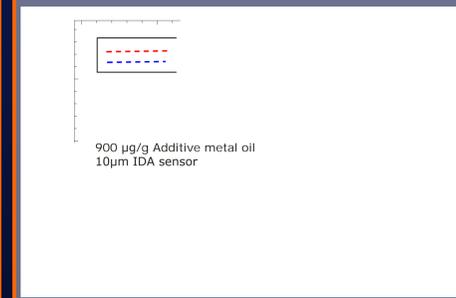
Wear Metal Composition in Oil



Oil With Various TAN



Repeatability/ Effect of Sensor Spacing



Effect of Temperature

- Impedance of base stock oil decreases with increase in additive metal concentration and wear metal concentration.
- Impedance of oil is affected by total acid number (TAN).
- 10 μm spaced sensor has lower impedance than 3 μm spaced sensor.
- Impedance of oil decreases with the increase in temperature.

Conclusions

- Only micro sensors have acceptable oil sensing capability.
- EIS data obtained from micro sensors were repeatable and dependent on sensor geometry.
- EIS test results were able to sense changes in oil composition including wear metals, additive metals and TAN.
- EIS results showed greater sensitivity at higher temperature indicating improved performance under typical engine operating conditions.
- Custom sensors were designed, built and are currently being tested to optimize sensor performance.

Acknowledgements

NSF SBIR Phase I lead by Technology Holding LLC, Feng Zhou, Tony Elongovan, Electrode fabrication help from Lynn Fuller, Electrode design help from Patrick Price.

Experimental

Oils used for testing:

- Certified reference oils (with known composition) were used to ensure consistency during electrochemical tests.
- Tests were conducted separately using oil with known quantities of wear metals, additive metals, & TAN (Total Acid Number)

Oil Type	Composition	
	Concentration	Metal ions
Base stock oil with Wear metals	10 μg/g 100 μg/g 500 μg/g 900 μg/g 3000 μg/g	Al, Cr, Cu, Fe, Pb, Mg, Ni, Si, Ag, Na, Sn, Ti
Base stock oil with Additive metals	10 μg/g 100 μg/g 500 μg/g	Ba, Ca, Mg, P, Zn
Base stock oil with various TAN	0.10 KOH/g 1.53 KOH/g 2.96 KOH/g	