Resonance Enhanced Surface Impedance (RESI)

Layerlab has developed a new proprietary technology for impedance analysis called Resonance Enhanced Surface Impedance (RESI). RESI enables real-time measurements of changes in the capacitance and the electrical resistance at surface interfaces. The RESI technology can be applied for example in studies of protein adsorption and/or interactions at surfaces, surface degradation, molecular film formation, charge transport and ion-channel activity.

Background

There are many electrochemical methods that can be employed in studies of interfaces and surface processes. Electrochemical Impedance Spectroscopy (EIS), wherein the impedance is measured over a wide frequency range (usually from mHz to MHz) is among the most popular. This method is generally powerful but data acquisition is usually rather slow making it best suited for static-state measurements. Alternatively, the impedance can be monitored at a fixed frequency over time allowing fast data acquisition at the cost of increased noise. **By operating in resonance mode (RESI), the data quality can be significantly enhanced, enabling time resolved impedance measurements at low noise levels.**

Principle of operation

By connecting a pair of micro electrodes in parallel with an external inductance, the electrode pair becomes part of a resonator whose resonance frequency is effectively determined by the interface capacitance. Shifts in the resonance frequency can be detected by mapping the resonance peak, a method that can resolve very small changes in capacitance. Figure 2 shows a Bode-plot representation of the impedance and illustrates the effect of connecting an inductive element in parallel with the sensor. The resulting impedance spectrum exhibit a sharp maximum resonance, the frequency of which is a function of the capacitance, *C* at the sensor/solution interface. Any surface process, for example protein adsorption or the formation of a thin molecular film, will induce a change in the interfacial capacitance and resistance causing a shift in the resonance as illustrated in Figure 3.

The capacitance can then be estimated from the resonance frequency according to equation 1.

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \qquad \text{Eq. 1}$$

The damping of the resonance peak is affected by the interfacial resistance. Therefore, any charge-transfer process, such as a redox reaction or altered ion-transport resistance across a lipid membrane can be detected as changes in the amplitude of the peak. This effect is exemplified in Figure 4, wherein incorporation of ion channels in a supported membrane substantially lowers the amplitude of the peak.

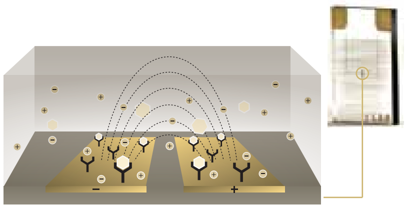

Figure 1: Schematic illustration of an ac-impedance measurement with a dual electrode configuration. Changes in the impedance, induced for example by a biomolecular recognition event at the surface, influences the applied electric field.

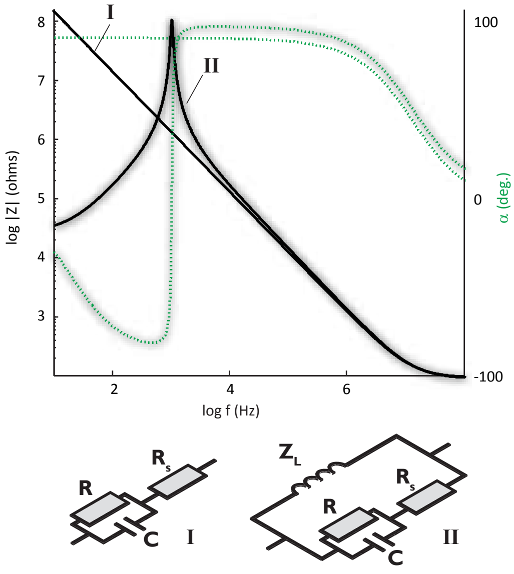

Figure 2: Bode-plot illustrating the effect of the inductive impedance (Z_L) connected in parallel with the sensor (circuit diagram II). A sharp resonance peak appear in the spectra, the frequency of which is proportional to the capacitance, C.

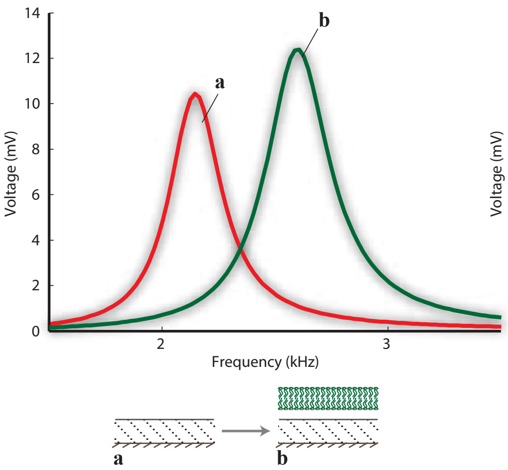

Figure 3: The graph illustrates how the resonance shifts when an insulating layer is formed on the sensor surface.

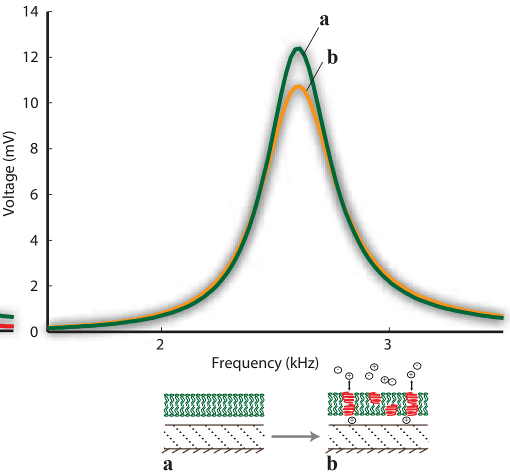

Figure 4: The graph illustrates how the amplitude shifts when the interfacial resistance is lowered.

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Capacitance

The RESI technology enables real-time measurements of changes in the capacitance. Typically, surface adsorption phenomena lowers the capacitance while desorption, or rupture of a surface film, leads to an increase in capacitance.

For the formation of a molecular film directly on the sensor electrode the measured capacitance change may be evaluated in terms of surface coverage, θ, according to equation 2, wherein C is the measured capacitance, C_{min} the end capacitance for a fully formed film and C_0 the start capacitance:

$$\theta = \frac{C_0 - C}{C_0 - C_{min}} \qquad \text{Eq. 2}$$

In addition to specific adsorption / desorption phenomena, the capacitance may also respond to changes in the dielectric properties, charge distribution, molecular organization and conformational changes in surface immobilized biomacromolecules.

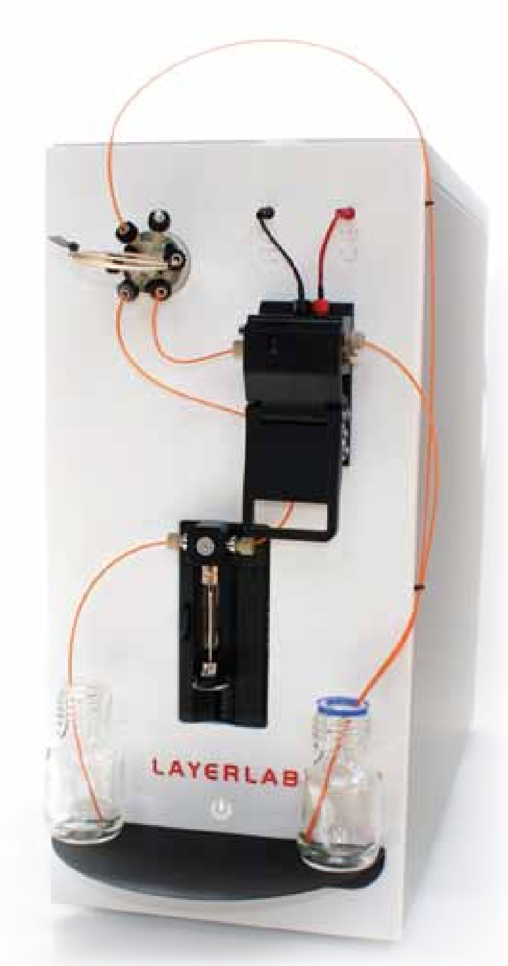
Amplitude

The amplitude of the resonance peak correspond to the damping which is related to the resistance of the system. Therefore, the amplitude can be used to study charge-transfer reactions at the interface. For example, the presence of a redox-active species at the interface will lower the amplitude. Changes in ion transport over the interface, due to for example changes in the permeability of a supported or suspended molecular film will also influence the amplitude.

The amplitude, V_{peak}, may be used to derive the total current, I, through the resonator, a more comprehensive charge transport measure, according to equation 3:

$$I = \frac{U_0 - V_{peak}}{R} \qquad \text{Eq. 3}$$

wherein U_0 is the applied AC voltage, and R an instrument constant.



Conclusions

With RESI, it is possible to measure changes in interfacial capacitance and resistance in real-time. The unique resonance based methodology allows for fast data acquisition with high sensitity and resolution.

Implementation

The z-LAB™ instrument from Layerlab (Figure 5) implements the RESI technology in a complete system comprising microfluidics, potential- and temperature control, data acquisition, and functional micro electrode sensors.

Figure 5: Photo of the z-LAB™ instrument, which implements the RESI technology for real-time capacitance and resistance measurements.