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Sodium chloride sensing by using a near-field microwave microprobe

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The authors observed the NaCl concentration of solutions using a near-field microwave microprobe (NFMM). Instead of the usual technique, they take advantage of the noncontact evaluation capabilities of a NFMM. A NFMM with a high Q dielectric resonator allows observation of small variations of the permittivity due to changes in the NaCl concentration. By measuring the reflection coefficient S_{11}, they could observe the concentration of NaCl. The measured signal-to-noise was about 53 dB and the minimum detectible signal was about 0.005 dB/(mg/ml). In order to determine the probe selectivity, they measured a mixture solution of NaCl and glucose. © *2006 American*

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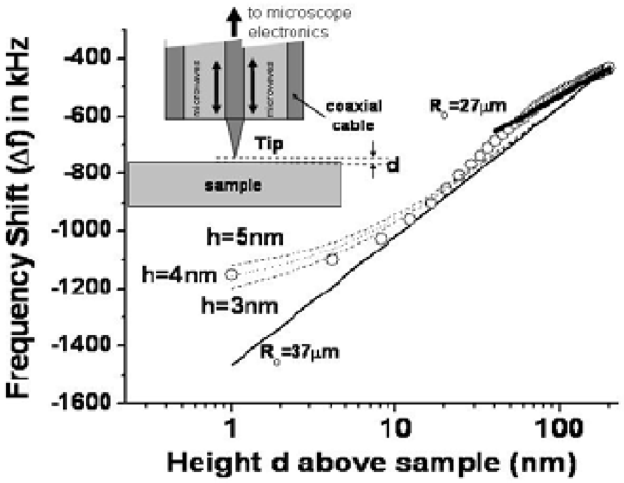
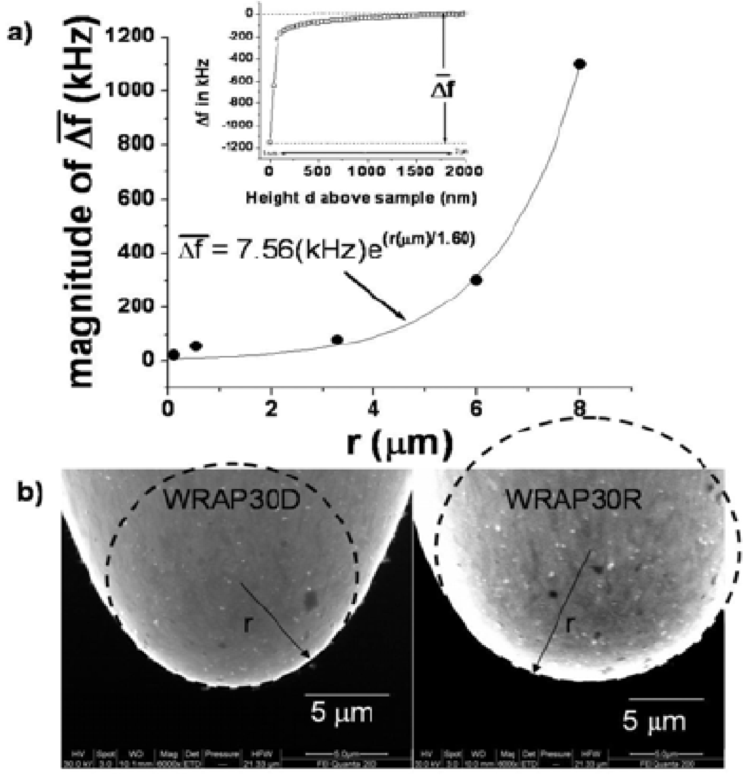
Near-**F**ield **M**icrowave **M**icroprobe (NFMM) – ref. at google





Near-**F**ield **M**icrowave **M**icroprobe (NFMM) – J. Am. Chem. Soc 127, 9666 (2005)

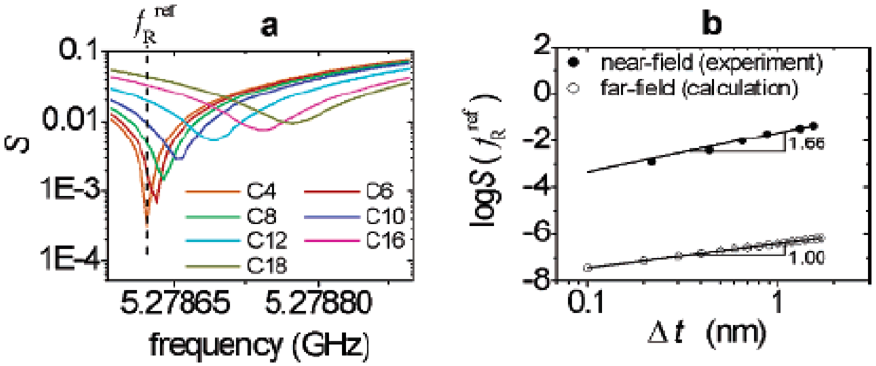


Figure 1. Near-field microwave measurements on *n*-alkylthiol ($HS-(CH_2)_{n-1}CH_3$) monolayers. Tip−sample distance: 10 nm. (a) S as a function of frequency. The butanethiol (C4) sample was used as reference for S tuning, with the minimum found at f_R^{ref} = 5.278 6217 GHz. (b) (●) log S measured under near-field conditions at 5.278 6217 GHz (dashed line in plot a), as a function of thickness increase $\Delta t = t - t_{C4}$. (○) Calculated log S for far-field reflection.

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Result -1

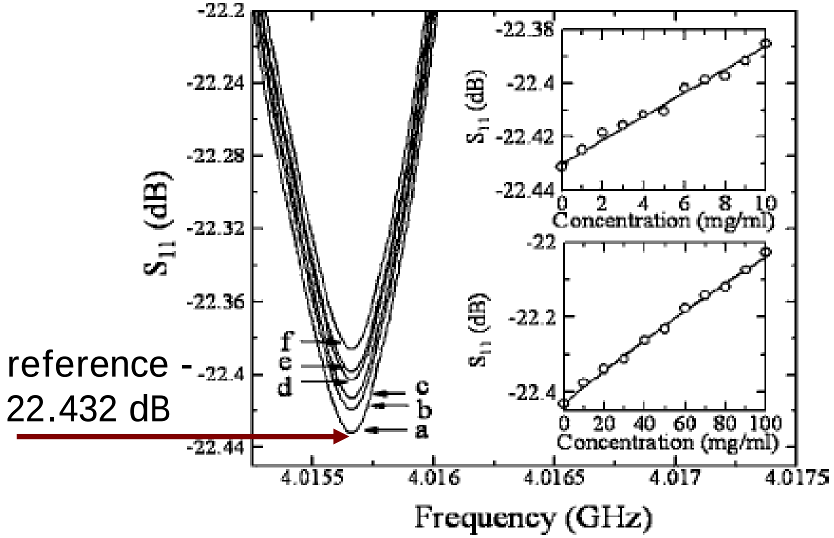

FIG. 1. Measured reflection reflectivity S_{11} plotted as a function of the NaCl concentrations from (a) DI water, (b) 2 mg/ml, (c) 4 mg/ml, (d) 6 mg/ml, (e) 8 mg/ml, and (f) 10 mg/ml. The upper inset shows the measured reflection reflectivity S_{11} plotted as a function of the NaCl concentrations at 4.015 GHz. The lower inset plotted the measured reflection reflectivity S_{11} of higher concentration from DI water to 100 mg/ml with the interval of 10 mg/ml at 4.015 GHz. A solid line shows a fit to Eq. (1) with Z_0=50 Ω.

sample volume : 50 micro-liter

probe tip sample distance : 1 micro-meter

$$S_{11} = 20\log\left|\frac{Z^R - Z_0}{Z^R + Z_0}\right|$$

Z_0 : effective impedance of the probe tip

Z^R : real part of the complex impedance of the NaCl solution

The ionic permitivity of NaCl solution may be estimated by the intensity of the reflection coefficient at the resonance frequency.

Result -2 (equation)

$$S_{11} = 20\log\left|\frac{Z^R - Z_0}{Z^R + Z_0}\right|$$

$$Z^R = \mathrm{Re}\left[\frac{Z_a}{\sqrt{\varepsilon}} \times \frac{(Z_a/\sqrt{\varepsilon_s}) + j(Z_a/\sqrt{\varepsilon})\tan(k_a\sqrt{\varepsilon}v/s)}{(Z_a/\sqrt{\varepsilon}) + j(Z_a/\sqrt{\varepsilon_s})\tan(k_a\sqrt{\varepsilon}v/s)}\right]$$

Z_a air impedance (377Ω), K_a air wavenumber (K_a=84m^{-1} at 4 GHz), ε_s cylindrical glass cell substrate (ε_s=5 at 4 GHz), ε NaCl solution permittivity, v solution volume, s surface area of solution (25mm^2)

$$\varepsilon = (\varepsilon_0' + c\gamma') - j(\varepsilon_0'' + c\gamma'')$$

c NaCl solution concentration, γ molar increment value

$$Z^R = \frac{Z_a}{\sqrt{\varepsilon_s}} \frac{1 + [\tan(k_a(v/s)\sqrt{\varepsilon_0' + c\gamma'}]^2}{1 + [(\varepsilon_0' + c\gamma')/\varepsilon_s][\tan(k_a(v/s)\sqrt{\varepsilon_0' + c\gamma'})]^2}$$

Result -3

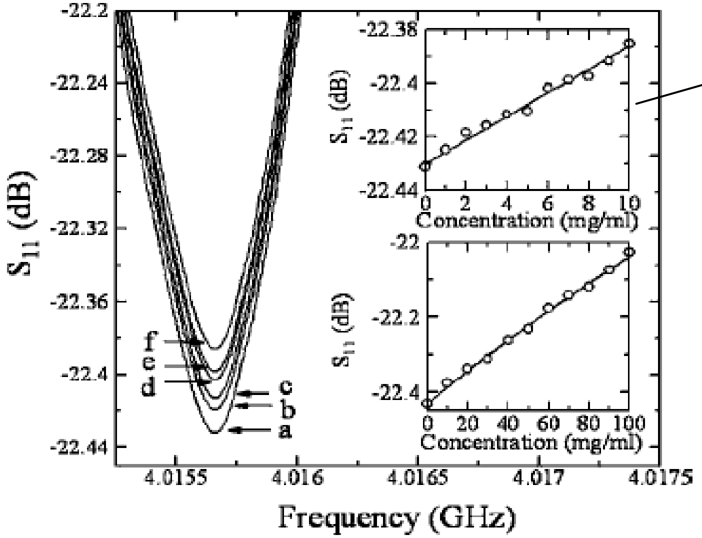

FIG. 1. Measured reflection reflectivity S_{11} plotted as a function of the NaCl concentrations from (a) DI water, (b) 2 mg/ml, (c) 4 mg/ml, (d) 6 mg/ml, (e) 8 mg/ml, and (f) 10 mg/ml. The upper inset shows the measured reflection reflectivity S_{11} plotted as a function of the NaCl concentrations at 4.015 GHz. The lower inset plotted the measured reflection reflectivity S_{11} of higher concentration from DI water to 100 mg/ml with the interval of 10 mg/ml at 4.015 GHz. A solid line shows a fit to Eq. (1) with Z_0=50 Ω.

$$\Delta S_{11} / \Delta c = 5\times10^{-5}\,\mathrm{dB/(mg/ml)}$$

root-mean-square noise in S_{11}

$$1.1\times10^{-5}\,\mathrm{dB}$$

The smallest detectable change in concentration

0.005 (mg/ml) at SNR 53 dB

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Result -4

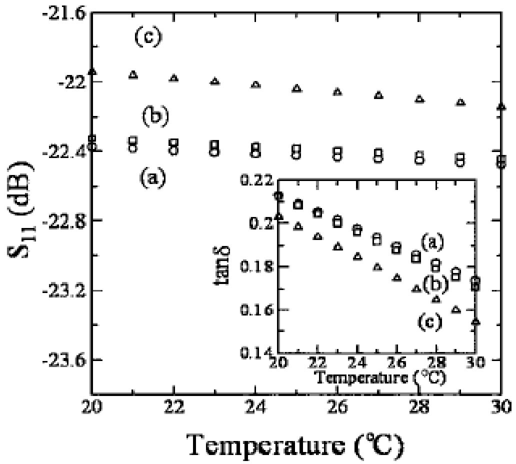

FIG. 2. Measured reflection coefficient S_{11} dependence on temperature for different NaCl concentrations for (a) 1 mg/ml, (b) 10 mg/ml, and (c) 100 mg/ml. The inset shows the measured loss tangent tan δ as a function on temperature for different NaCl concentrations, (a) 1 mg/ml, (b) 10 mg/ml, and (c) 100 mg/ml.

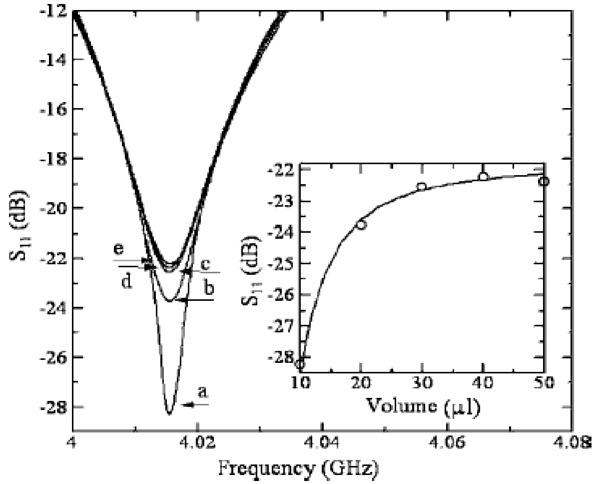

FIG. 3. Measured microwave reflection reflectivity S_{11} for different volume of NaCl solutions with concentration of 10 mg/ml for (a) 10 μl, (b) 20 μl, (c) 30 μl, (d) 40 μl, and (e) 50 μl. The inset shows the measured reflection coefficients S_{11} for different volume of NaCl solutions. A solid line shows a fit to Eq. (1) with $Z_0 = 50\ \Omega$.

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'}$$

$\varepsilon'' > \varepsilon'$ decreasing rate

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Result -5

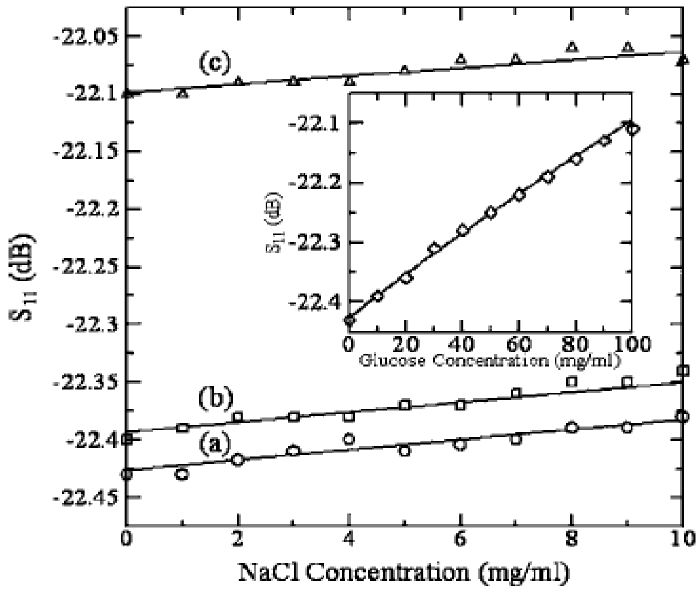

FIG. 4. Microwave reflection coefficient S_{11} of the mixture solution of NaCl and glucose plotted as a function of the NaCl solutions with the glucose concentration of (a) 1 mg/ml, (b) 10 mg/ml, and (c) 100 mg/ml. The inset shows the measured reflection coefficients S_{11} as a function of different glucose concentration at the NaCl concentration of 1 mg/ml. A solid line shows a fit to Eq. (1) with Z_0=50 Ω.