European Network on New Sensing Technologies for Air Pollution Control and Environmental Sustainability - *EuNetAir*

COST Action TD1105

WGs and MC Meeting at LINKOPING, 3 - 5 June 2015

Action Start date: 01/07/2012 - Action End date: 30/06/2016

Year 3: 1 July 2014 - 30 June 2015 (*Ongoing Action*)

Theory of QCM and SAW devices in sensors and biosensors applications

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Function in the Action (WG Member, Substitute member of MCM)

Chalmers University of Technology / Sweden

cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

EuNetAir
European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability

COST is supported by the EU Framework Programme

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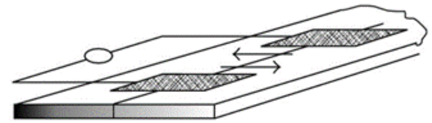
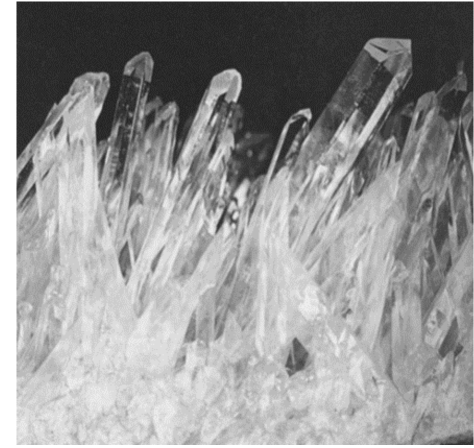
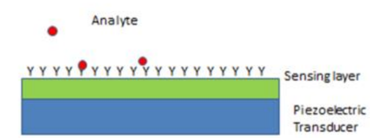
Scientific context and objectives in the Action



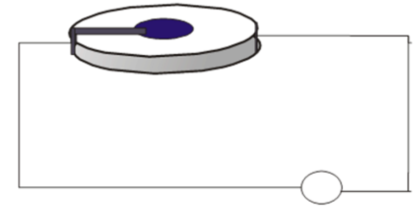


- **Background / Problem statement:**
- Modeling of dynamics of thin viscoelastic films on the surface of acoustic resonators (BAW, SAW)



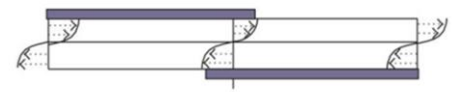
- **Brief reminder of MoU objectives:** WG2 (Sensors, Devices and Systems for AQC)
- Objective: general theory and physico-mathematical analysis of acoustic waves propagation in layered systems in sensors and biosensors applications

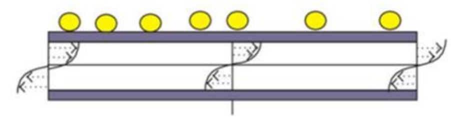
Modeling the dynamics of viscoelastic films on QCM-based sensors and biosensors

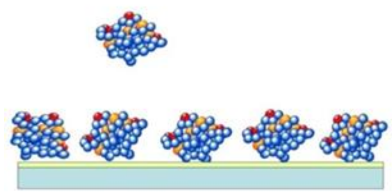


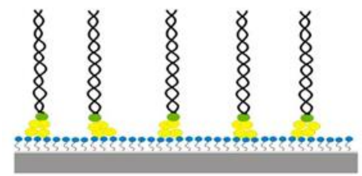
- **Surface modification of QCM sensors**

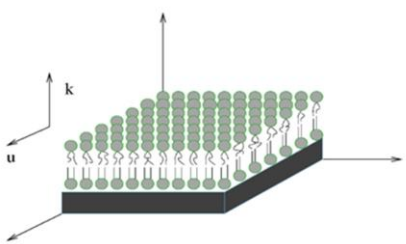
$$\Delta f = f - f_0 = -\left(\frac{2 f_0^{\,2}}{\rho_q V}\right)\Delta M = -C \cdot \Delta M$$



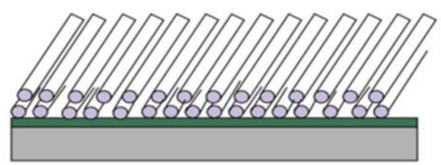


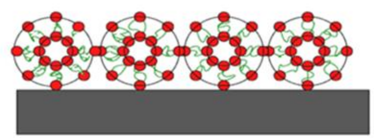




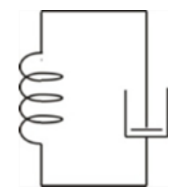


a)





c)

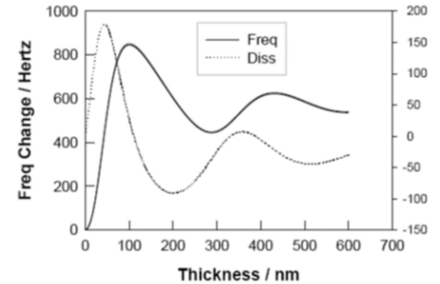


$$\Delta f = f - f_0 = -(\frac{2 f_0^2}{\rho_q V})\Delta M = -C \cdot \Delta M$$

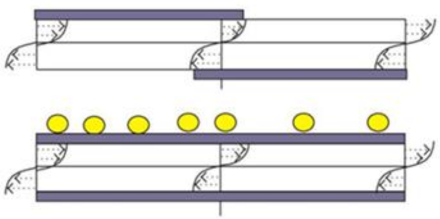
Background:

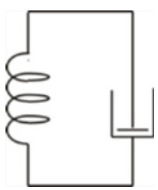
Viscoelastic corrections of Sauerbrey’s relation

Theory of QCM in biosensors’ applications

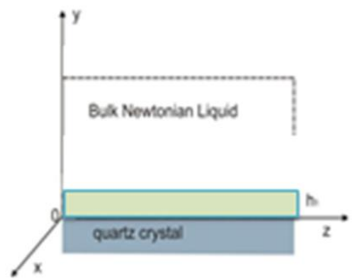


Kanazawa, K., Frank, C.W., and Hardesty, J.: Resonances of soft films under liquids on the QCM, ECS Transactions, 16, 419-429, 2008





Simultaneous viscoelastic and liquid loading of the quartz resonator: a single soft layer (Voigt viscoelastic solid) under Newtonian bulk liquid



$$\sigma_{xy} = \mu \frac{\partial u_x(y,t)}{\partial y} + \eta \frac{\partial v_x(y,t)}{\partial y}$$

Impedance $$Z = \frac{\sigma_{xy}}{v_x}\Big|_{y=0}$$

$$\Delta f = \mathrm{Im}\left\{\frac{Z}{2\pi\rho_q h_q}\right\}$$

$$\Delta D = \mathrm{Re}\left\{\frac{Z}{\pi f \rho_q h_q}\right\}$$

$$\Delta f \approx -\frac{1}{2\pi\rho_q h_q}\left\{\frac{\eta_L}{\delta_L} + h\rho\omega - 2h\left(\frac{\eta_L}{\delta_L}\right)^2 \frac{\eta\omega^2}{\mu^2 + \eta^2\omega^2}\right\}$$

$$\Delta D \approx \frac{1}{f\rho_q h_q}\left\{\frac{\eta_L}{\delta_L} + 2h\left(\frac{\eta_L}{\delta_L}\right)^2 \frac{\mu\omega}{\mu^2 + \eta^2\omega^2}\right\}$$

(Voinova, Rodahl, Jonson, Kasemo 1999)

QCM: The ’missing mass” effect

Viscoelastic corrections to the measured mass M of the soft layer under Newtonian liquid:

$$M_s = M\left\{1 - \frac{\eta_L \rho_L \omega}{\rho} \frac{G''}{G'^2 + G''^2}\right\}$$

Soft layer under Newtonian bulk liquid:
the total shift in the resonance frequency is a sum of the frequency shift due to the surface mass $M = \rho \cdot h$, contribution of bulk liquid Δf_L and corrections due to the layer viscoelasticity $G^* = G' + iG''$

$$\Delta f - \Delta f_L \approx -\frac{h\rho\omega}{2\pi\rho_q h_q}\left\{1 - 2\left(\frac{\eta_L}{\delta_L}\right)^2 \frac{J''}{\rho}\right\} \qquad J'' = \frac{G''}{G'^2 + G''^2}$$

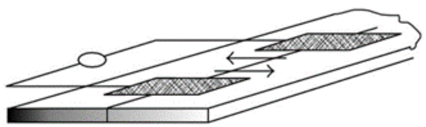
The change in the dissipation factor:

$$\Delta D - \Delta D_L \approx \frac{h\rho\omega}{f\rho_q h_q}\left\{2\left(\frac{\eta_L}{\delta_L}\right)^2 \frac{J'}{\rho}\right\} \qquad J' = \frac{G'}{G'^2 + G''^2}$$

Modeling SAW:
SH-SSW resonators

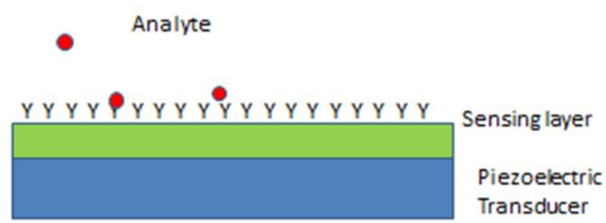
$$\frac{\Delta V}{V_0} = \frac{1}{2}\frac{\omega^2 \rho_1{}^2 h^2}{V_0^2 \rho_0^2}\left\{1 + \frac{\rho_2}{\rho_1}\right\}^2,$$

In the air



$$\frac{\Delta V}{V_0} = \frac{1}{2}\frac{\omega^2 \rho_1{}^2 h^2}{V_0^2 \rho_0^2}\left\{1 - \left(\frac{\omega\eta}{\rho V_0^2}\right)^2\right\}.$$

$$\Delta V / V_0 \approx \frac{\omega^2 \rho_1{}^2 h_1{}^2 V_0{}^2}{2 g_0^2}\left(1 - \frac{\rho_1}{\rho_0}\frac{g_0}{g'}\right)^2$$

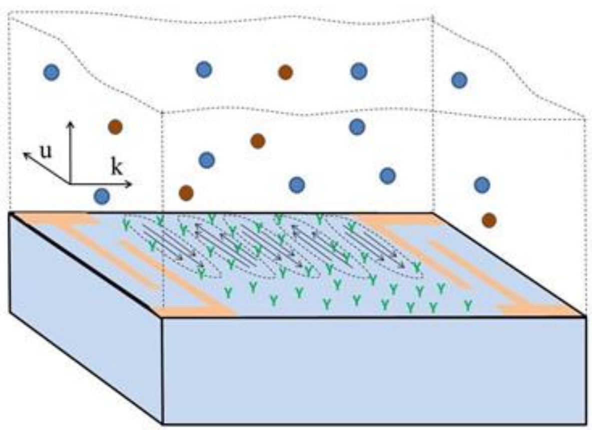


Modeling SAW:
SH-SSW resonators

$$\kappa^2 = \frac{g^{*2}\zeta_1^2}{g_0^2}\left\{\frac{(g^*\zeta_1 - G^*\zeta_2) - e^{2\zeta_1 h}(g^*\zeta_1 + G^*\zeta_2)}{(g^*\zeta_1 - G^*\zeta_2) + e^{2\zeta_1 h}(g^*\zeta_1 + G^*\zeta_2)}\right\}^2$$

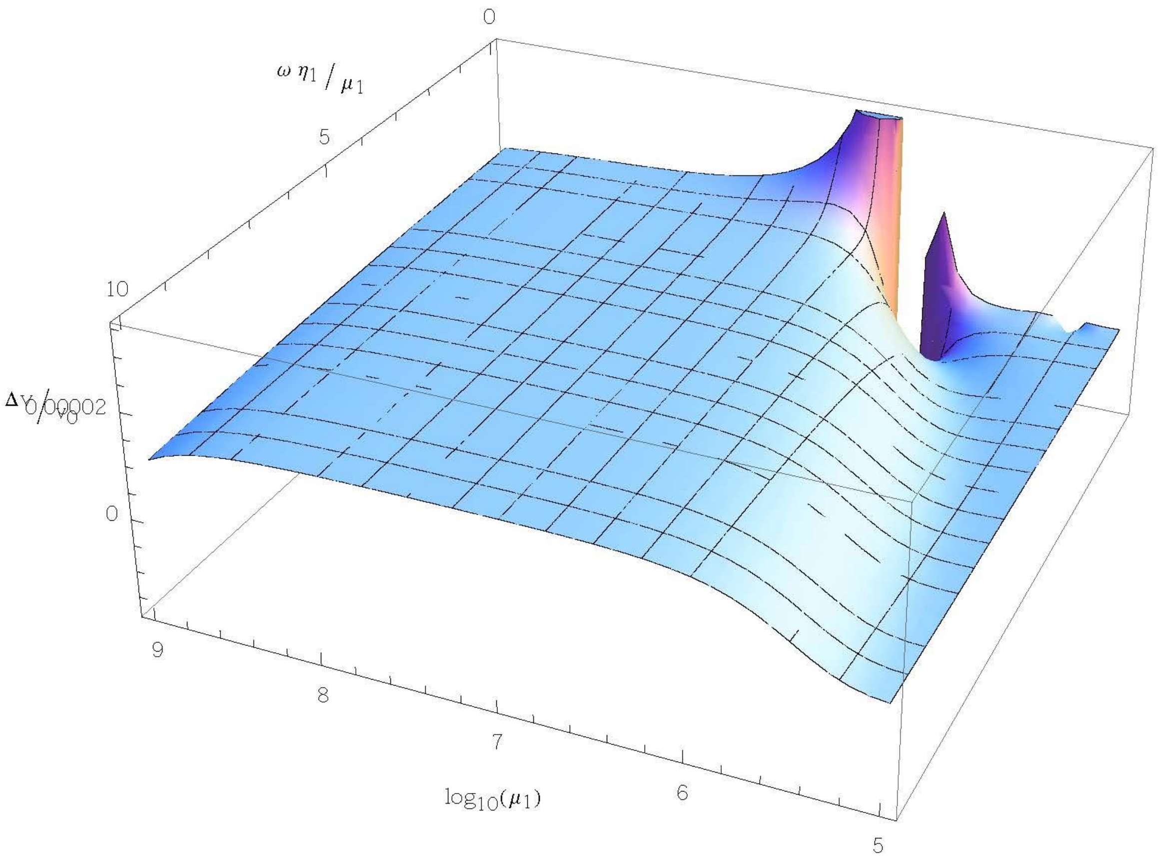
- In vapors or liquid phase : a ’missing mass” effect predicted

$$\Delta V / V_0 \approx \frac{\omega^{3/2}\rho_1 h_1 V_0^2}{2 g_0^2}\sqrt{2\eta_2\rho_2}\left\{1 - \frac{\eta_2\omega(g' + g'')}{g'^2 + g''^2}\frac{\rho_2}{\rho_1}\right\}$$



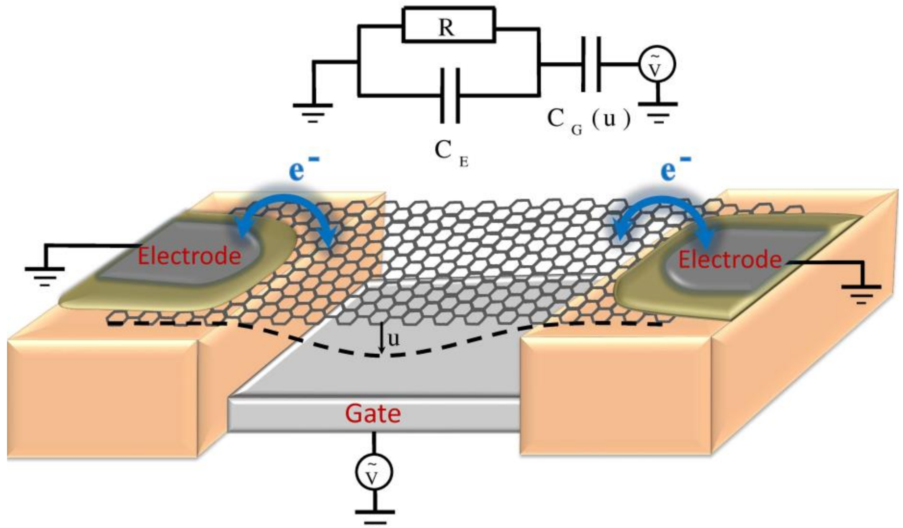
(Voinova, JSSS , 2015)

<u>Current research activities</u>: modelling and numerical simulations of SH-SSW sensors response in AQC's and biosensors applications



A.Vikström (CTU, 2015)

Current research activities: modelling and numerical simulations of graphene-based nanoresonator



- Axel M. Eriksson,∗ Marina V. Voinova, and Leonid Y. Gorelik (J.Appl.Phys. 2015)

Suggested R&I Needs for future research

- **Research directions as R&I NEEDS:**

1. Theoretical modelling and numerical simulations of dynamics of adsorbed films in SAW and QCM resonators.

Software **based on the theoretical calculations can be used for the quantitative analysis of the acoustic experiments in AQC and biosensors' applications.**

2. Theoretical modeling of a graphene-based sensor