Measurement of INK Viscosity using AFM cantilever

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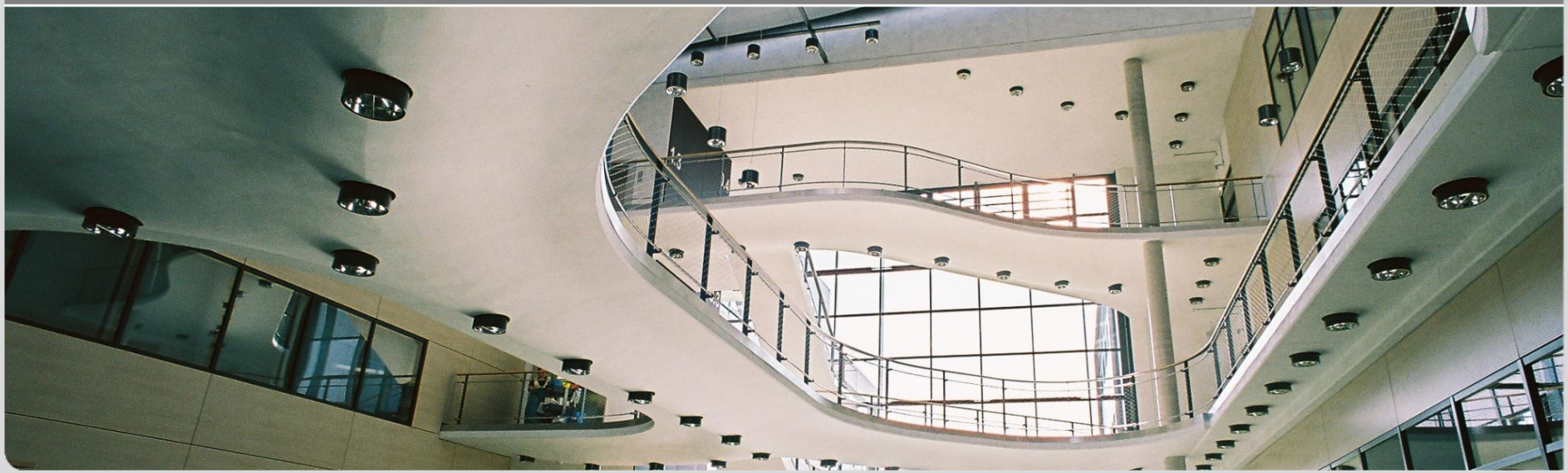
INSTITUTE OF NANOTECHNOLOGY



Motivation of the work

❖ The Dip-Pen Nanolithography (DPN) process uses a chemically coated scanning probe tip (the “pen”) to directly deposit a material (“ink”) with nanometer precision onto a substrate.

❖ Several experimental parameters have been observed to influence the ink transport in DPN – relative humidity, temperature, **viscosity** and **density** of the ink are the two important parameters which play a crucial role in ink transport in DPN.

❖ It is necessary to understand and control these parameters in order to optimize DPN processes for a particular application.

❖ It is difficult to measure the viscosity of this ink using standard processes of measuring viscosity because the DOPC is not dissolved into some organic solution while writing.

Previous work

1) "Measurement of solution viscosity by atomic force microscopy", REVIEW OF SCIENTIFIC INSTRUMENTS**,** VOLUME 72, NUMBER 6 JUNE 2001

2) "Detection of microviscosity by using uncalibrated atomic force microscopy Cantilevers", APPLIED PHYSICS LETTERS **93**, 124102, 2008

Relation between the Resonance frequency and the Viscosity of the medium

$$\omega = \frac{1}{8}\left(\sqrt{9(K\eta\rho)^4 + 64\omega_0^2} - 3(K\eta\rho)^2\right),$$

$$\omega_0 = \sqrt{k/m^*}.$$

K = a constant for a given cantilever
η= viscosity of the medium
ρ= density of the medium
k= spring constant of the cantilever
m*= mass of the cantilever

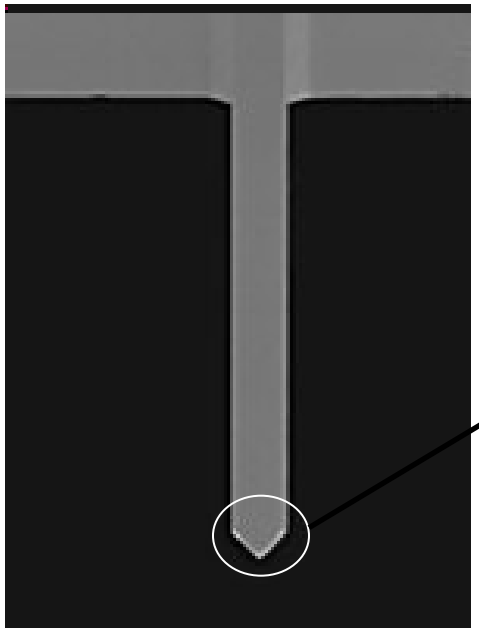
Ref.: G. Chen, R. Warmack, T. Thundat, and D. P. Allison, Rev. Sci. Instrum., **65**, 2532, (1994).

Specification of the cantilever

Cantilever Specifications

Material: Silicon

Shape: Rectangular



Tip Specifications

Material: Silicon

Shape: Pyramidal

Height (µm): 14-16

Aspect Ratio: 1.5-3.0

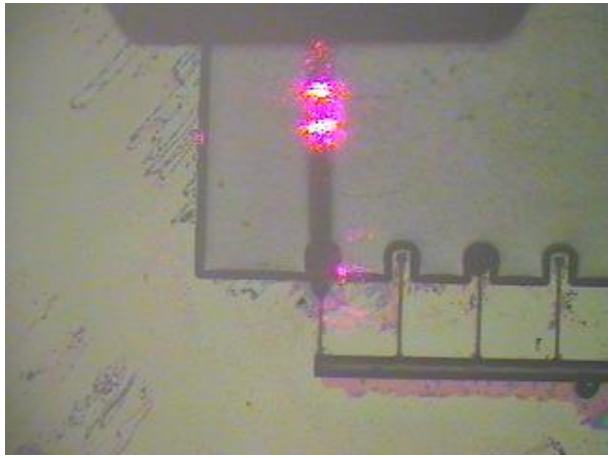
ROC* (nm): < 10 nm

Coating: None

Ref. http://www.appnano.com

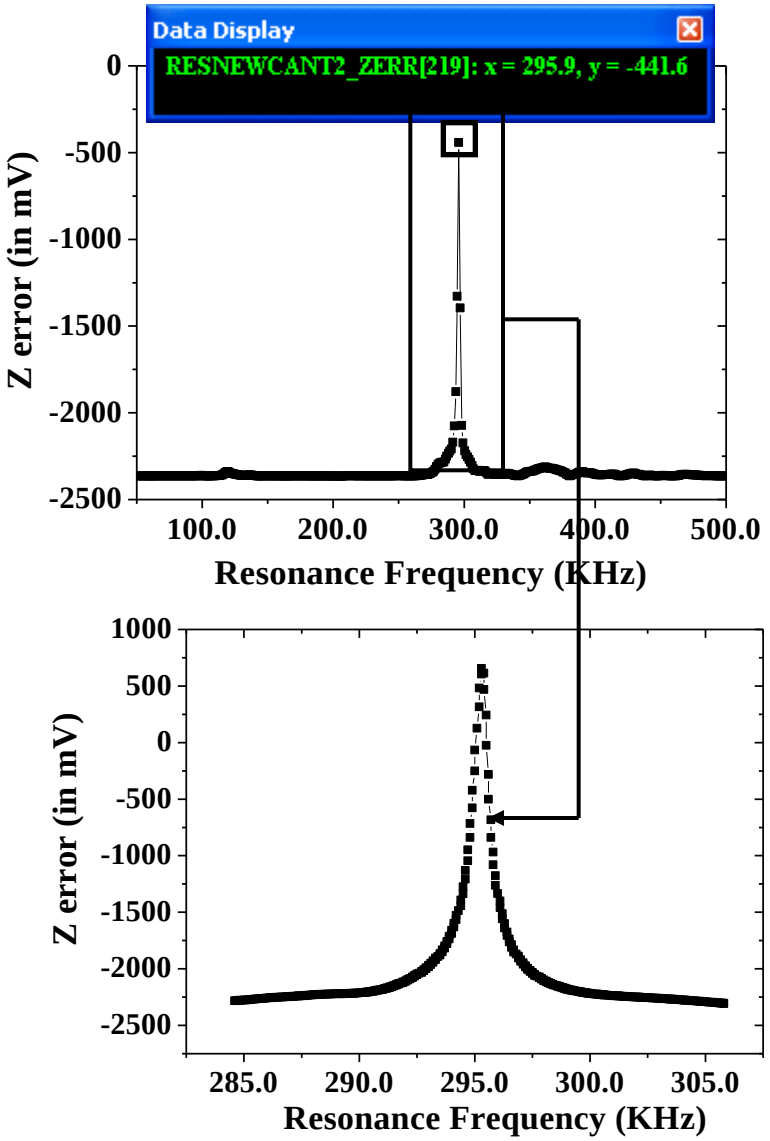
Parameter	Nominal Value	Minimum Value	Maximum Value
Spring Constant (N/m)	40	25	75
Frequency (kHz)	300	200	400
Length (µm)	125	115	135
Width (µm)	35	30	40
Thickness (µm)	4.5	4.0	5.0

Resonance frequency of the cantilever in air

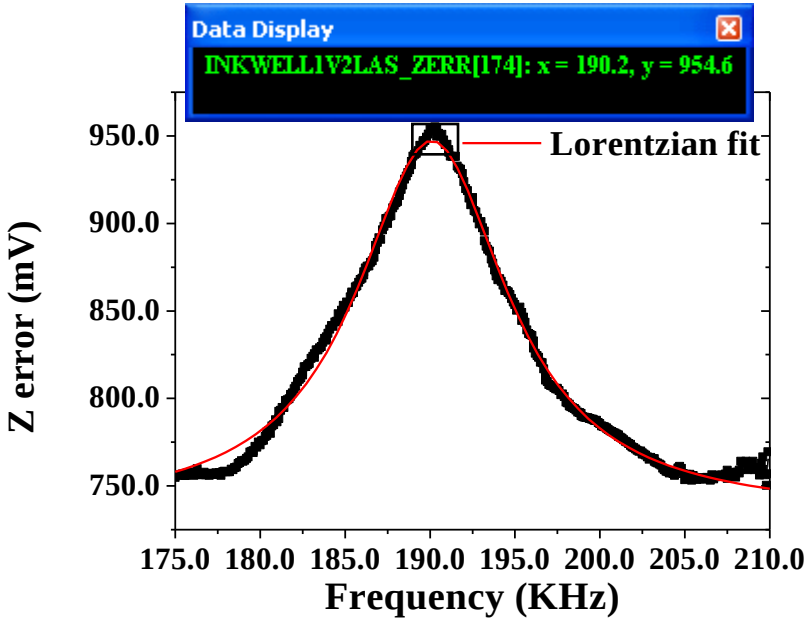


Optical microscopic image of the cantilever tip dipped in the micro wells containing DOPC ink.

$T = 21^0C \pm 2^0C$
RH = 40.8 % ± 2%



Resonance frequency of the cantilever in water



$T = 21^0C \pm 2^0C$

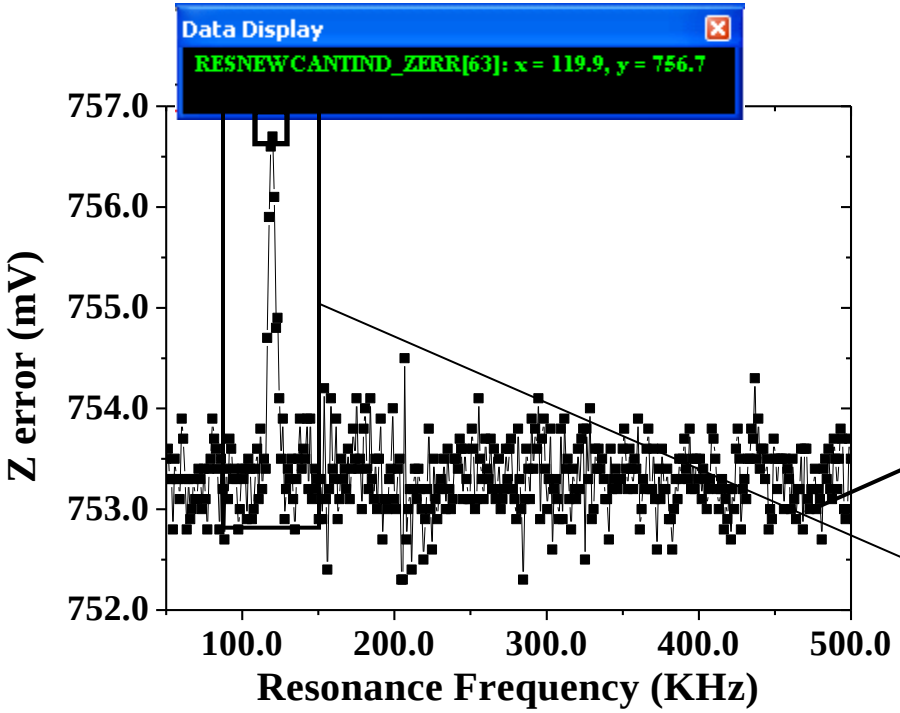
$RH = 40.8\ \% \pm 2\%$

$K = 590.741\ m^4s^{1/2}/kg^2$

$\eta = 1.002X10^{-3}\ N.s/m^2$

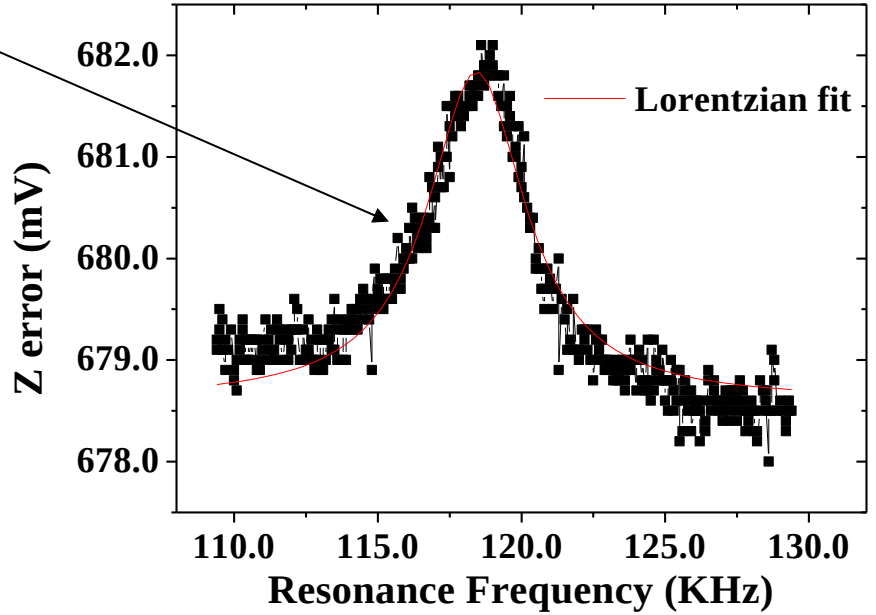
$\rho = 998.2\ kg/m^3$

Resonance frequency of the cantilever in DOPC



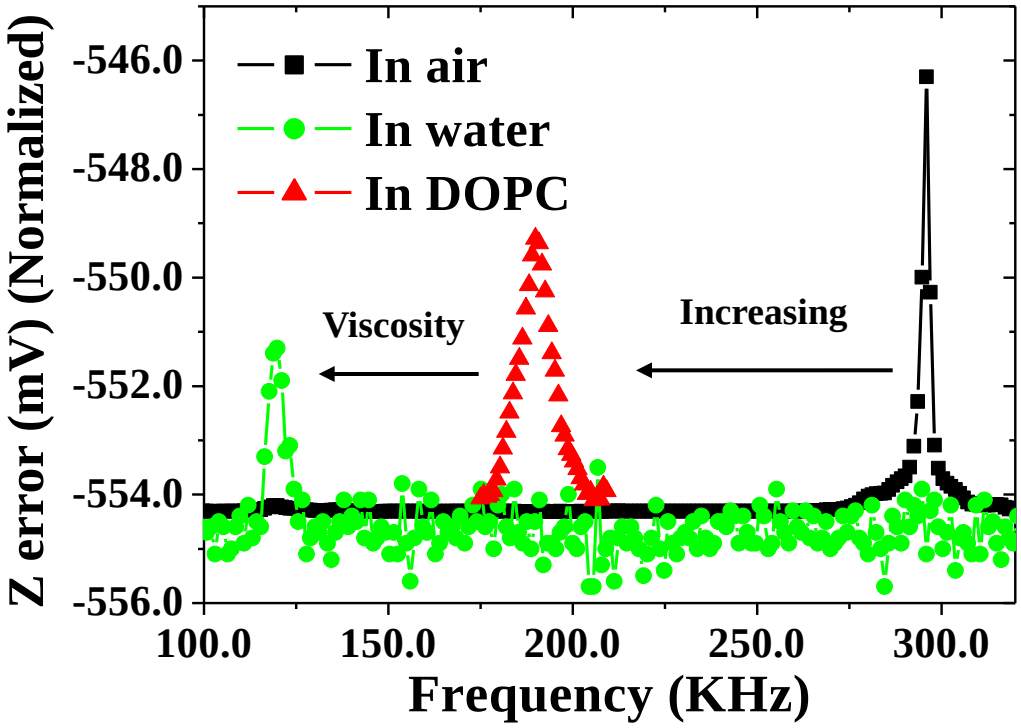
$T = 21^0C \pm 2^0C$
$RH = 40.8\ \% \pm 2\%$

Drastic decrease in S/N ratio



$\eta\rho = 1.58\ kg^2/m^4.s$

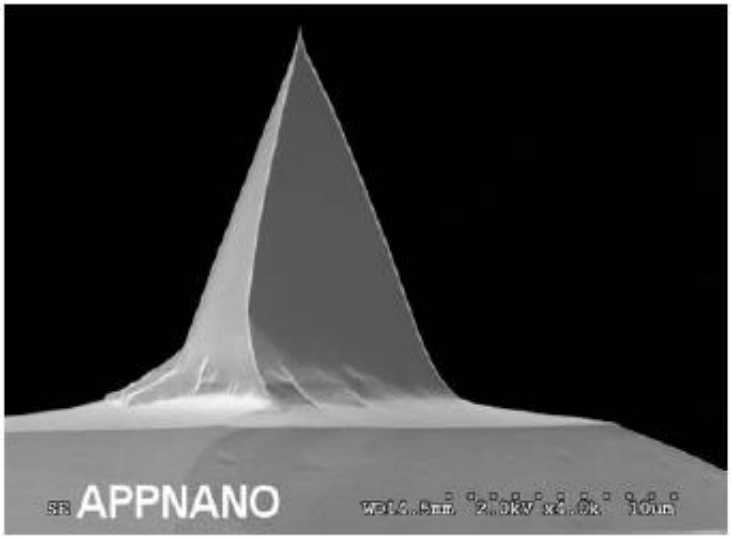
Comparison between the resonance frequencies in different medium



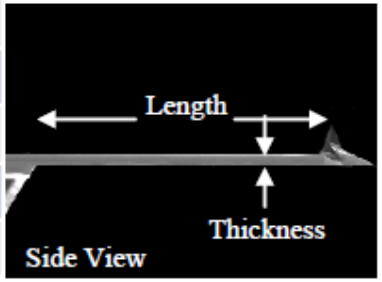
Different cantilever

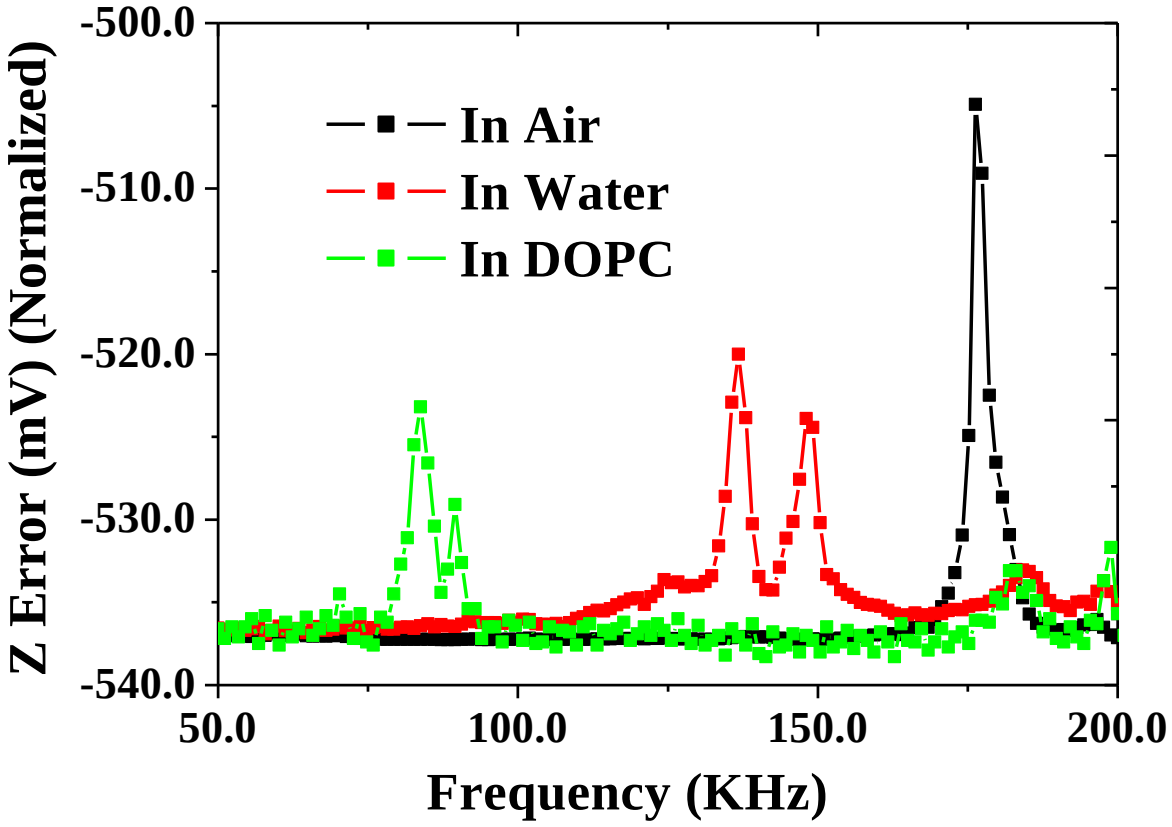
Tip Specifications	
Shape	Pyramidal
Height (µm)	14 - 16
ROC (nm)	6
Coating	None
Cantilever Specifications	
Material	Si
Shape	Rectangular
Front Coating	None
Reflex Side Coating	None

Ref. http://www.appnano.com



Parameter	Value		
	Nominal	Minimum	Maximum
Spring Constant (N/m)	45	20	90
Frequency (kHz)	190	145	230
Length (µm)	225	215	235
Width (µm)	40	35	45
Thickness (µm)	8.5	8.0	9.0

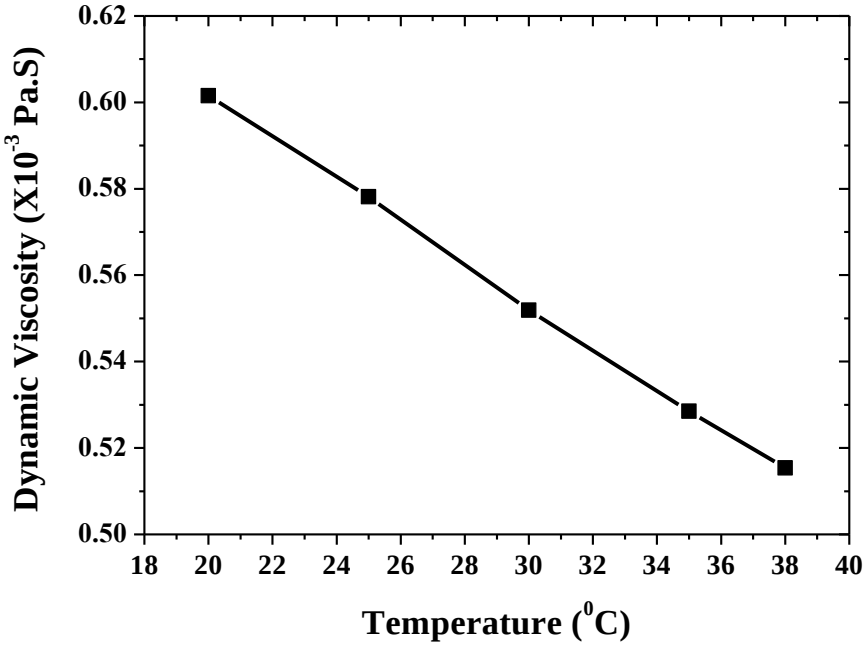




$\eta\rho = 1.75\ kg^2/m^4.s$

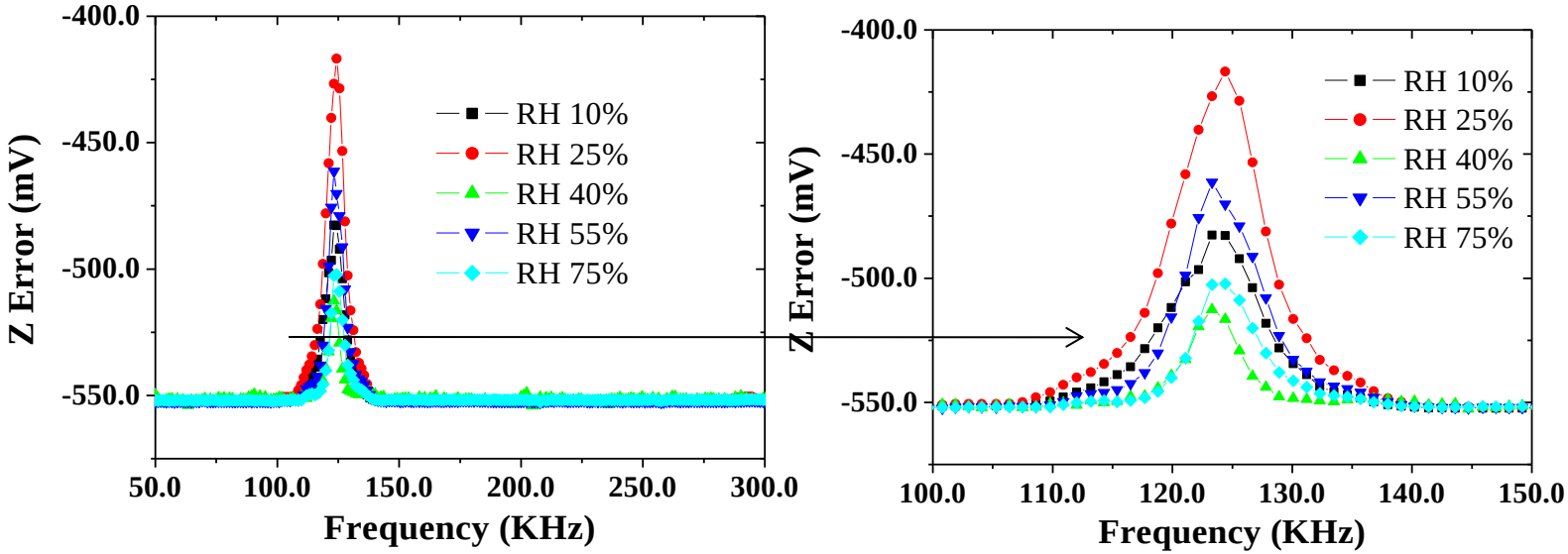
Variation of the Viscosity of the solution with temperature

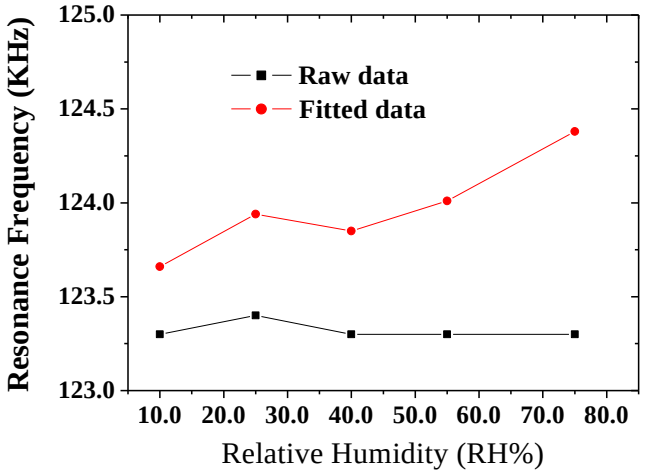
10 mg/ml 1, 2-Dioleoyl-sn-Glycero-3-phosphocholine (DOPC) in $CHCl_3$



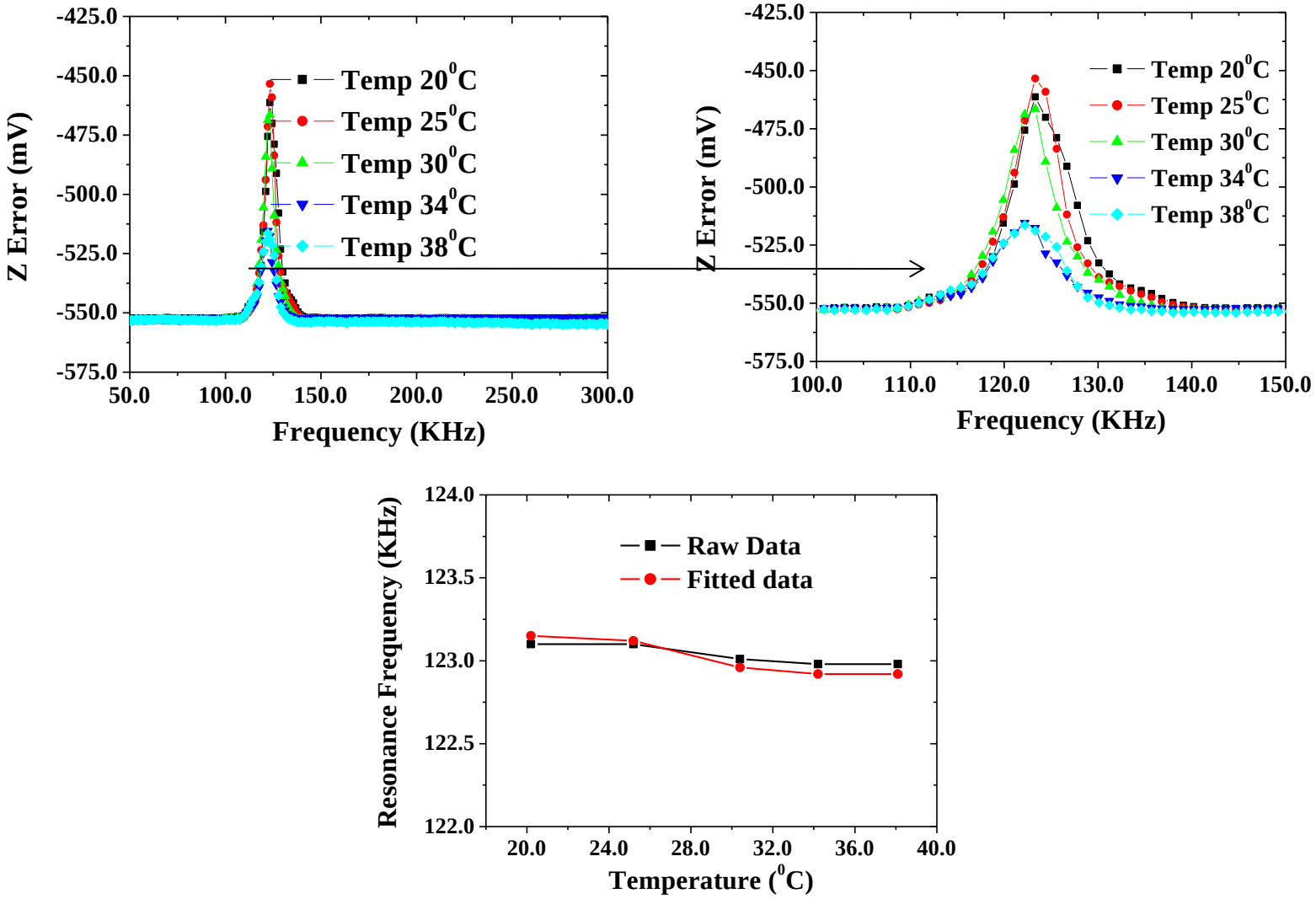
ρ = 1.460 gm/cm^3 , at 24^{0}C

Effect of Relative Humidity

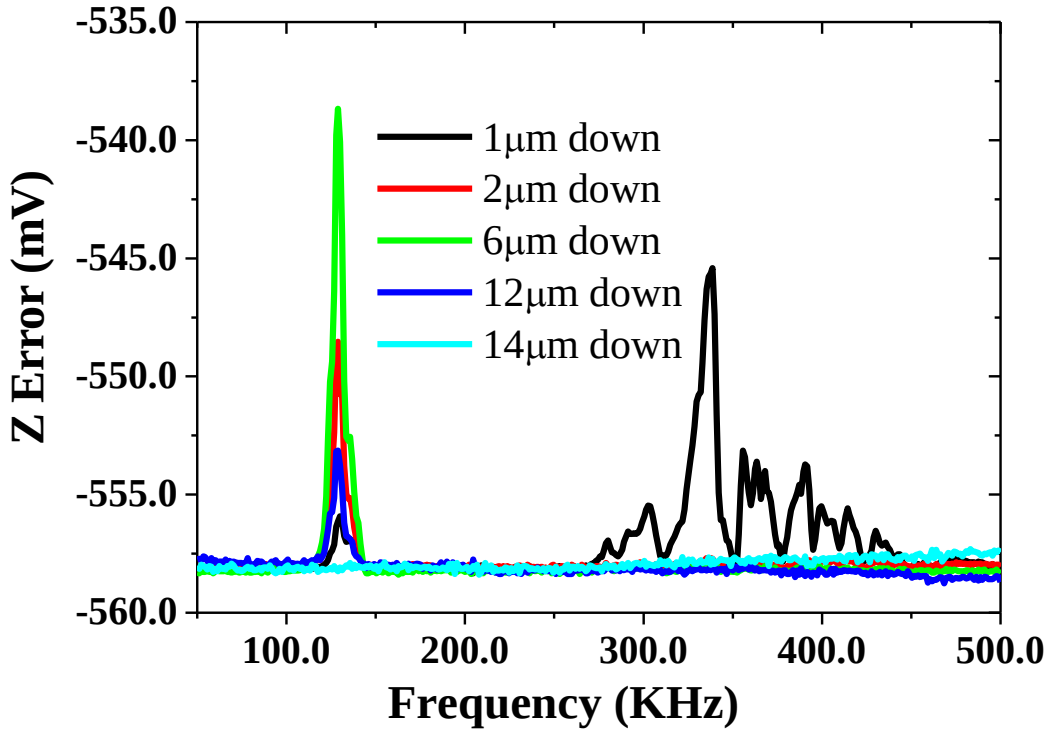




Effect of Temparature



Height dependence



Conclusions and future scope of the work

❖ The viscosity of inks used for DPN can be determined from the shift in resonance frequency of a cantilever vibrating in the ink as compared to that in air.

❖ This method for monitoring viscosity is of relevance to all biorheologic and microfluidic applications where functionalized cantilevers have to be used.

❖ It is a simple, yet reliable nondestructive procedure.

❖ The effect of RH and temperature on the viscosity of the ink has been studied using the same method.

❖ This technique will be used to screen broader range of different inks and ink mixtures to understand the influence of admixing (e.g. cholesterol in DOPC) on the viscosity.

Thank you

- Average of 5 measurements, sd <2%
- The diameter of the micro wells where the tip of the cantilever has been dipped is 20 µm and the depth is 85 µm.
- Sample volumes were ~ 0.03 nl.
- The ink reservoir is large enough for convenient handling with pipettes and is connected to the actual micro wells for dipping the tips via micro channels (typical width ~ 6 µm).