Progress on DRDC projects

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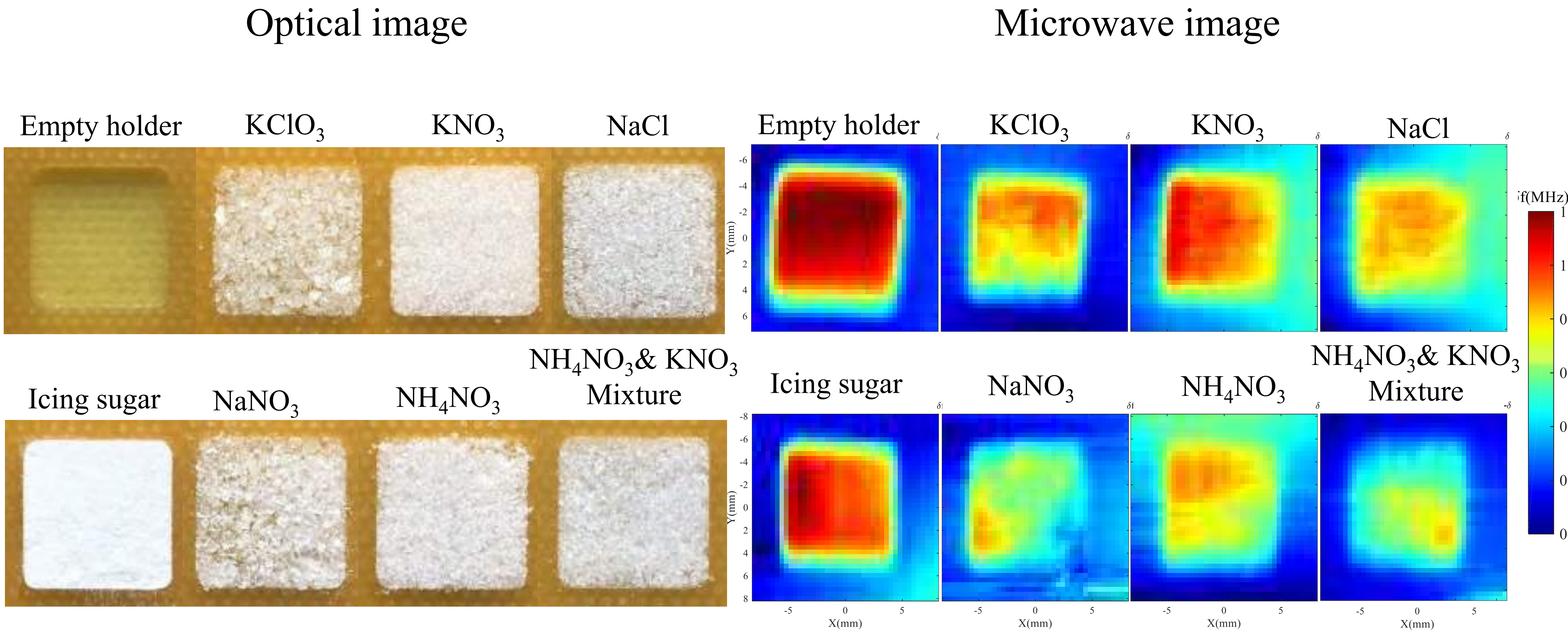
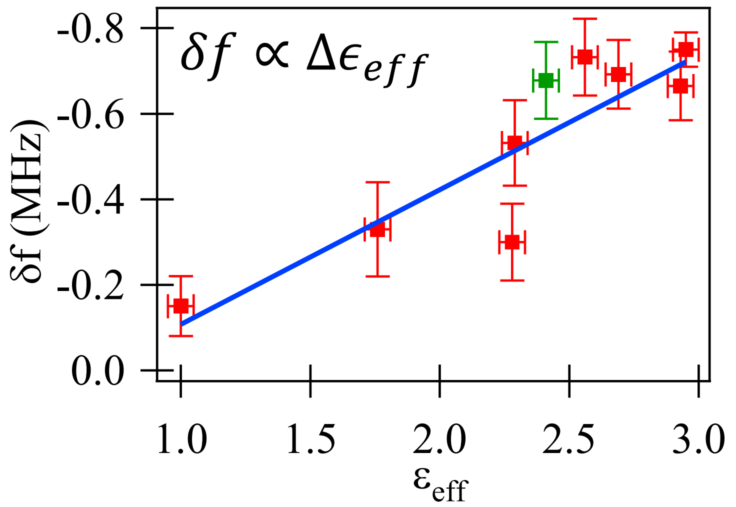


Optical image
Microwave image
Empty holder
KClO3
KNO3
NaCl
Icing sugar
NaNO3
NH4NO3
NH4NO3& KNO3
Mixture
Y(mm)
X(mm)
-5
0
5

Using Cavity perturbation theory:

$$\frac{\delta f}{f_0} \approx \frac{\iiint_V \Delta\epsilon |E|^2 dv}{\iiint \epsilon |E|^2 dv} = \frac{\Delta\epsilon_{eff} \cdot V}{\epsilon \cdot V}$$

$$\frac{\Delta\epsilon_{eff} \cdot V}{\epsilon \cdot V} = \frac{\epsilon_{sample} V_{sample} + \epsilon_{air} V_{air}}{\epsilon_{air}(V_{sample} + V_{air})}$$



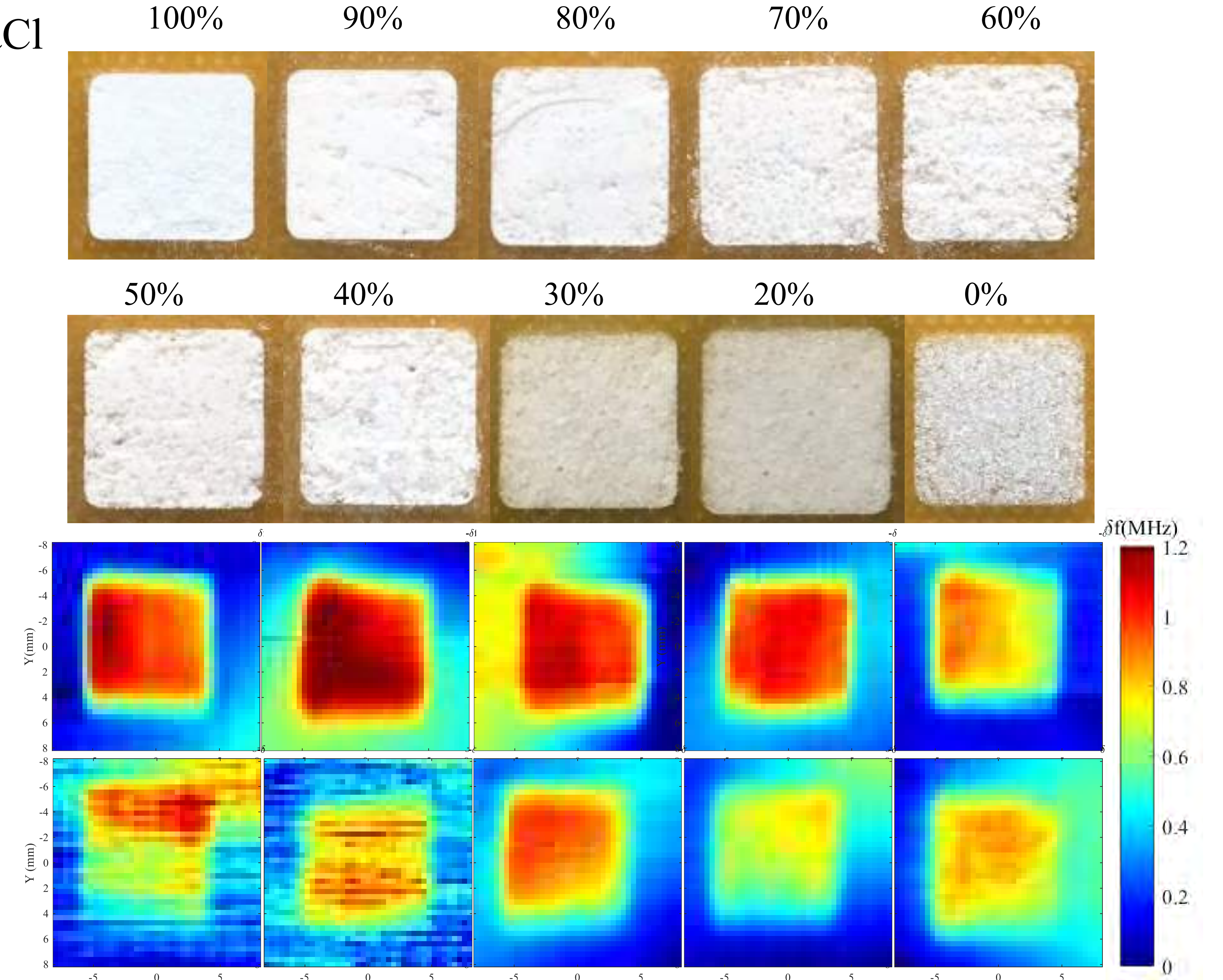
Materials	Sample mass(mg)	Density	Volume fraction	Permittivity(ϵ)	ϵ_{eff}	-$\delta\bar{f}$(MHz)
Air	0	~ 0	100%	~1	1	1.001
$KClO_3$	79	2.32 g/cm^3	38.01%	4.36	2.28	0.852
KNO_3	84	2.109 g/cm^3	44.27%	3.91	2.28	0.618
NaCl	102	2.17 g/cm^3	52.03%	4.71	2.95	0.485
$NaNO_3$	95	2.257 g/cm^3	36.59%	4.60	2.69	0.418
NH_4NO_3	56	1.72 g/cm^3	47.06%	5.37	2.56	0.458
Icing sugar	49	0.65 g/cm^3	84.27%	1.90	1.76	0.820
NH_4NO_3 & KNO_3 Mixture	68	1.94 g/cm^3	38.89%	4.63	2.41	0.472

Mixture of icing sugar and NaCl

In volume fraction

Optical image

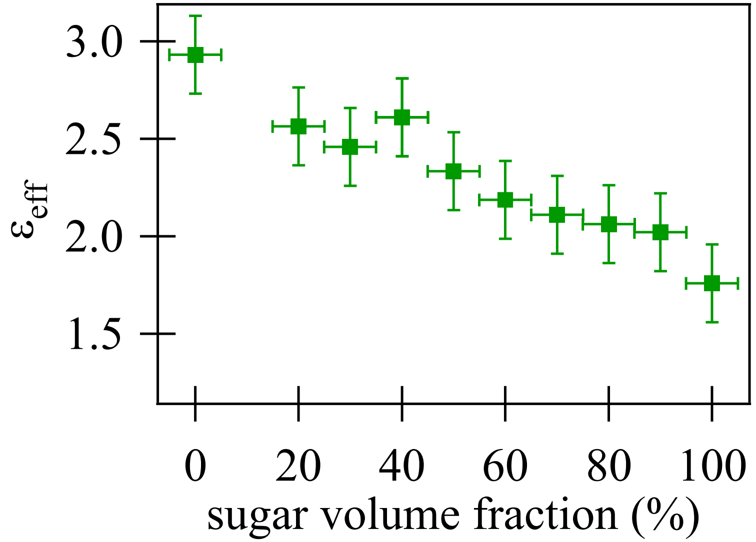
Microwave image



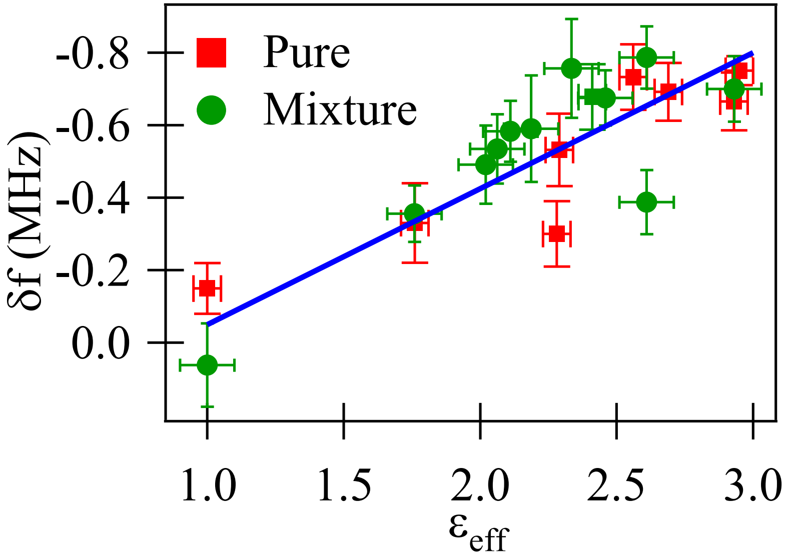
Mixture summary

Sugar Volume fraction(%)	Sample mass(mg)	ϵ_{eff}	$-\delta\bar{f}$(MHz)
0	101	2.93	0.450
20	83	2.57	0.475
30	78	2.46	0.763
40	87	2.61	0.393
50	73	2.33	0.560
60	66	2.19	0.567
70	63	2.11	0.616
80	62	2.06	0.659
90	62	2.02	0.794
100	49	1.76	0.364

Prediction of effective dielectric constant



Measured data plot as function of ϵ_{eff}



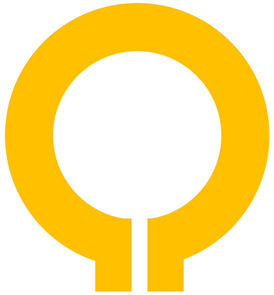
Summary:

1. The resonant shift of the is approximate a linear relation as effective permittivity.
2. It is unlikely to give the precise value due to large error bars.
3. The spatial distribution of chemical powders can be obtained using this method.

Next step:

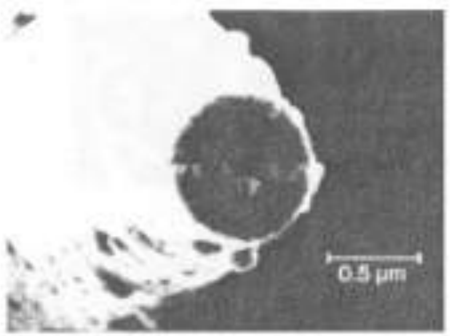
1. Determine the dielectric constant of chemical solutions using broadband technique. (non-resonant method).
2. Compare these results with different methods.

Sensor design:



Penetration depth: ↑
Resolution: ↓

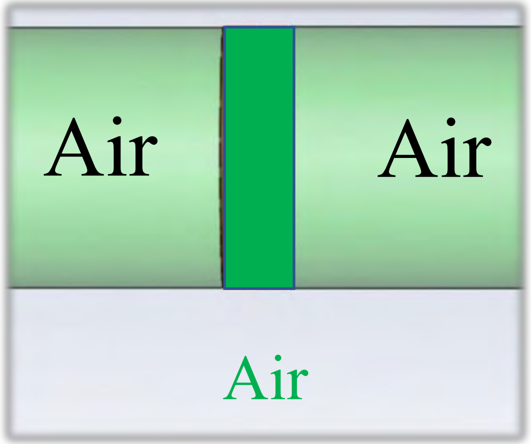
Penetration depth: ↓
Resolution: ↑



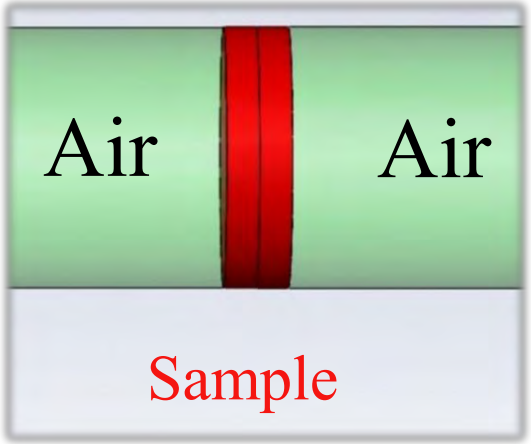
Resolution: ~ nm
Only surface properties

Finished first draft of the paper of dielectric imaging

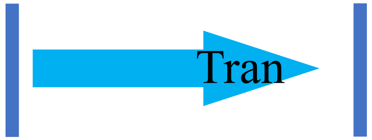
Broadband method



$$M_1 = x \cdot T_{ref_1} \cdot T_1 \cdot T_{ref1}^{-1} \cdot y$$

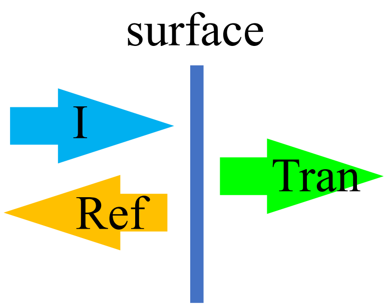


$$M_2 = x \cdot T_{ref_2} \cdot T_2 \cdot T_{ref2}^{-1} \cdot y$$



$$T_i = \begin{pmatrix} e^{-\gamma_i d} & 0 \\ 0 & e^{\gamma_i d} \end{pmatrix} \qquad \gamma_i = \gamma_i(\epsilon_i^*)$$

$$M_i = \begin{pmatrix} S_{12}^i - \dfrac{S_{11}^i S_{22}^i}{S_{21}^i} & \dfrac{S_{11}^i}{S_{21}^i} \\ -\dfrac{S_{22}^i}{S_{21}^i} & \dfrac{1}{S_{21}^i} \end{pmatrix}$$



$$T_{refi} = \begin{pmatrix} \dfrac{1}{1-\Gamma_i} & \dfrac{\Gamma_i}{1-\Gamma_i} \\ \dfrac{\Gamma_i}{1-\Gamma_i} & \dfrac{1}{1-\Gamma_i} \end{pmatrix} \qquad \Gamma_i = \Gamma_i(\epsilon_i^*)$$

$$Tr(M_1 M_2^{-1}) = Tr(T_{ref1} T_1 T_{ref1}^{-1} \cdot T_{ref2} T_2^{-1} T_{ref2}^{-1})$$

Propagation constant

$$\gamma_i = -i\frac{(2\pi)}{\lambda_0}\sqrt{\epsilon_{ri}^* - \left(\frac{\lambda_0}{\lambda_c}\right)^2}$$

Numerical equation:

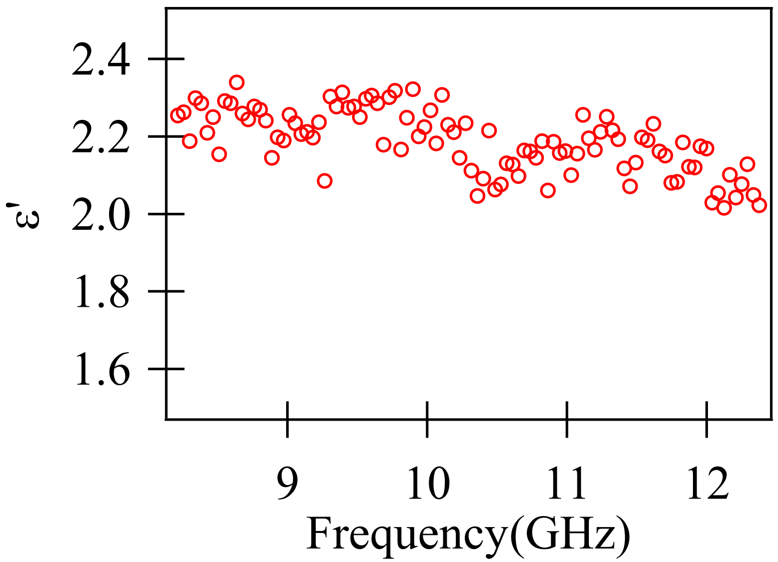
$$f(\gamma_2, \omega) = C_1(\omega) - C_1(\gamma_2, \omega) = 0 \qquad \rightarrow \gamma_2(\omega)$$

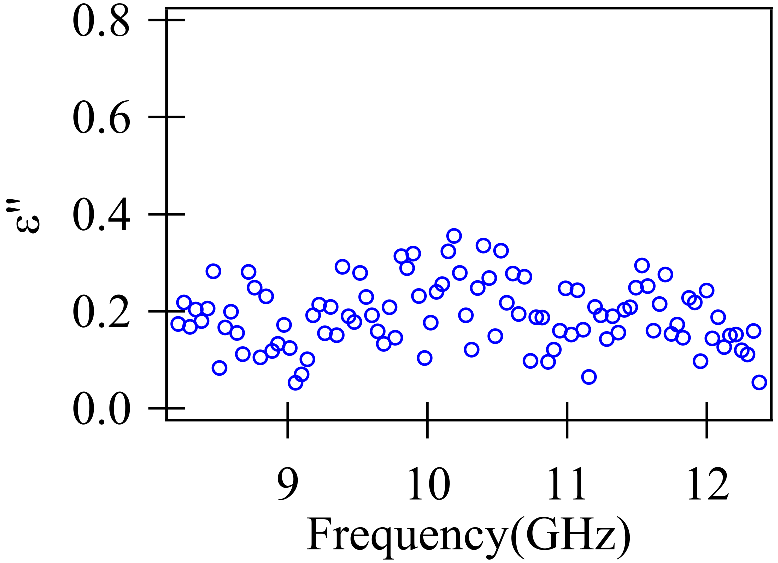
Multi-solutions.
Choose one that make sense
(good initial guess)

Dielectric constant: $$\epsilon_{r2}^* = \frac{\gamma_2^2}{\gamma_1^2}\left(1 - \left(\frac{\lambda_0}{\lambda_c}\right)^2\right) + \left(\frac{\lambda_0}{\lambda_c}\right)^2$$

Air: $\epsilon_{r1}^* = 1$
$\mu_i^* = 1$

RO5880 material:





Datasheet:
$\epsilon_r = 2.20 + 0i$
Measured:
$\epsilon_r = 2.19(0.1) + 0.2(0.1)i$

Next step: perform broadband dielectric constant measurement on water based solutions of

NaCl, NH4NO3, KNO3,NaNO3,KClO3 and icing sugar.

To fulfill the requirement of DRDC contract.

Next experiment: Relative permeability (μ) imaging using scanning near-field microwave microscope

Related research:

APPLIED PHYSICS LETTERS VOLUME 77, NUMBER 26 25 DECEMBER 2000

Magnetic permeability imaging of metals with a scanning near-field microwave microscope

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Material Research Science and Engineering Center, and Center for Superconductivity Research, Department of Physics, University of Maryland, College Park, Maryland 20742-4111

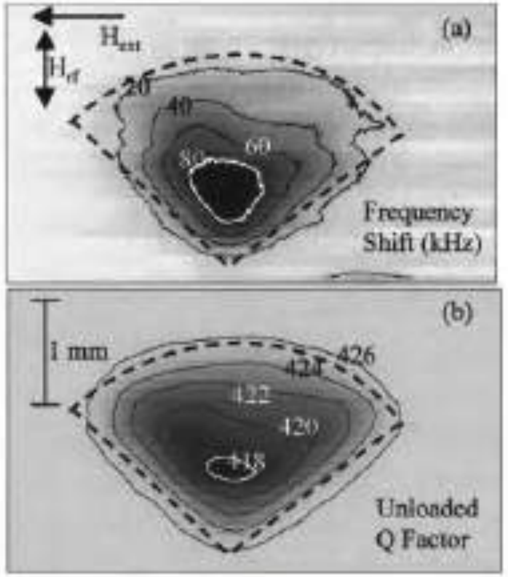

FIG. 4. Images of a LSMO single crystal taken at 6.037 GHz at a sample-probe separation of 10 μm. (a) Δf image of LSMO sample at external field H_{ext} = 1317 Oe, chosen to give a minimum unloaded Q factor at the center of the sample, and (b) unloaded Q factor image at external field H_{ext} = 1411 Oe, chosen to give a minimum Δf at the center of the sample. A background frequency shift has been subtracted from (a). The dashed line shows the approximate location of the sample.

Sample from Lanzhou University ➔ magnetic powder

Using a permanent magnet and microwave absorber to do the imaging.