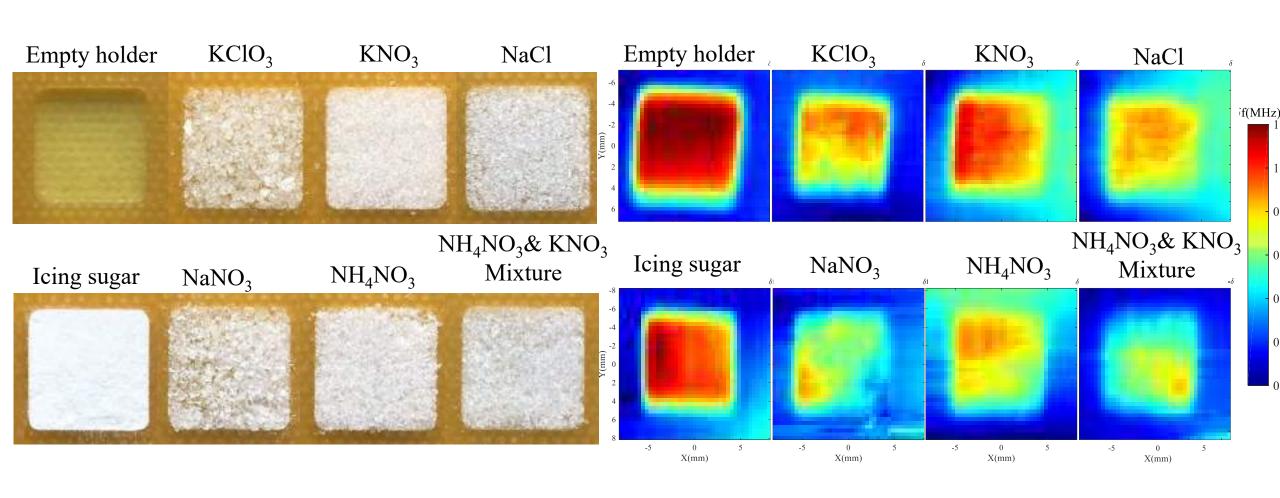
Progress on DRDC projects

Yutong Zhao

Dec 17th 2018

Optical image

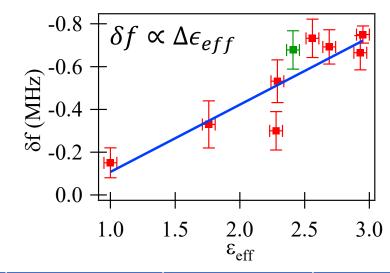
Microwave image



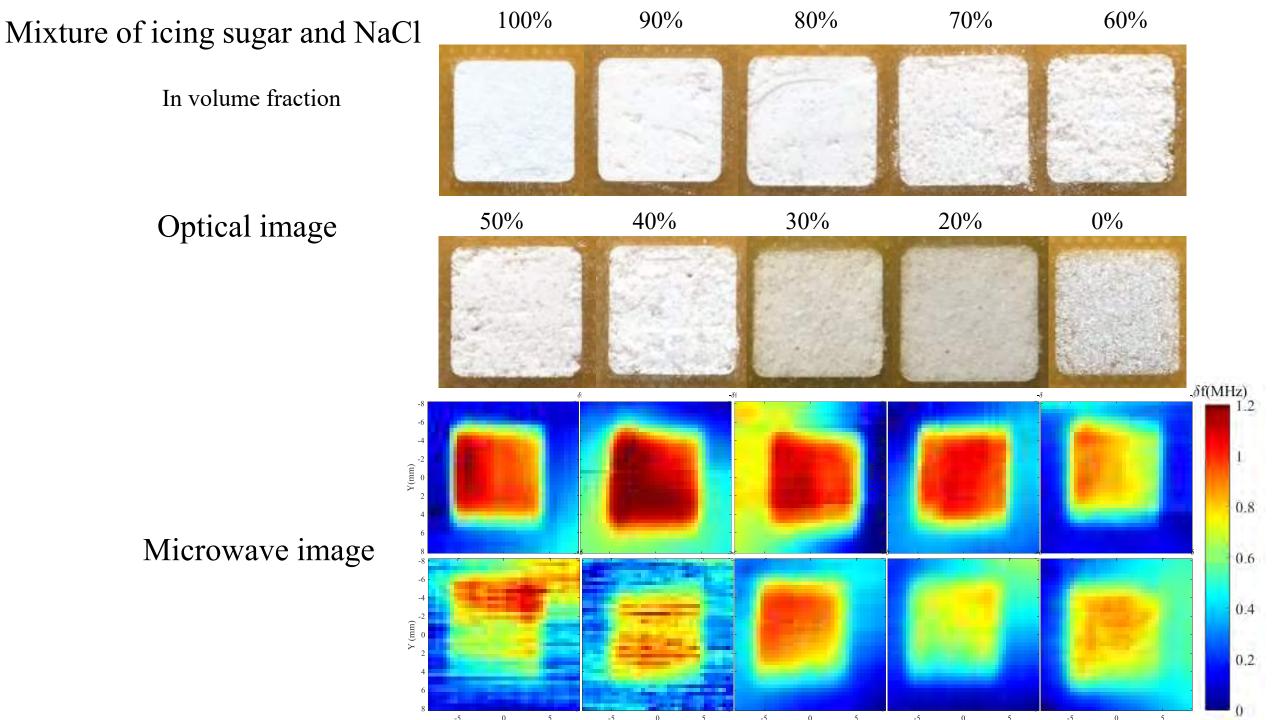
Using Cavity perturbation theory:

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

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



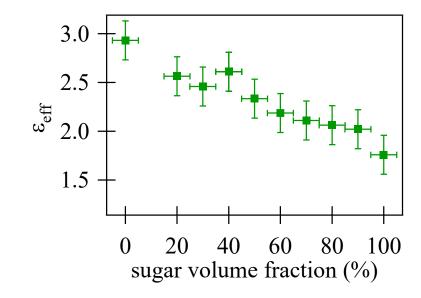
Materials	Sample mass(mg)	Density	Volume fraction	Permittivity(ϵ)	ϵ_{eff}	$-\delta \bar{f}(ext{MHz})$
Air	0	~ 0	100%	~1	1	1.001
KClO ₃	79	2.32 g/cm^3	38.01%	4.36	2.28	0.852
KNO_3	84	2.109 g/cm^3	44.27%	3.91	2.28	0.618
NaCl	102	2.17 g/cm^3	52.03%	4.71	2.95	0.485
NaNO ₃	95	2.257 g/cm^3	36.59%	4.60	2.69	0.418
NH ₄ NO 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 ₄ NO ₃ & KNO ₃ Mixture	68	1.94 g/cm^3	38.89%	4.63	2.41	0.472



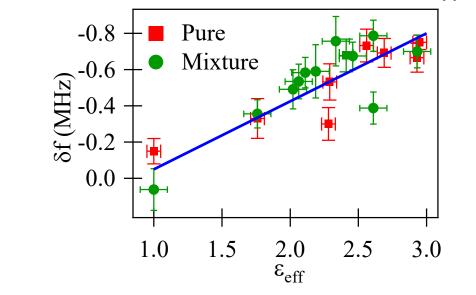
Mixture summary

Sugar Volume fraction(%)	Sample mass(mg)	ϵ_{eff}	$-\delta \overline{f}(\mathrm{MHz})$
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.

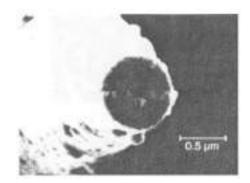
Sensor design:



Penetration depth: ↑
Resolution: ↓



Penetration depth: ↓ Resolution: ↑



Resolution: ~ nm Only surface properties

Finished first draft of the paper of dielectric imaging

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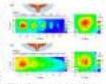
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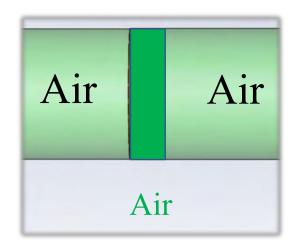
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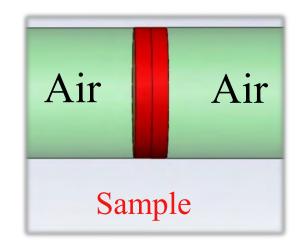
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Broadband method



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



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



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

$$T_{refi} = \begin{pmatrix} \frac{1}{1 - \Gamma_i} & \frac{\Gamma_i}{1 - \Gamma_i} \\ \frac{\Gamma_i}{1 - \Gamma_i} & \frac{1}{1 - \Gamma_i} \end{pmatrix}$$

$$\Gamma_i = \Gamma_i(\epsilon_i^*)$$

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

$$\Gamma_i = \Gamma_i(\epsilon_i^*)$$

$$Tr(M_1M_2^{-1}) = Tr(T_{ref1}T_1T_{ref1}^{-1} \cdot T_{ref2}T_2^{-1}T_{ref2}^{-1})$$

Propagation constant

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

Numerical equation:

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

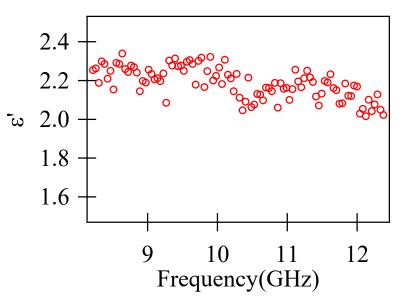
$$\rightarrow \gamma_2(\omega)$$

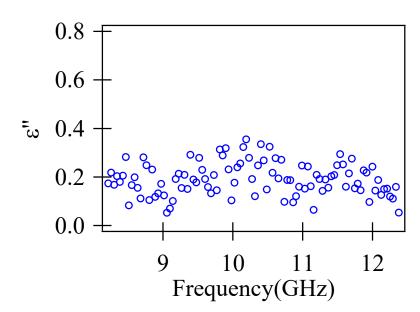
Multi-solutions.
Choose one that make sense (good initial guess)

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

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

Sheng-Chiang Lee, a) C. P. Vlahacos, b) B. J. Feenstra, c) Andrew Schwartz, d)
D. E. Steinhauer, e) F. C. Wellstood, and Steven M. Anlage
Material Research Science and Engineering Center, and Center for Superconductivity Research,
Department of Physics, University of Maryland, College Park, Maryland 20742-4111

Sample from Lanzhou University → magnetic powder

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

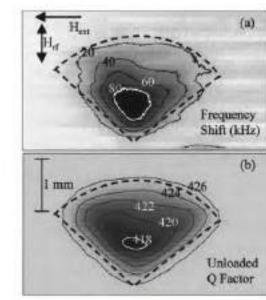


FIG. 4. Insages of a LSMO single crystal taken at 6.037 GHz at a sampleprobe separation of 10 μ m. (a) Δt image of LSMO sample at external field $H_{\rm stat} = 1317$ Ge, chosen to give a minimum unloaded Q factor at the center of the sample, and (b) unloaded Q factor image at external field $H_{\rm ext}$ = 1411 Ge, 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.