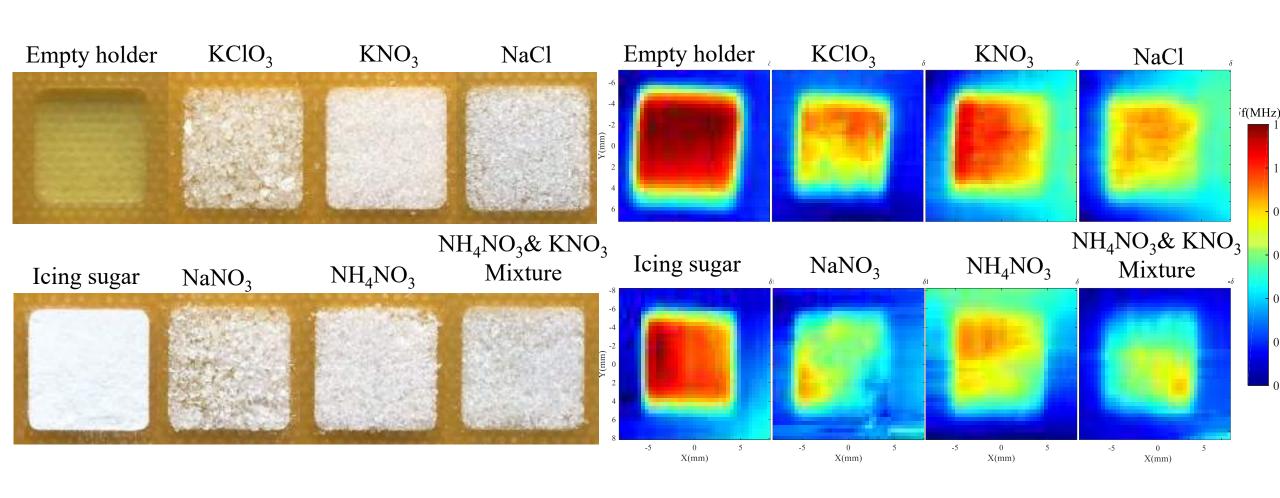
# Progress on DRDC projects

Yutong Zhao

Dec 17<sup>th</sup> 2018

# Optical image

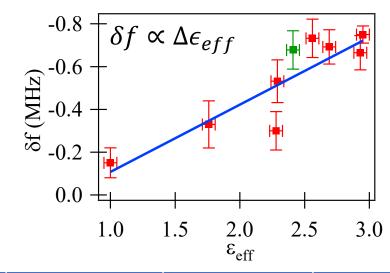
# Microwave image



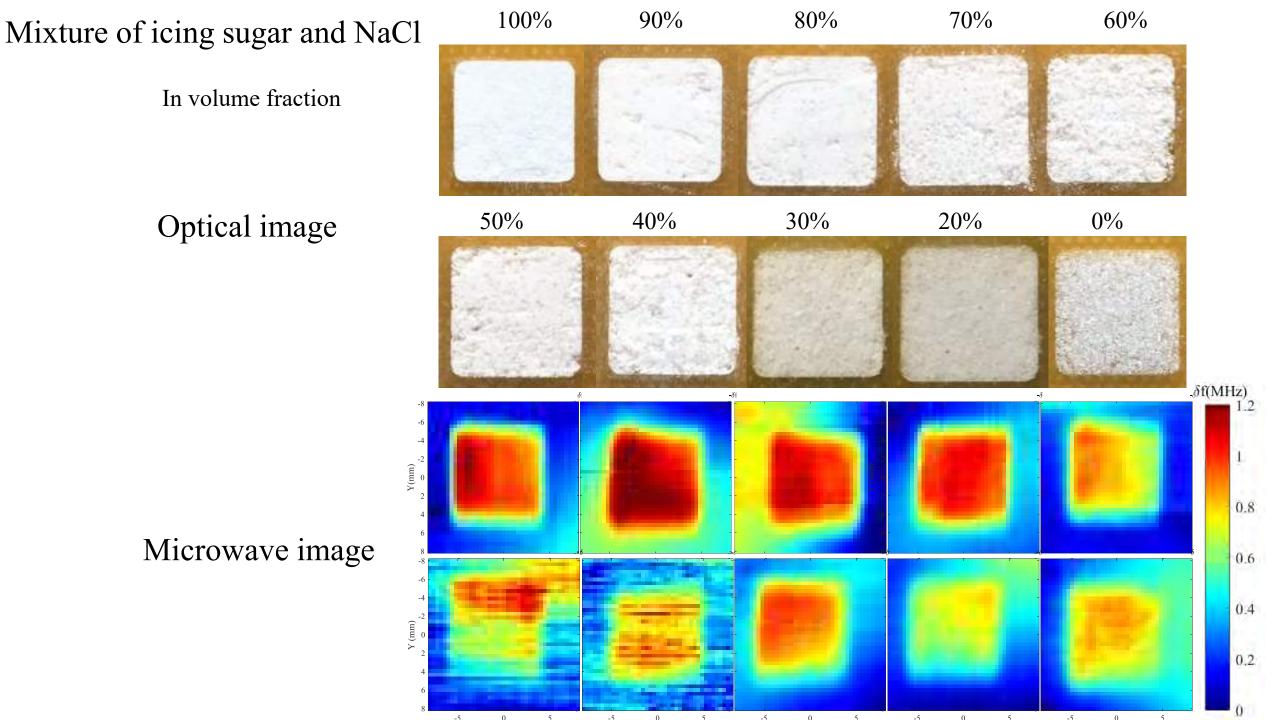
Using Cavity perturbation theory:

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

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



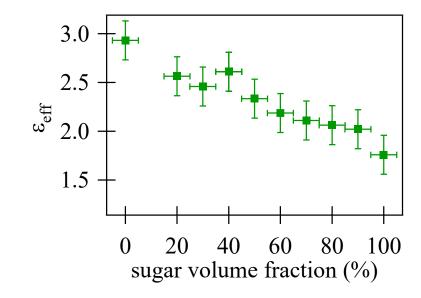
| Materials   | Sample<br>mass(mg) | Density                | Volume fraction | Permittivity( $\epsilon$ ) | $\epsilon_{eff}$ | $-\delta \bar{f}(	ext{MHz})$ |
|---|--------------------|------------------------|-----------------|----------------------------|------------------|------------------------------|
| Air   | 0                  | ~ 0                    | 100%            | ~1                         | 1                | 1.001                        |
| KClO <sub>3</sub>   | 79                 | $2.32 \text{ g/cm}^3$  | 38.01%          | 4.36                       | 2.28             | 0.852                        |
| $KNO_3$   | 84                 | $2.109 \text{ g/cm}^3$ | 44.27%          | 3.91                       | 2.28             | 0.618                        |
| NaCl  | 102                | $2.17 \text{ g/cm}^3$  | 52.03%          | 4.71                       | 2.95             | 0.485                        |
| NaNO <sub>3</sub>   | 95                 | $2.257 \text{ g/cm}^3$ | 36.59%          | 4.60                       | 2.69             | 0.418                        |
| NH <sub>4</sub> NO <sub>3</sub>                               | 56                 | $1.72 \text{ g/cm}^3$  | 47.06%          | 5.37                       | 2.56             | 0.458                        |
| Icing sugar   | 49                 | $0.65 \text{ g/cm}^3$  | 84.27%          | 1.90                       | 1.76             | 0.820                        |
| NH <sub>4</sub> NO <sub>3</sub> & KNO <sub>3</sub><br>Mixture | 68                 | $1.94 \text{ g/cm}^3$  | 38.89%          | 4.63                       | 2.41             | 0.472                        |



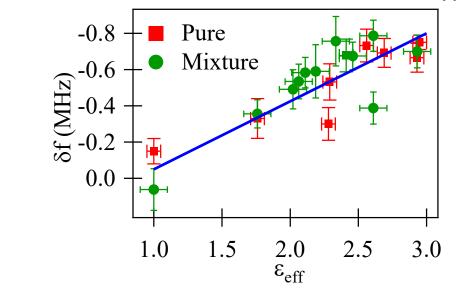
### Mixture summary

| Sugar Volume fraction(%) | Sample<br>mass(mg) | $\epsilon_{eff}$ | $-\delta \overline{f}(\mathrm{MHz})$ |
|--------------------------|--------------------|------------------|--------------------------------------|
| 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 $\epsilon_{eff}$



### 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.

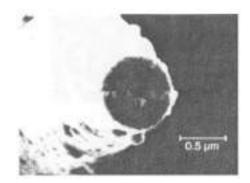
Sensor design:



Penetration depth: ↑
Resolution: ↓



Penetration depth: ↓ Resolution: ↑



Resolution: ~ nm Only surface properties

## Finished first draft of the paper of dielectric imaging

### Modinion split may receive for mar-field excounter maying.

II. DETERMINENTS, INSULTS AND INSULTANCE

The state of the s



A femography of the day, N, 2014, see The second state of the marking and other day on 4.0 and of 50 and 50

1700 and 2-1700 mile a hine representation is re-find over-

In discourse poor too the plants and extensis the parties of the p

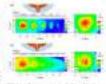
Chicagorhains of #18 years To universely of Characteristics of WB asset The content of a require content of the content of a require content of the content

may a dense beginn in second on long-special charge (FIR) of the native and is follow an ordered charge (FIR) of the native and is followed by the convolute charge. The FIR (FIR) are made in the convolute charge of the second of the second

months and is, on the 4' falls of law matter beauty agent in their before of the entry transmiss. It is beauty the may become it is not a say part both to may

the sea between A is that a new point match for man-ieral delivations from contrast of the co





Security as a continue for a part of the security reciproparities of the part of the security and part of the security an





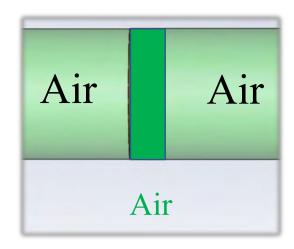
The control of the co

to the injury control property for the injuries; of manufacts and you former to describe. We find the to it will be present another than the described the side of the control of the control of the lay, to will us to copy to the copy of the lay, to will us the copy to the copy of the lay, to will us the copy of t

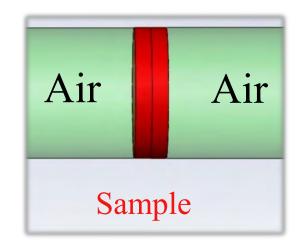
S. CINCLEGA 

If invariant this law case descript it is required, a process to a contract the law case descript it is required. The contract the law case descript it is required to a contract to the contrac

# 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:

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

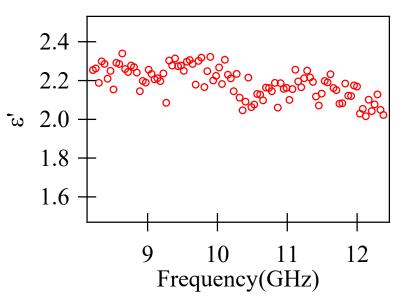
$$\rightarrow \gamma_2(\omega)$$

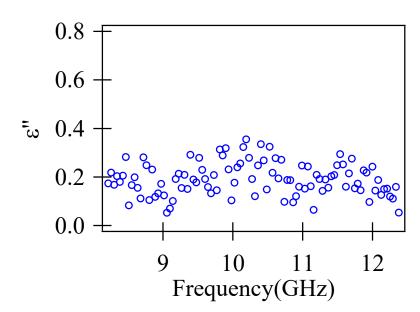
Multi-solutions.
Choose one that make sense (good initial guess)

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

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  $(\mu)$  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.

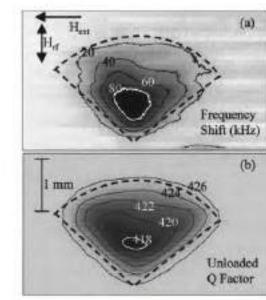


FIG. 4. Insages of a LSMO single crystal taken at 6.037 GHz at a sampleprobe separation of 10  $\mu$ m. (a)  $\Delta t$  image of LSMO sample at external field  $H_{\rm stat} = 1317$  Ge, chosen to give a minimum unloaded Q factor at the center of the sample, and (b) unloaded Q factor image at external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