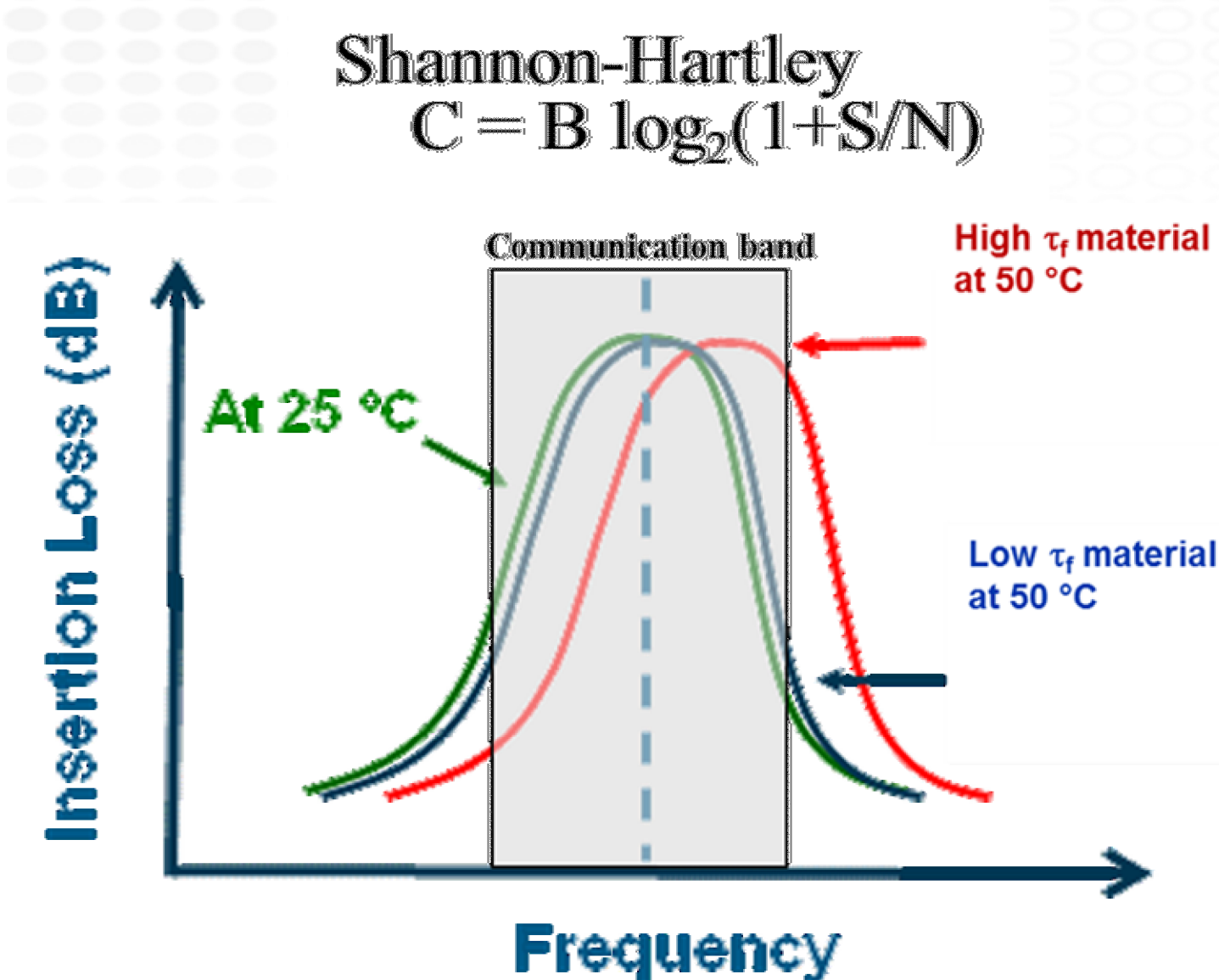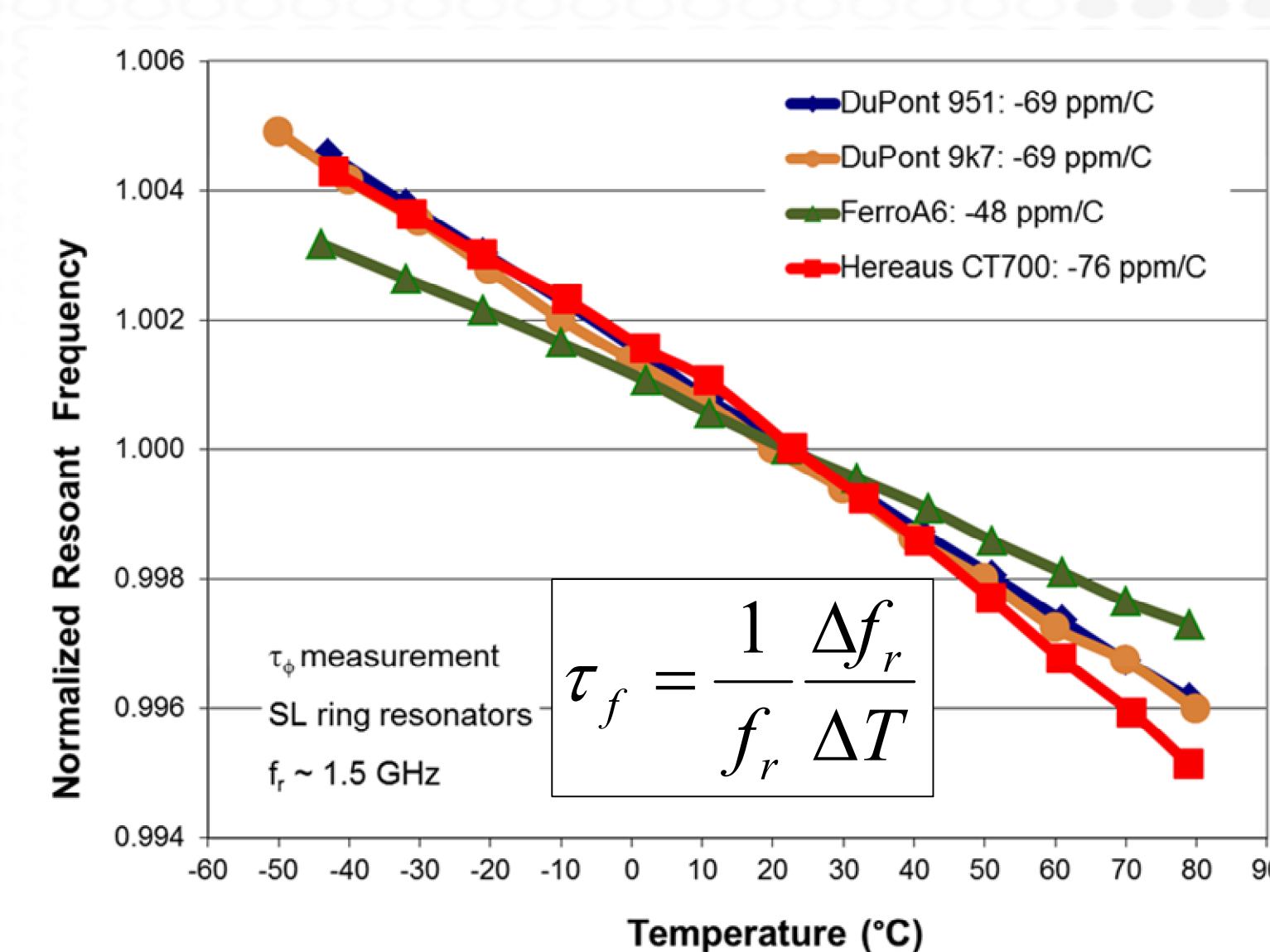# Bandpass Filters with Localized Temperature Compensation in LTCC

Steve Dai and Will Hsieh

Problem:

A low or near zero temperature coefficient of resonant frequency, τ_f, ensures efficient use of wireless bandwidth.


$$\tau_f = \frac{1}{f_r}\frac{\Delta f_r}{\Delta T}$$

τ_f measurement
SL ring resonators
$f_r \sim 1.5$ GHz

$$C = B \log_2(1+S/N)$$
Shannon-Hartley

High τ_f material at 50 °C
At 25 °C
Low τ_f material at 50 °C

Every Hz Counts!

Approaches

$$\tau_f = -\tfrac{1}{2}\tau_\varepsilon - \alpha$$

τ_ε: temp coef of dielectric constant
α: Coef of thermal expansion

Materials	Density (g/cm^3)	ε	τ_ε (ppm/°C)	τ_f (ppm/°C)	Sintering Temp (°C)
TiO$_2$	4.23	85	-750	370	~ 1200
CaTiO$_3$	3.98	180	-1850	920	~ 1400
SrTiO$_3$	5.13	300	-3000	1500	~ 1550
Al$_2$O$_3$	4.00	9.6	105	-60	~ 1600
V-glass	2.77	7.3	N/A	N/A	Tg= 625°C

Challenges

- Developing and cofiring of τ_f compensating materials, in a multilayer LTCC
- Effect of thickness and placement of τ_f compensating material
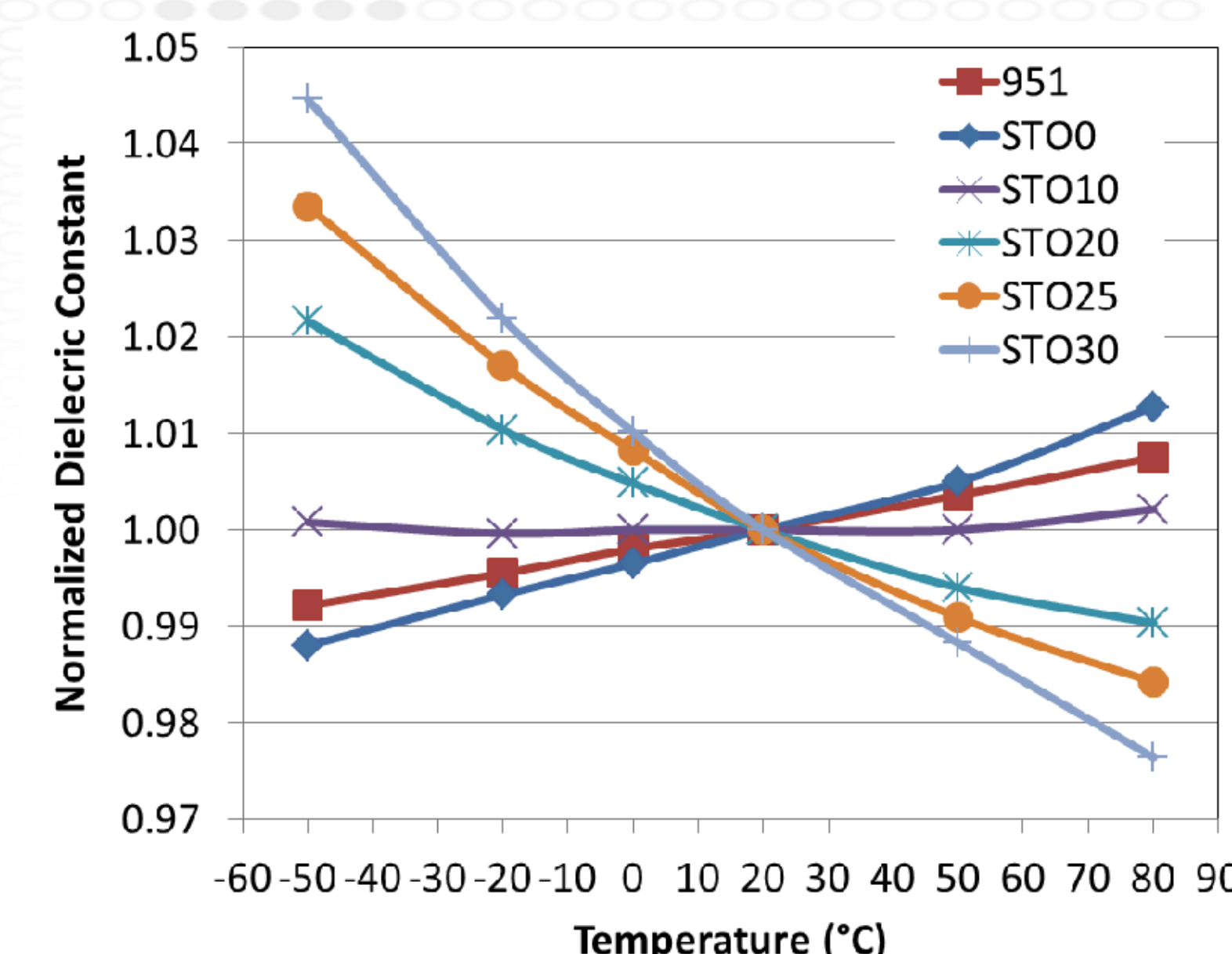

951: T_onset = 766°C
STO20: T_onset = 741°C
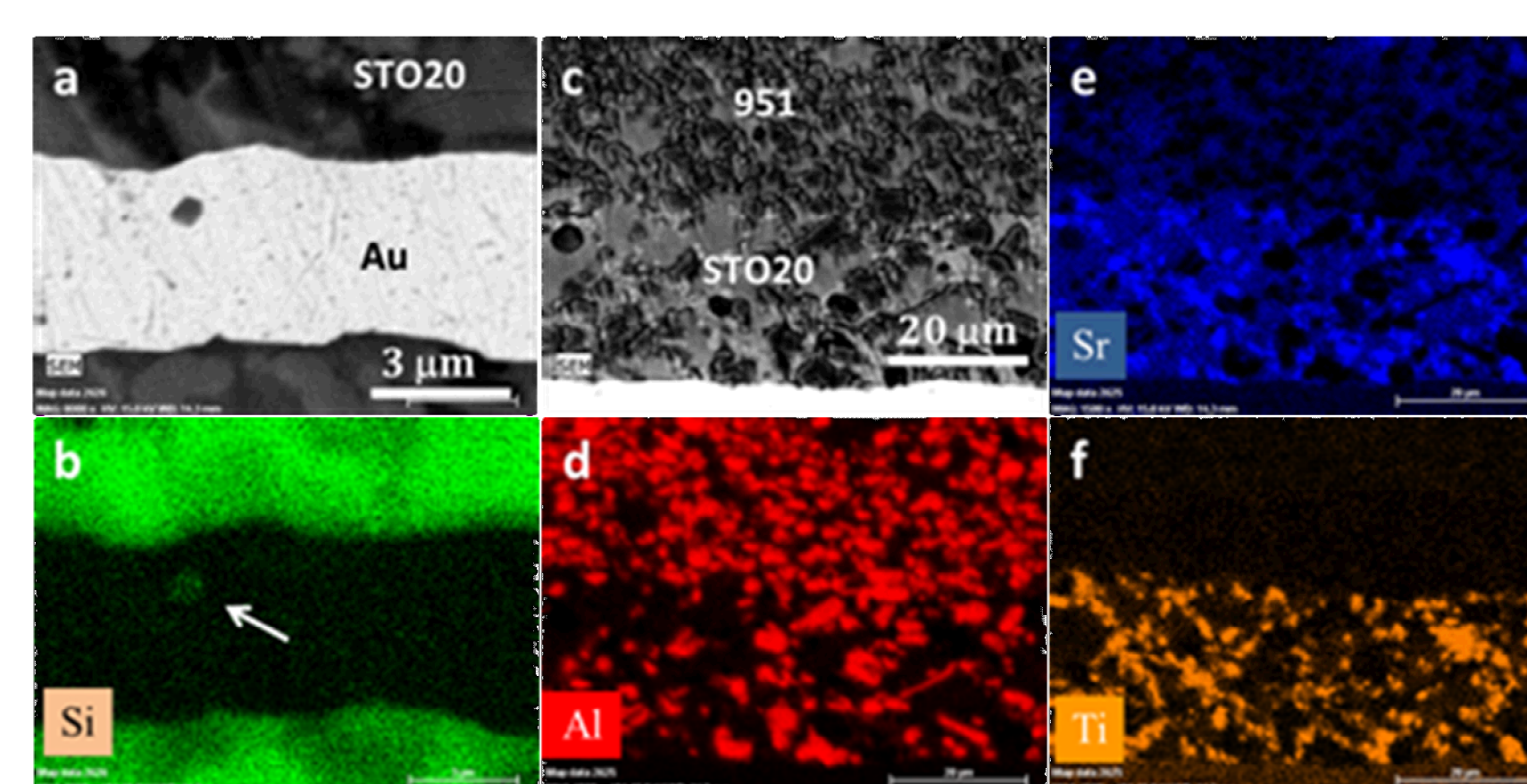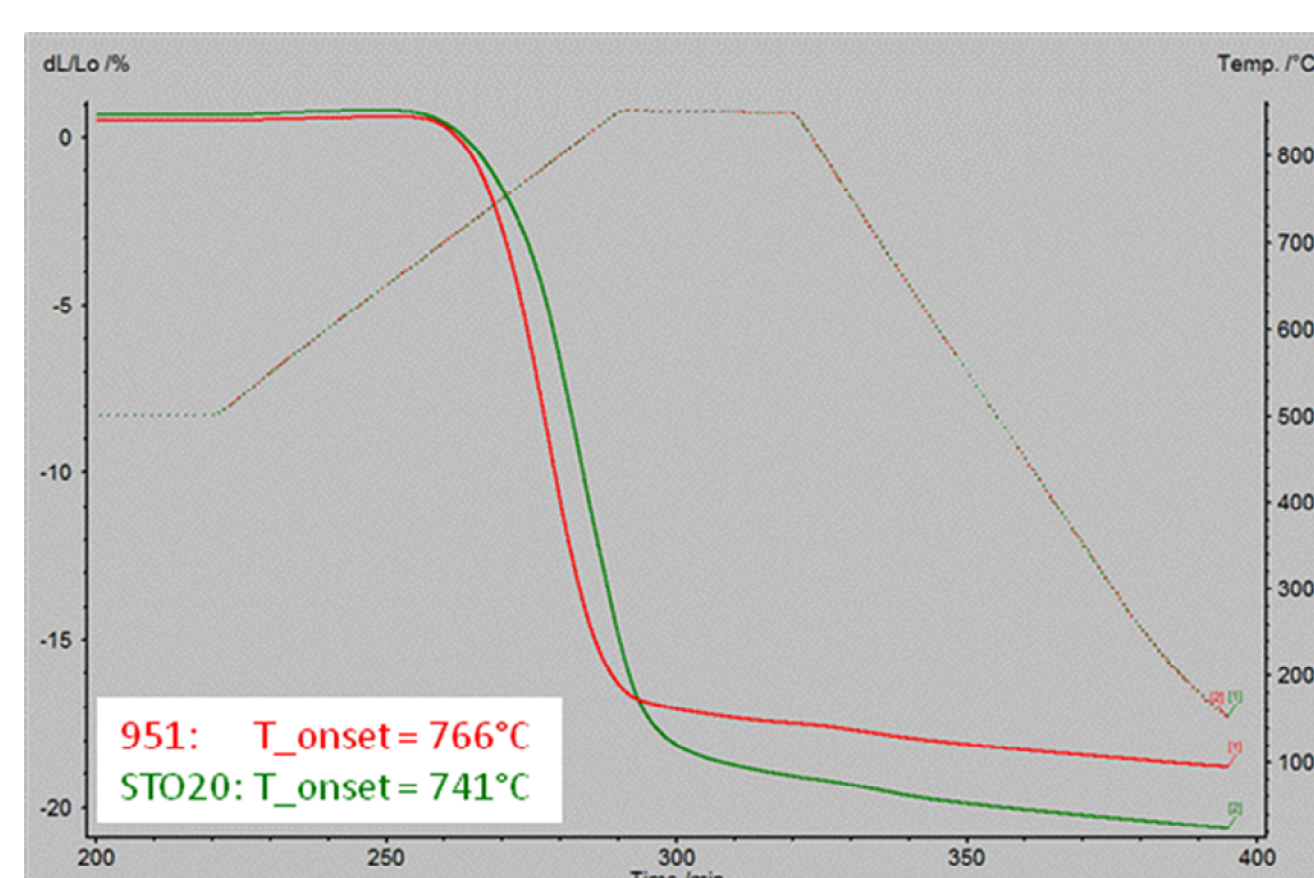
Summary/Impact

- τ_f compensating materials compatible to existing 951 LTCC have been successfully developed
- Stripline resonators with localized $0\tau_f$ have been demonstrated
- Energy concentration in compensating dielectrics is critical for effective τ_f adjustment
- Provide a material-science based engineering solution for Sandia mission critical radio-frequency applications, as well as an enabling technology for wireless industry
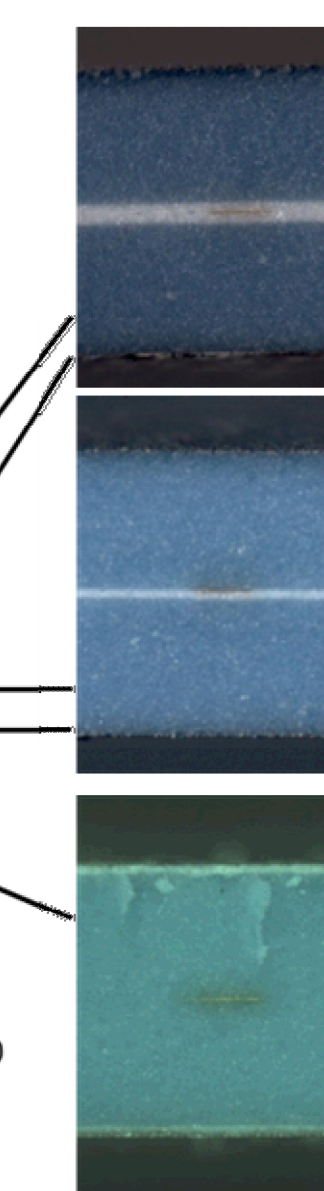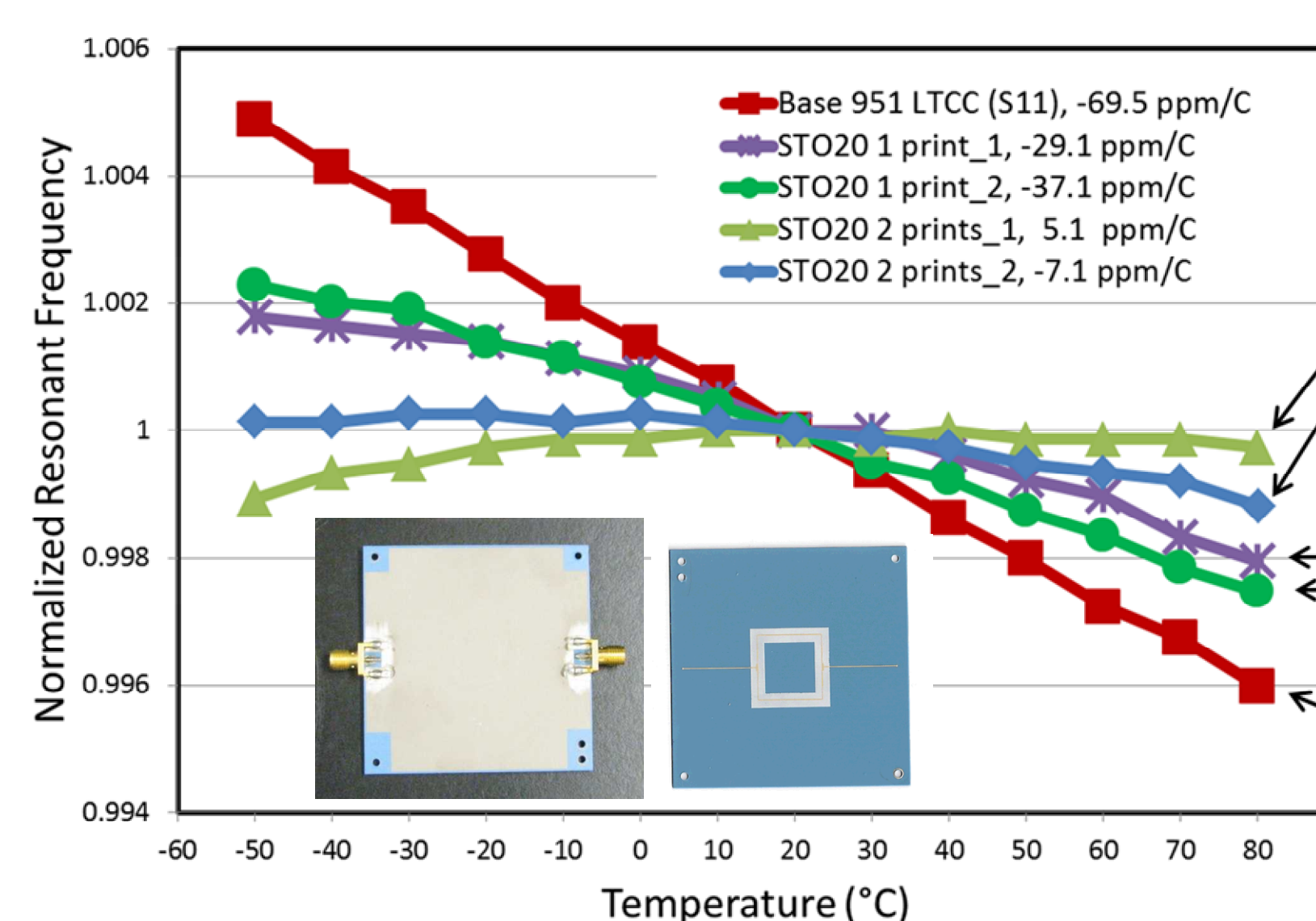
U.S. DEPARTMENT OF ENERGY — NNSA National Nuclear Security Administration

Key Accomplishment

τ_f compensating dielectrics

Composition	V- Glass (wt%)	Al$_2$O$_3$ (wt%)	SrTiO$_3$ (wt%)	Density (g/cc)
Base	55	45	0	3.19
STO10	55	35	10	3.21
STO20	55	25	20	3.30
STO25	55	20	25	3.31
STO30	55	15	30	3.35

τ_f compensated SL resonators

Base 951 LTCC (S11), -69.5 ppm/C
STO20 1 print_1, -29.1 ppm/C
STO20 1 print_2, -37.1 ppm/C
STO20 2 prints_1, 5.1 ppm/C
STO20 2 prints_2, -7.1 ppm/C

Compo-sition	STO (µm)	τ_f (ppm/°C) C_1	C_2	C_3
STO20	20	-28.8	-67.5	-71.2
	40	1.9		
STO30	20	1.0	-61.7	-69.3
	40	60.0	-54.8	-62.3

Case 1
Case 2
Case 3

951 tape
STO dielectric paste
Au print and Via
Ground plane
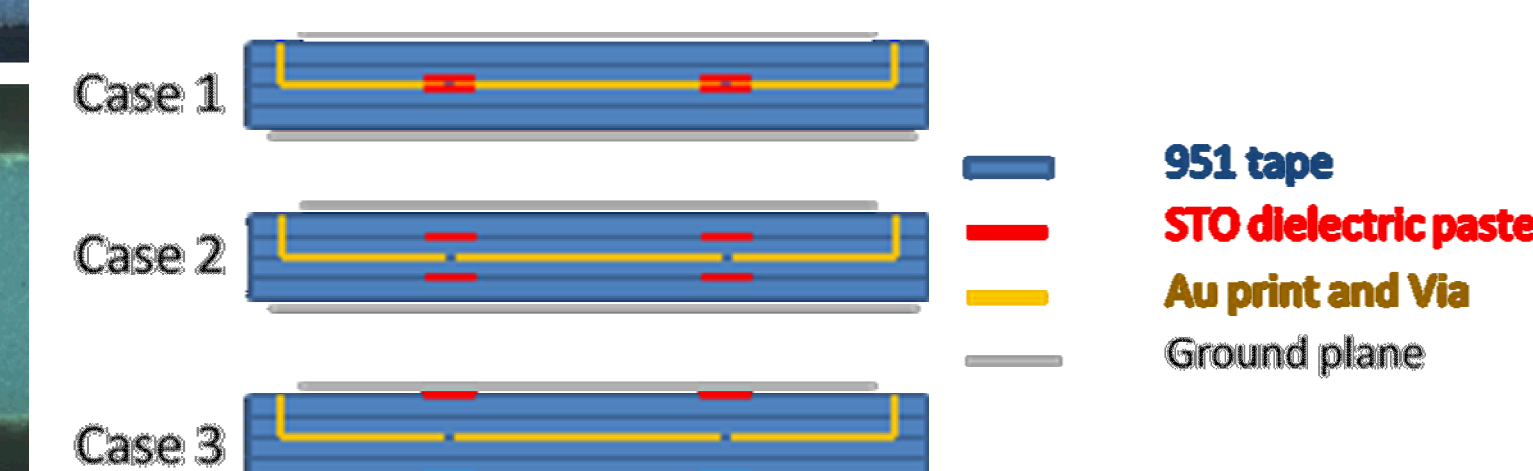
Energy concentration and effective τ_f com

$$\tau_f = \sum_i P_i \tau_{fi} \qquad P_i = E_i/E_{total}$$

951 LTCC — STO — Au — θ_c
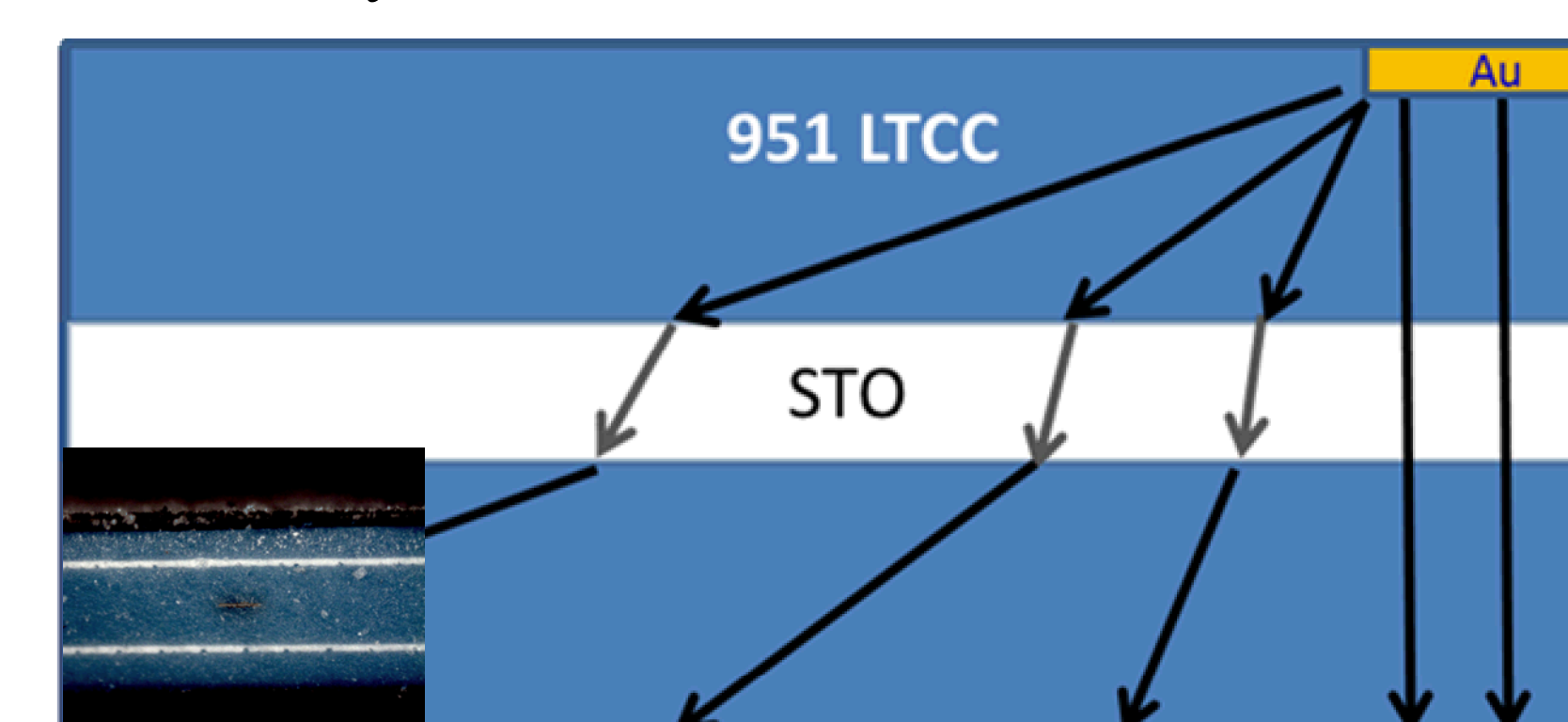
No energy concentration in STO → less t_f adjustment
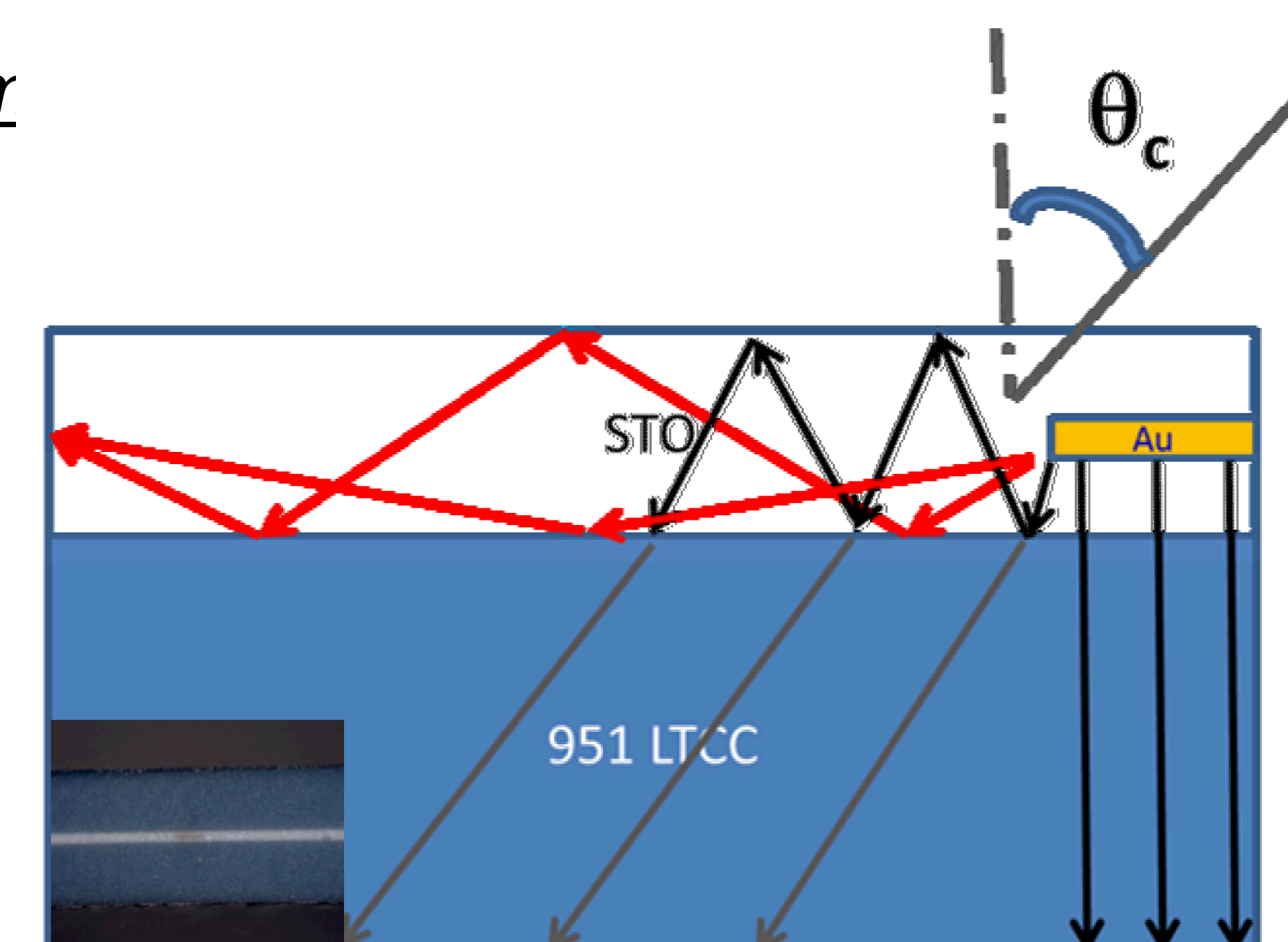
Energy concentration in STO from total internal reflection → $0t_f$

Proof-of-Concept S-band filters

STO layers

With 20 mm STO30, τ_f = 1.8 ppm/°C
Without STO, τ_f = -71.2 ppm/°C