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Glass and glass-ceramics for wireless communication

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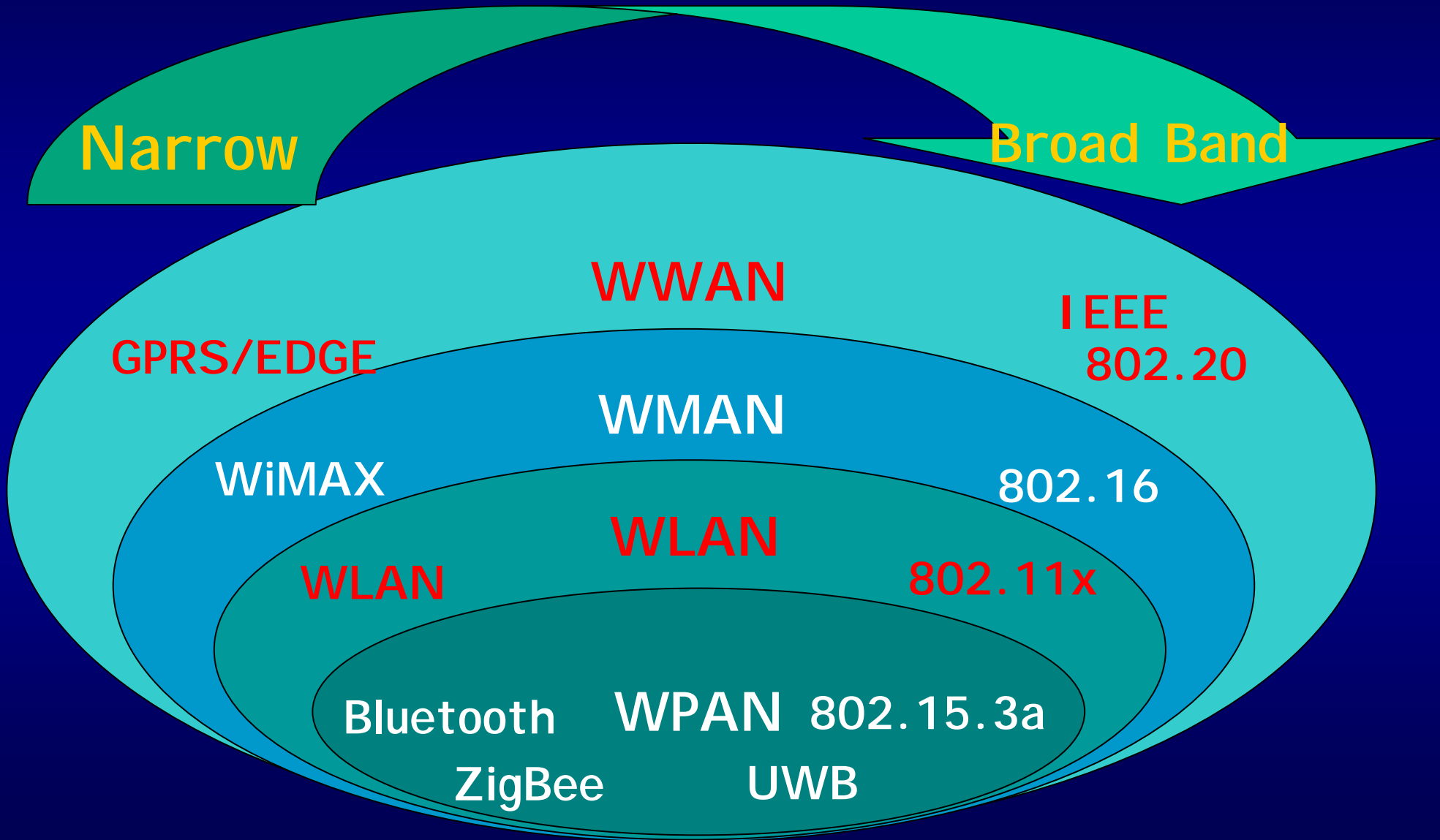
Glass and Glass-Ceramics for Wireless Communication

J.H. Jean

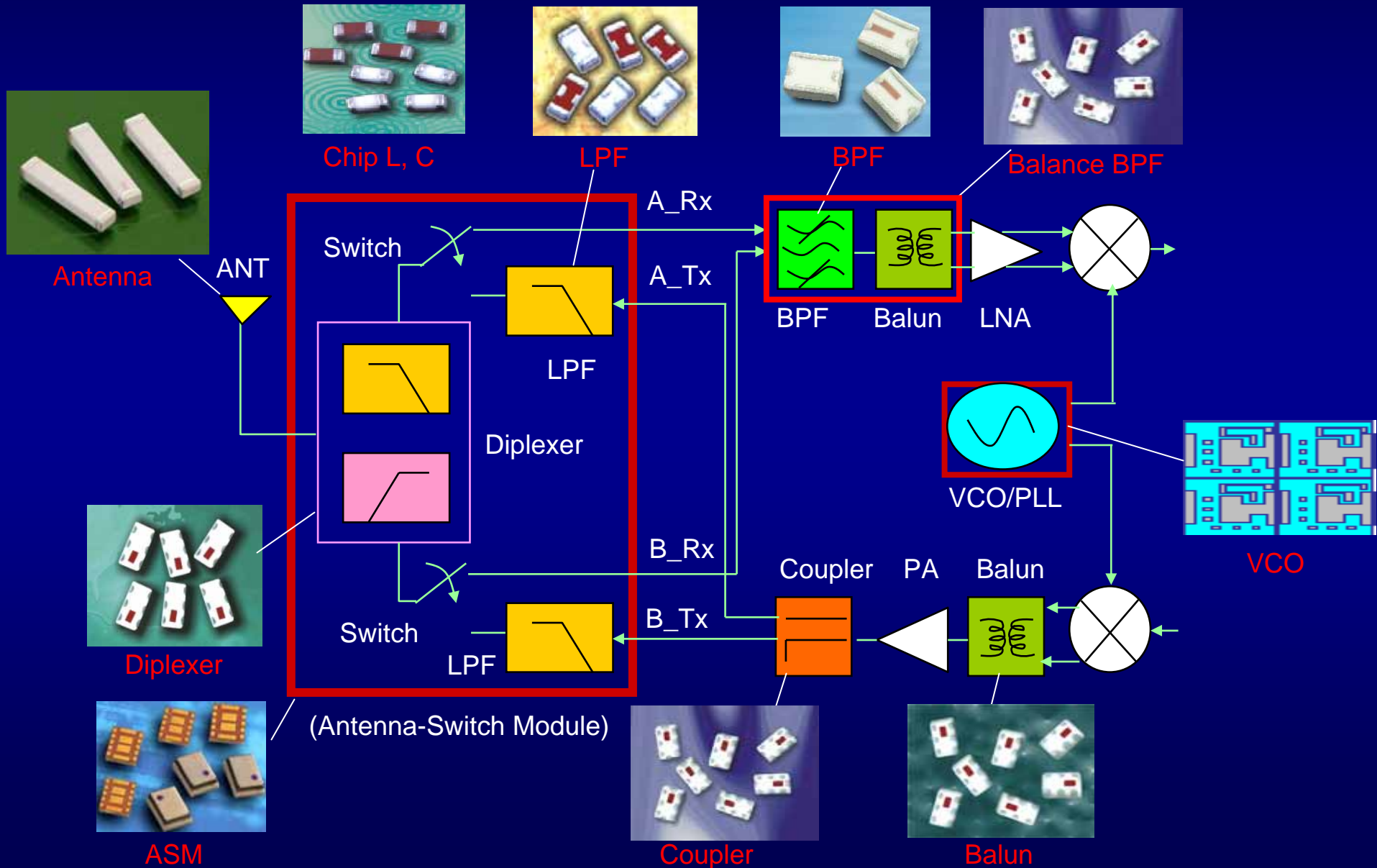
**Dept. Materials science and Engineering
National Tsing Hua University**

Hsinchu, Taiwan

Wireless Wonders

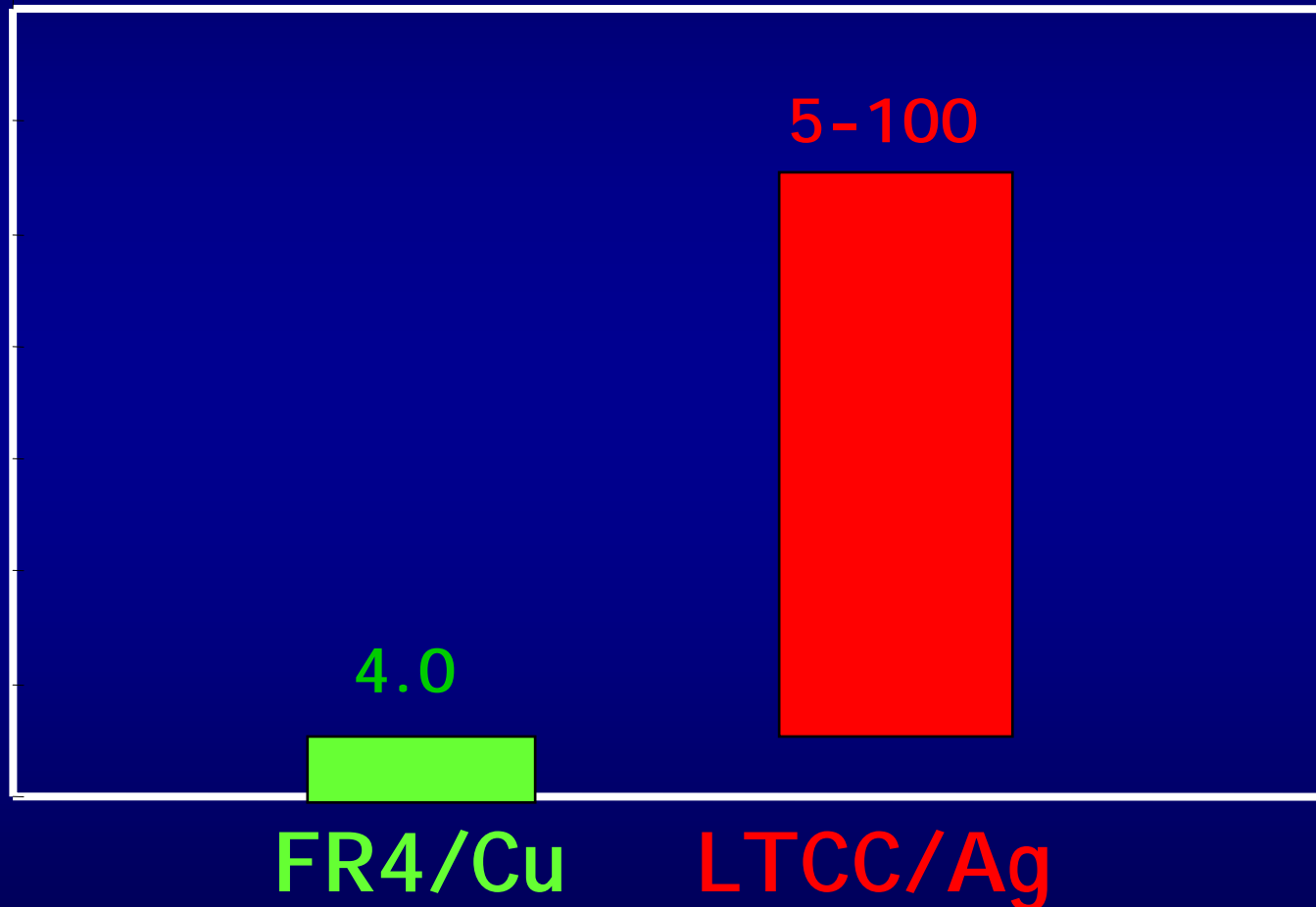


LTCC devices for RF Front-end



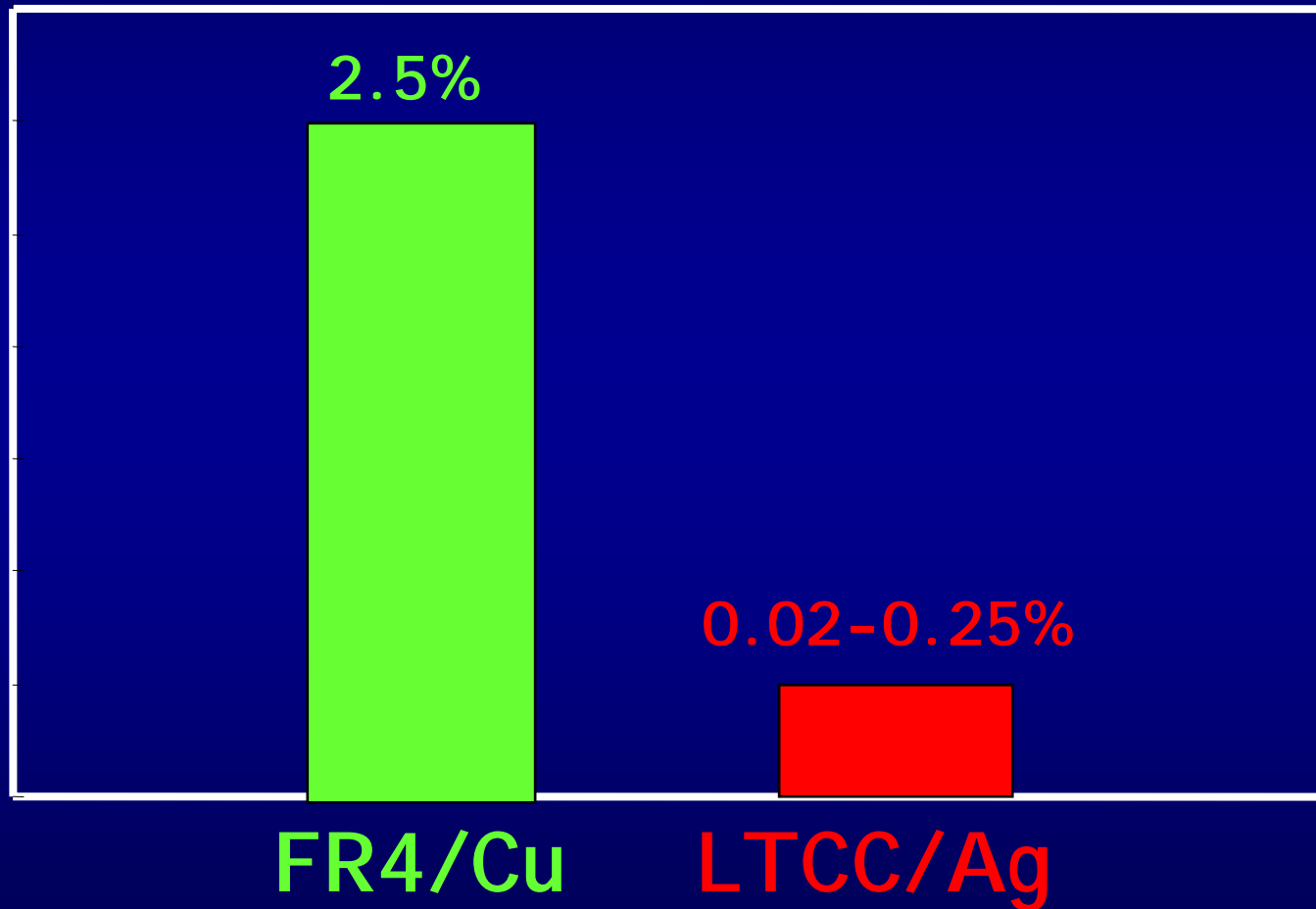
Why Ceramics ????????

Dielectric Constant



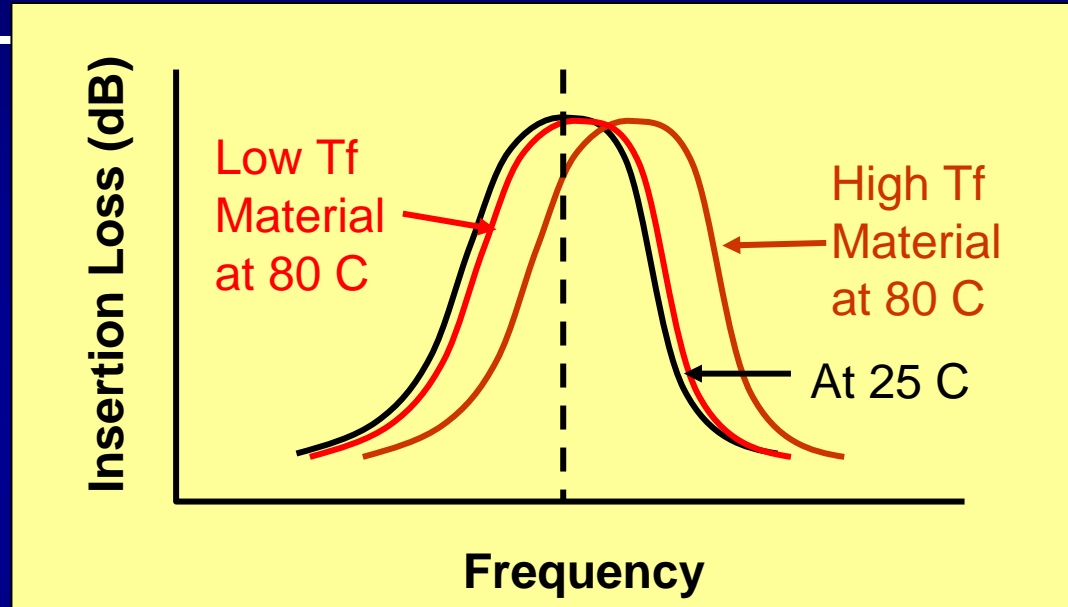
@4GHz

Dielectric Loss



@4GHz

Temp. Coefficient of Resonant Frequency (T_f)



$$T_f \approx -1/2 T_k + TCE$$

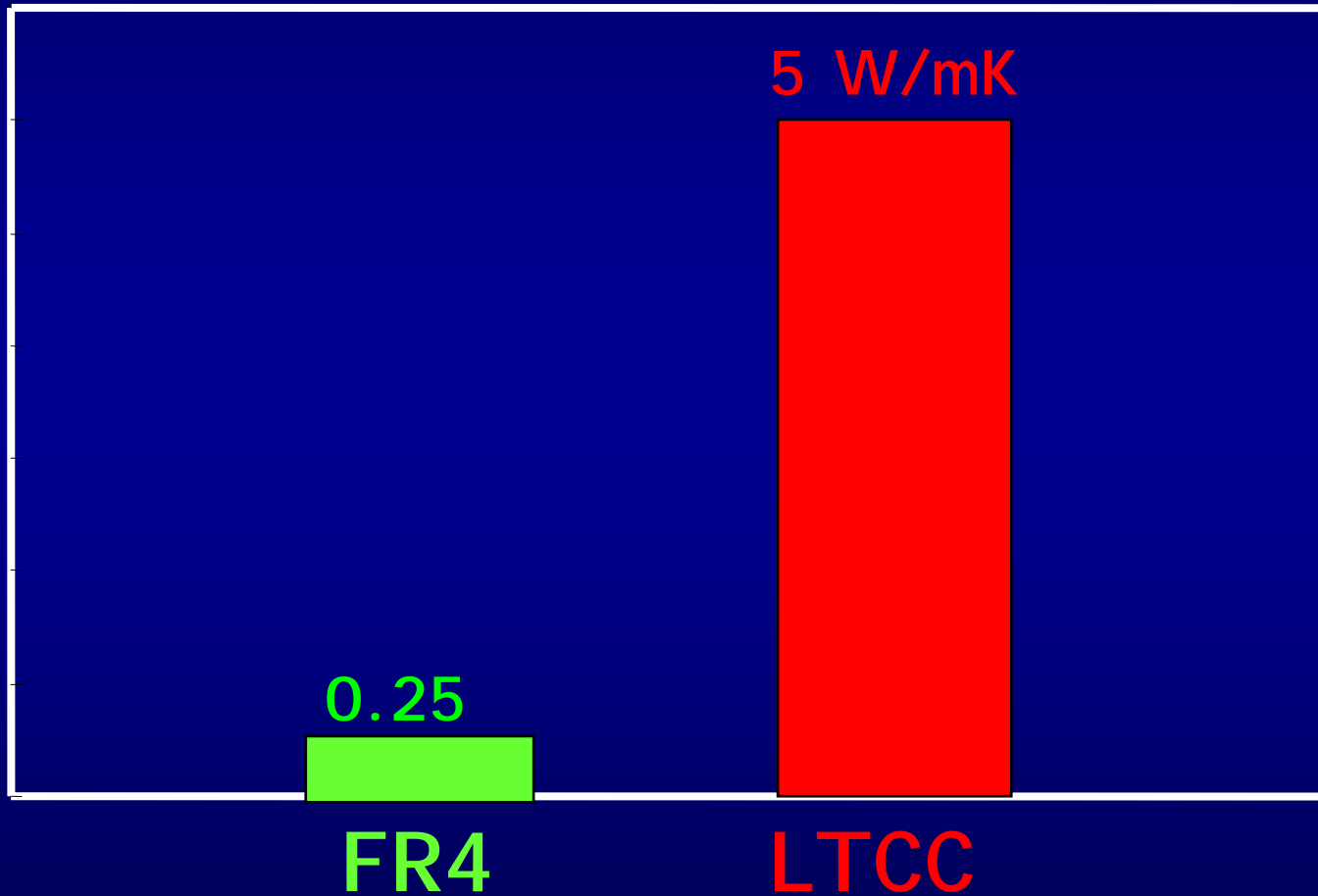
T_k : Temp. coefficient of capacitance

TCE: Thermal expansion coefficient

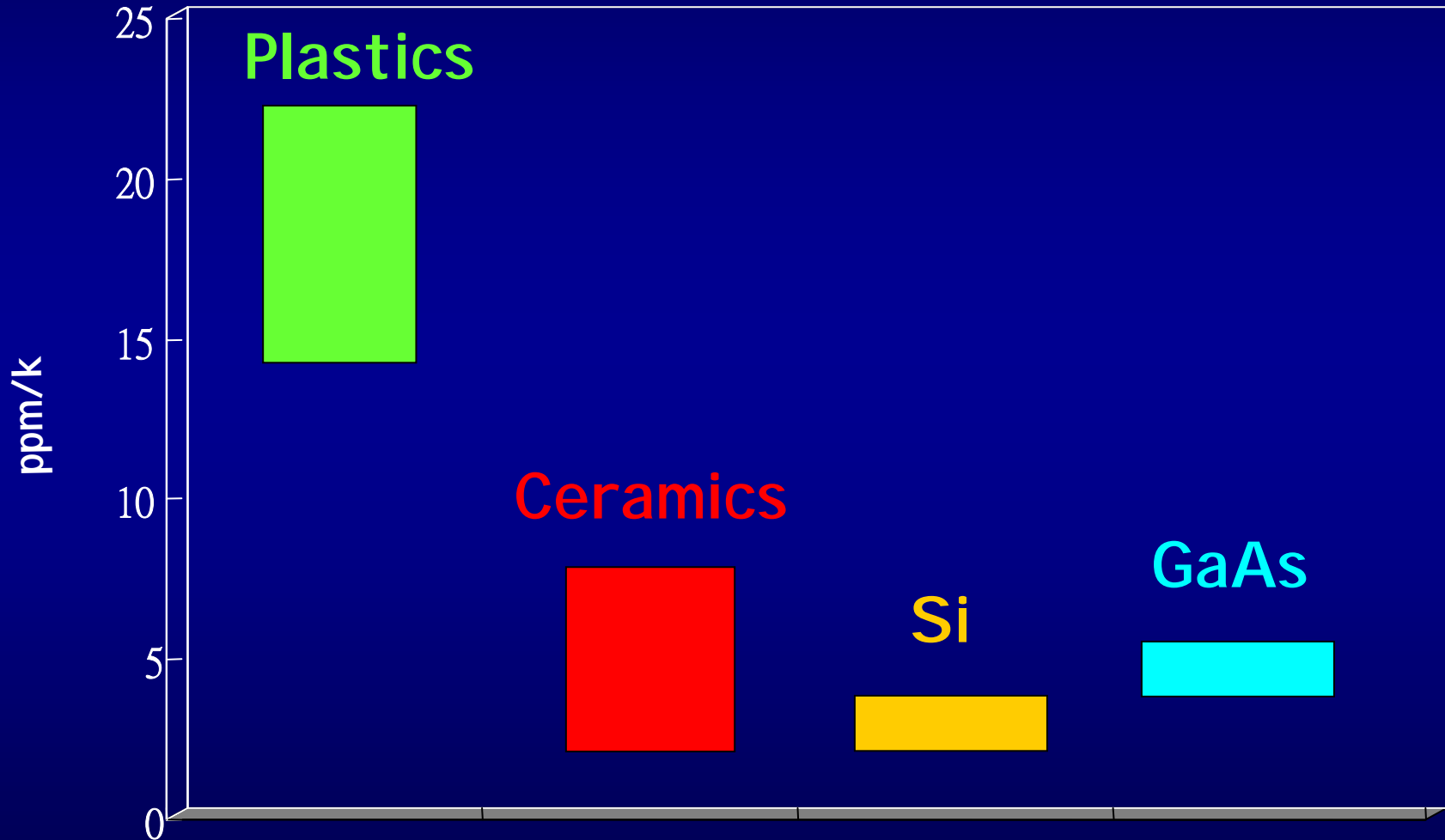
FR4/Cu

LTCC/Ag

Thermal Conductivity



Thermal Expansion Coefficient



Why LTCC ??????????

LTCC

Low Temperature Cofired Ceramics



<1000 °C

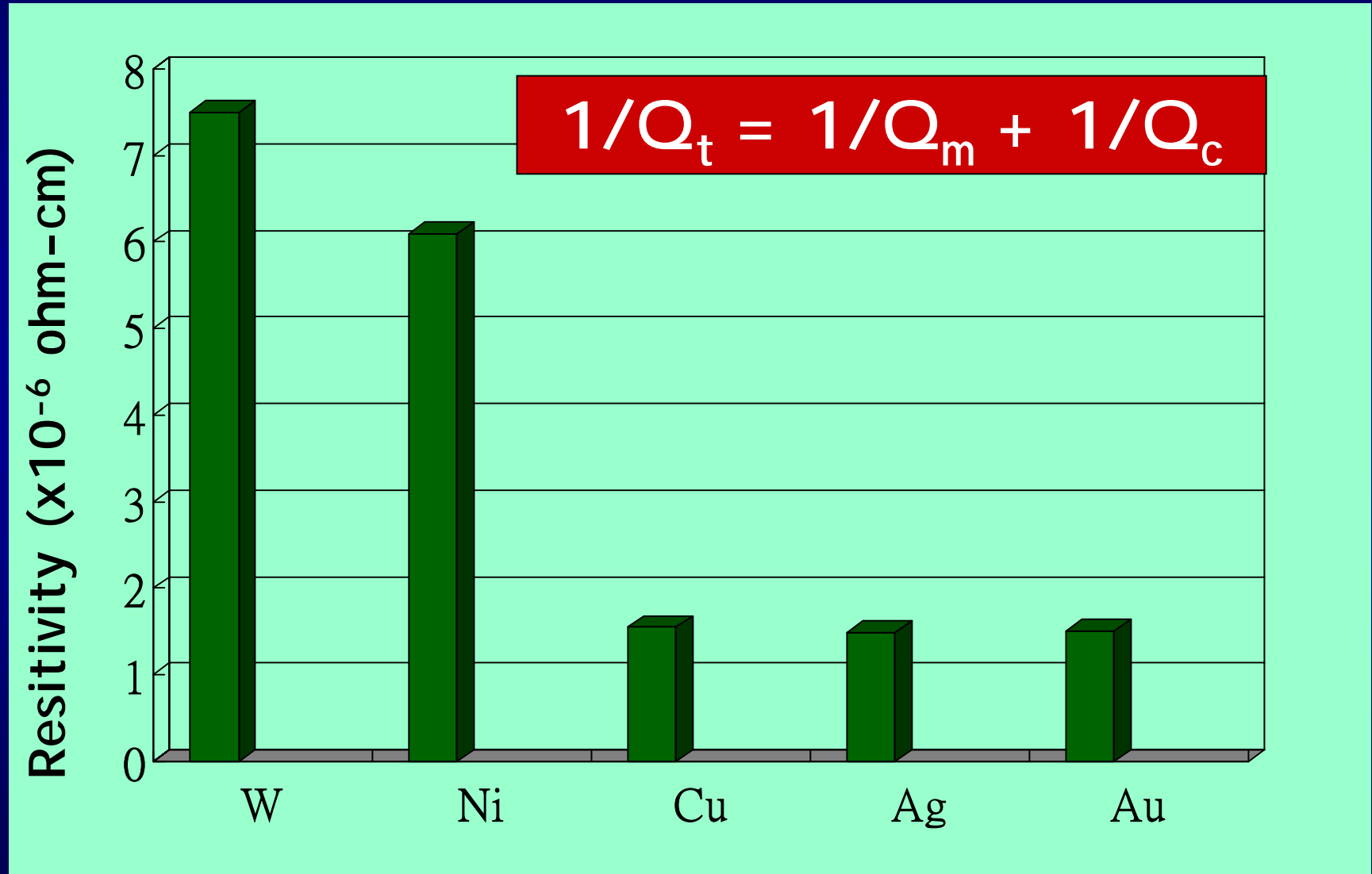


One fire

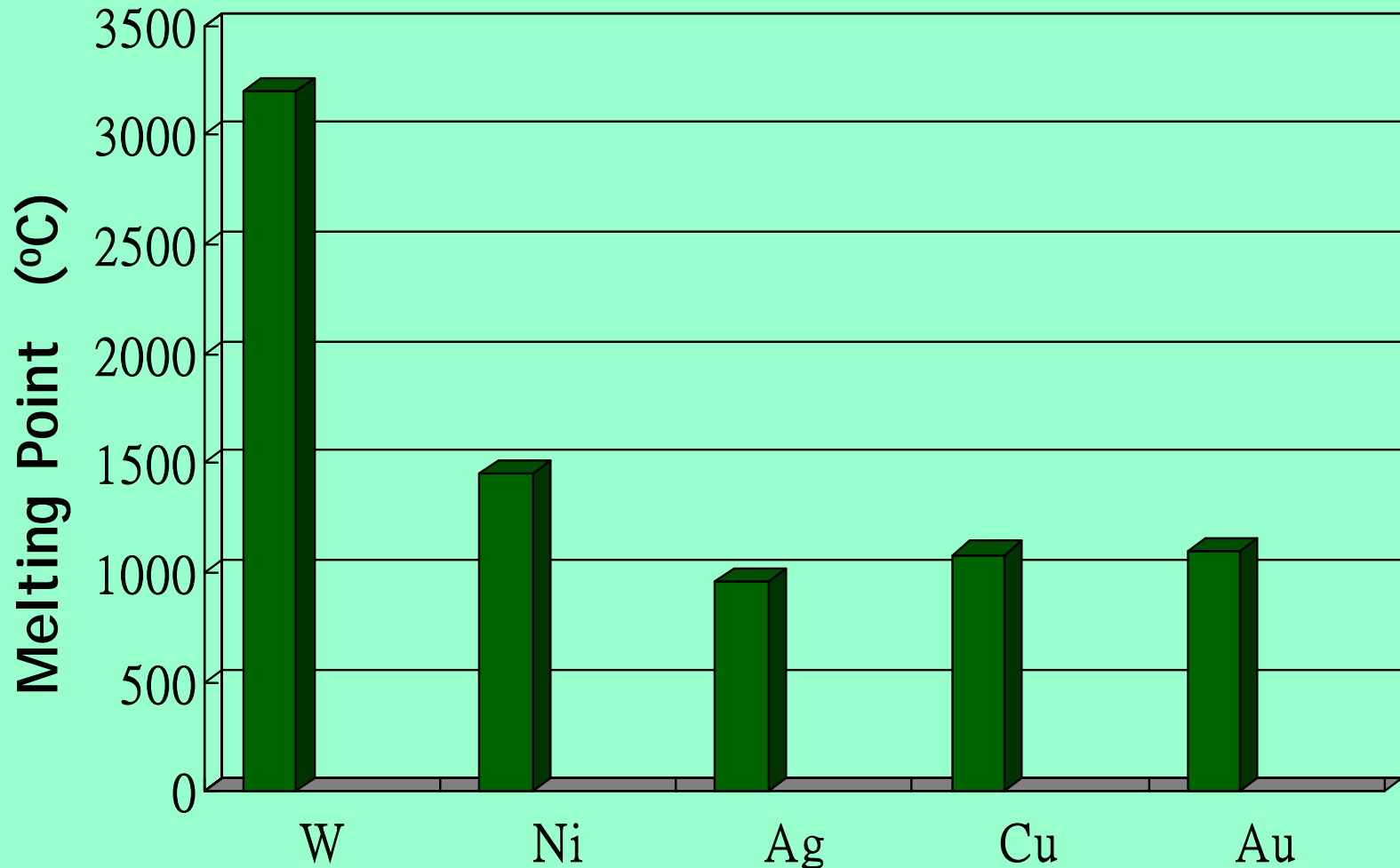


Ceramic base

Electrical Resistivity of Conductors



Melting Point of Conductors



LTCC Materials and Processes

Dielectric:

- * Glass-Ceramics, Glass+ceramics
- * Dielectric Constant: 5-100
- * Dielectric Loss: 0.01-0.5%

Conductors: Ag, Cu and Au

Resistors: RuO₂+Glass

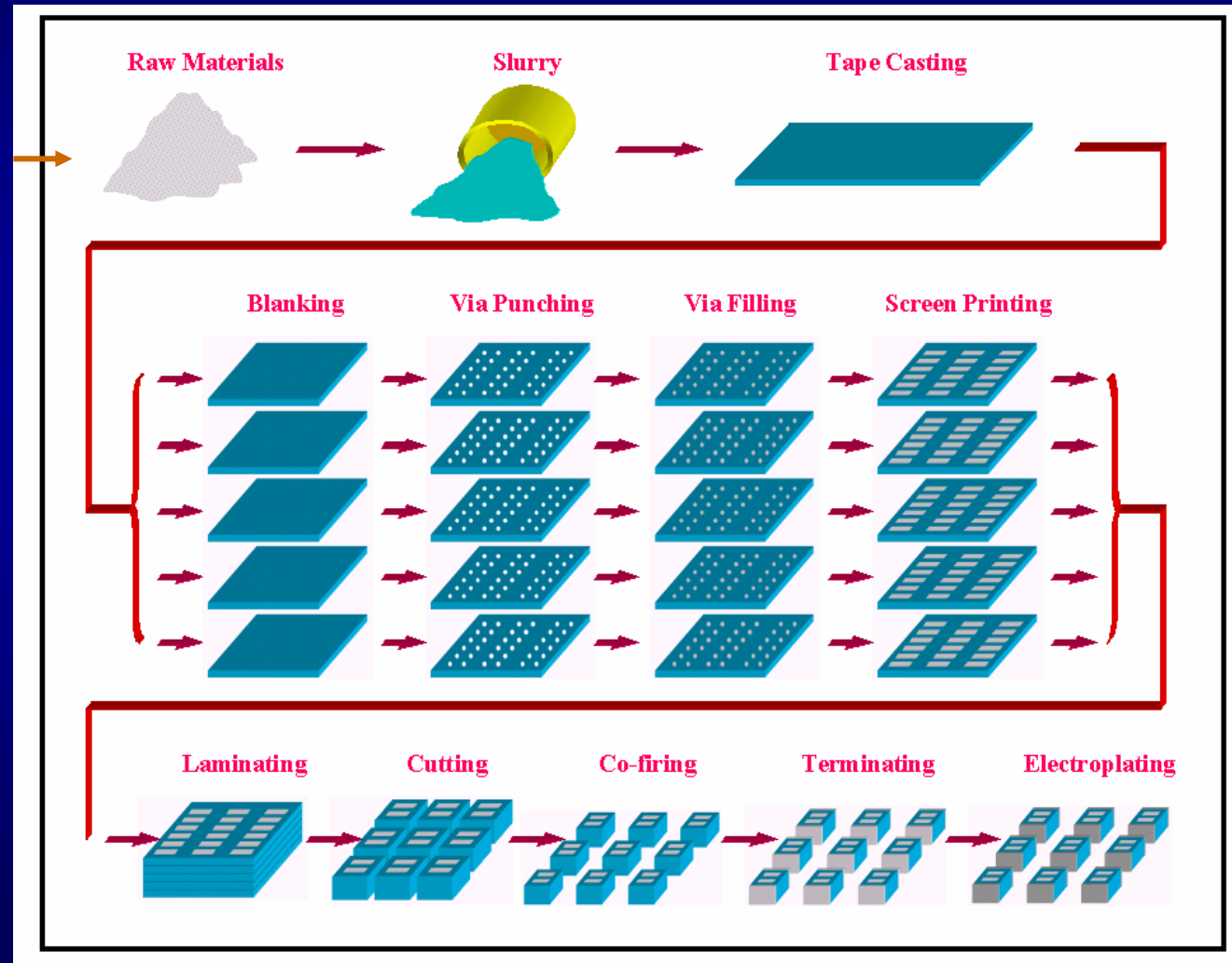
Firing conditions:

- * Temp.: 800-1000°C
- * Time: 10-60 min
- * Atmosphere: Air, H₂+N₂+H₂O

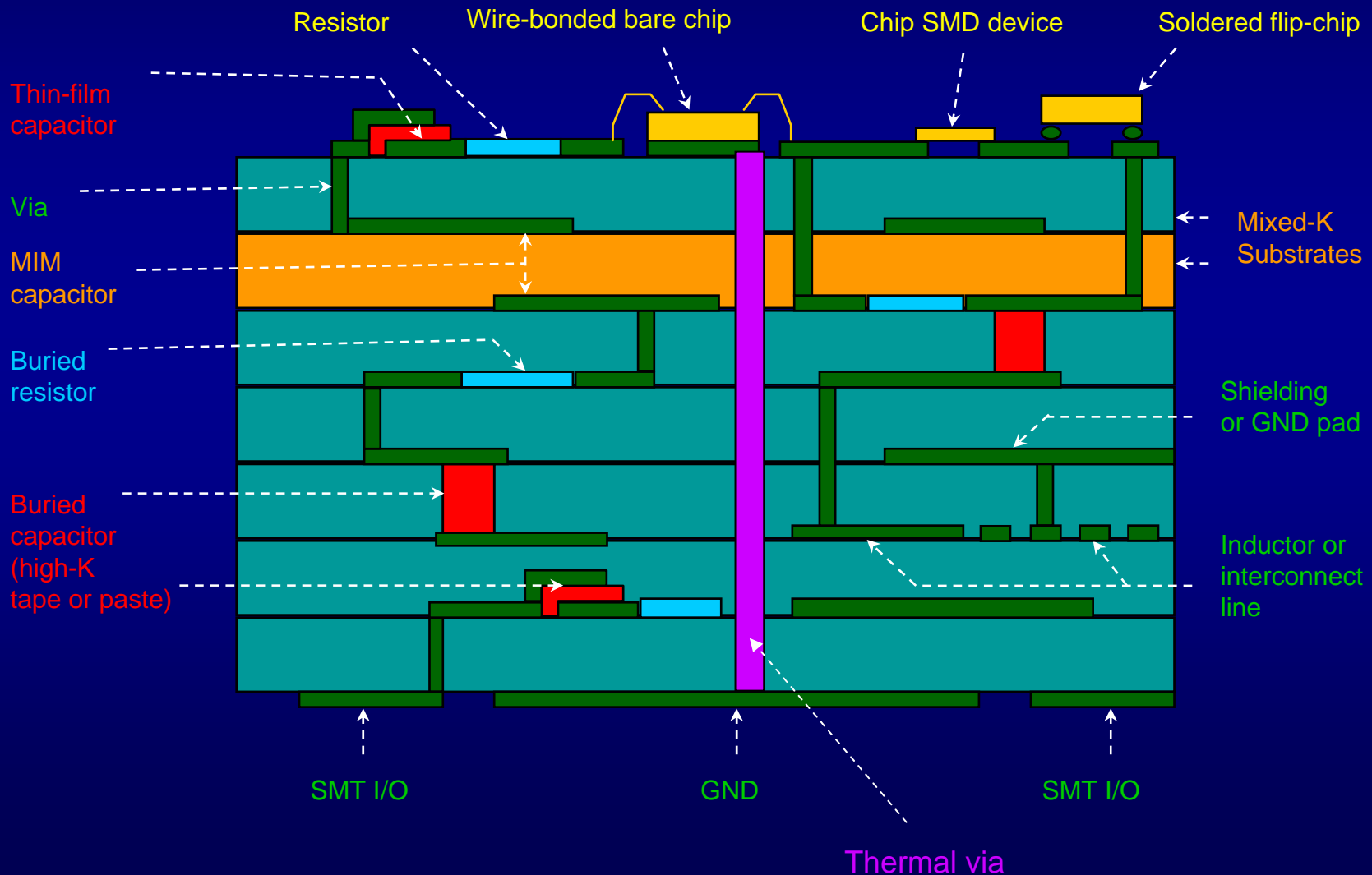
Low Temperature Cofired Ceramics

⌞ <1000 °C

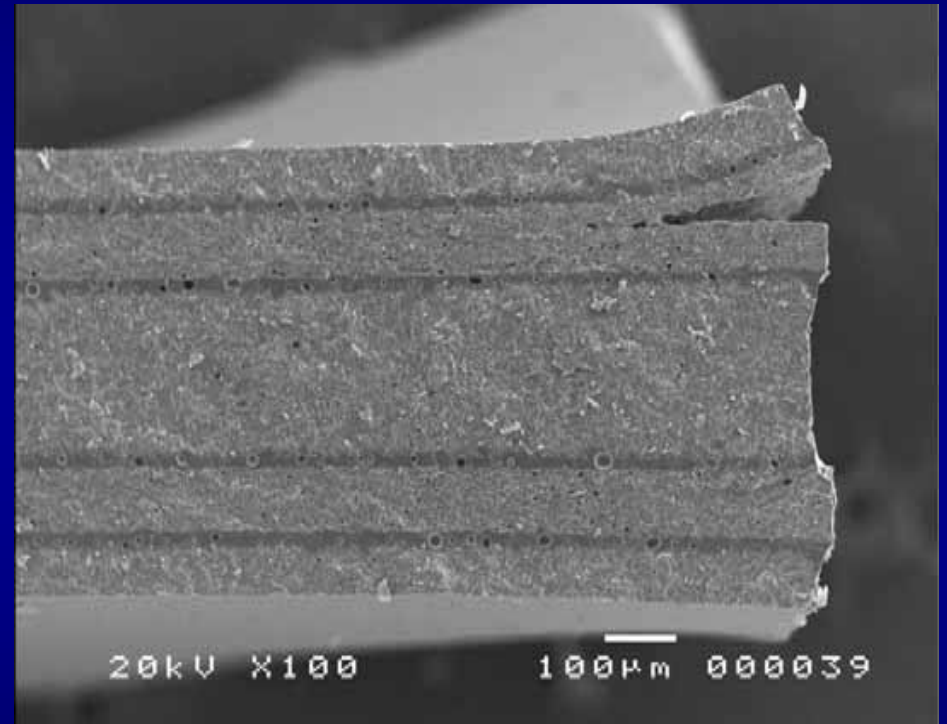
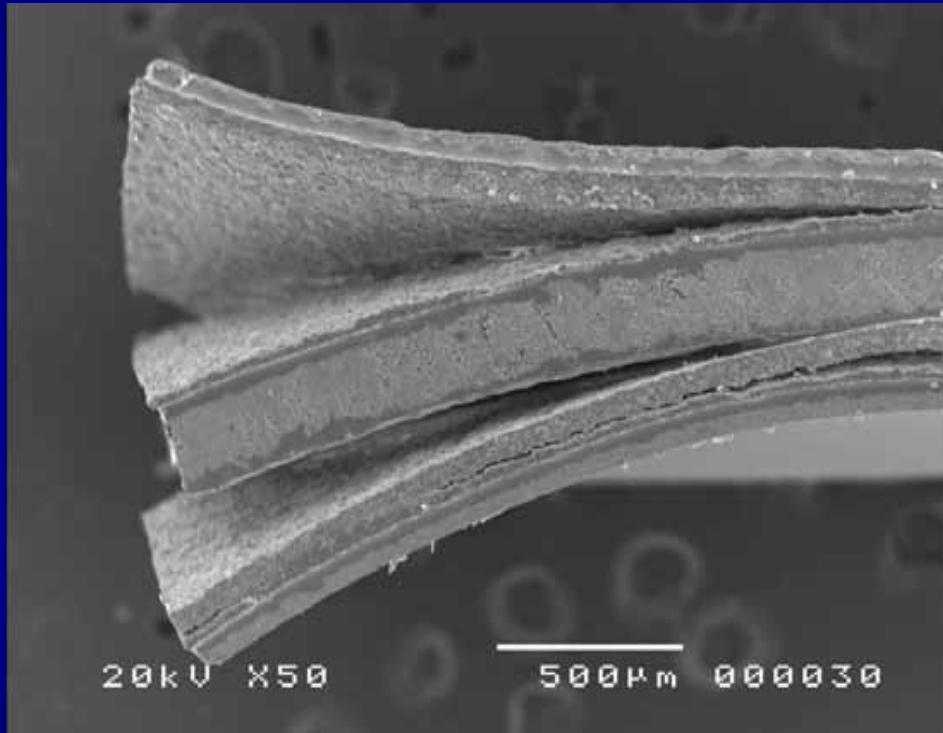
⌞ One fire ⌞ Ceramic base



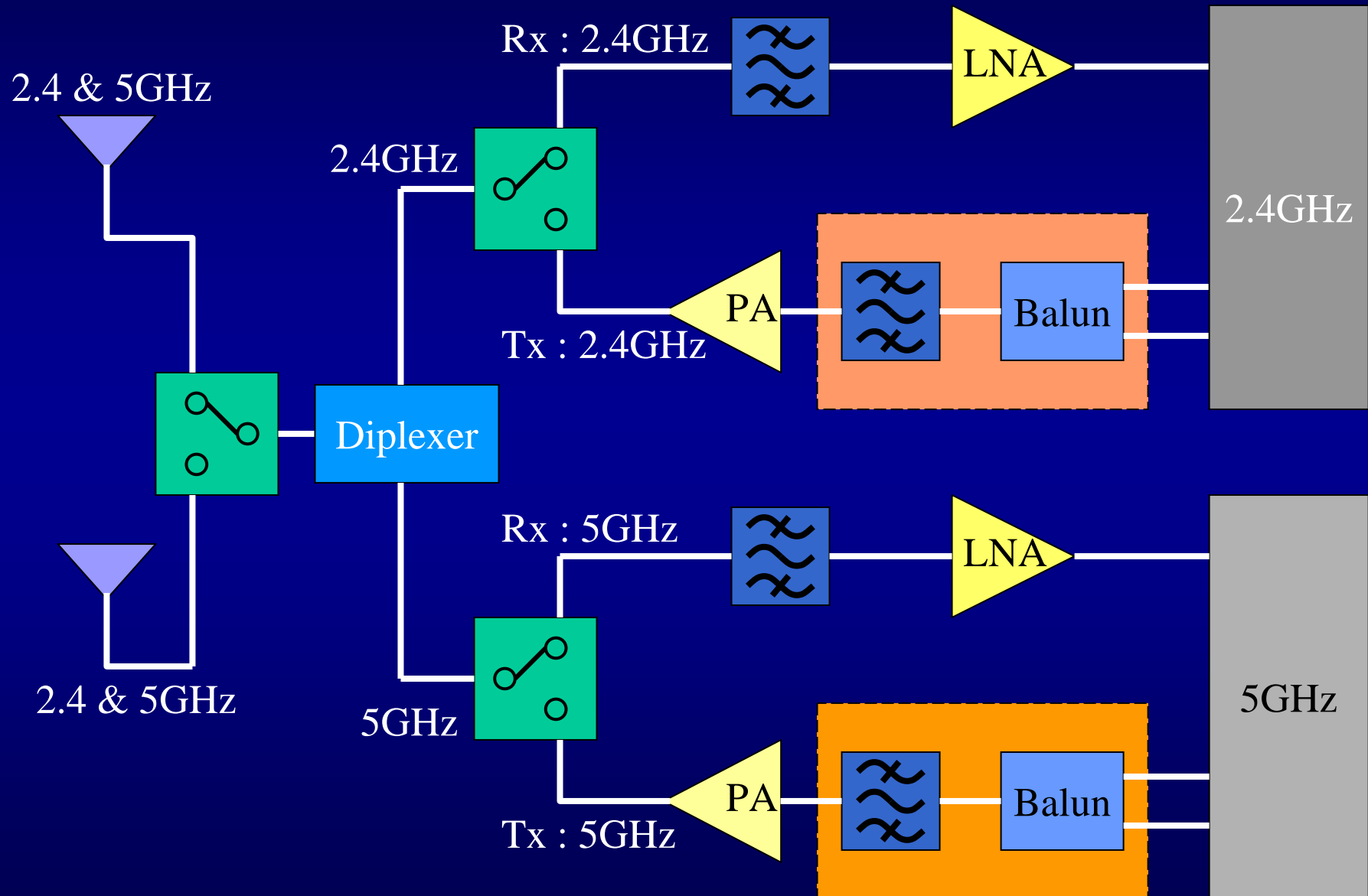
Integrated RF Module



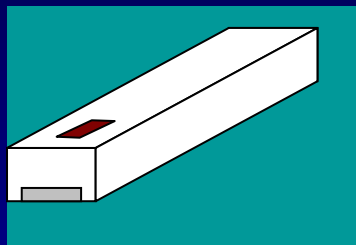
Cofiring Defects



WLAN 802.11a+b+g



LTCC Solutions to Bluetooth



Chip Antenna



Band Pass Filter



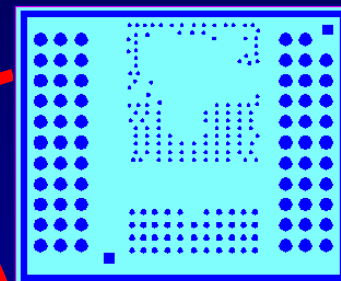
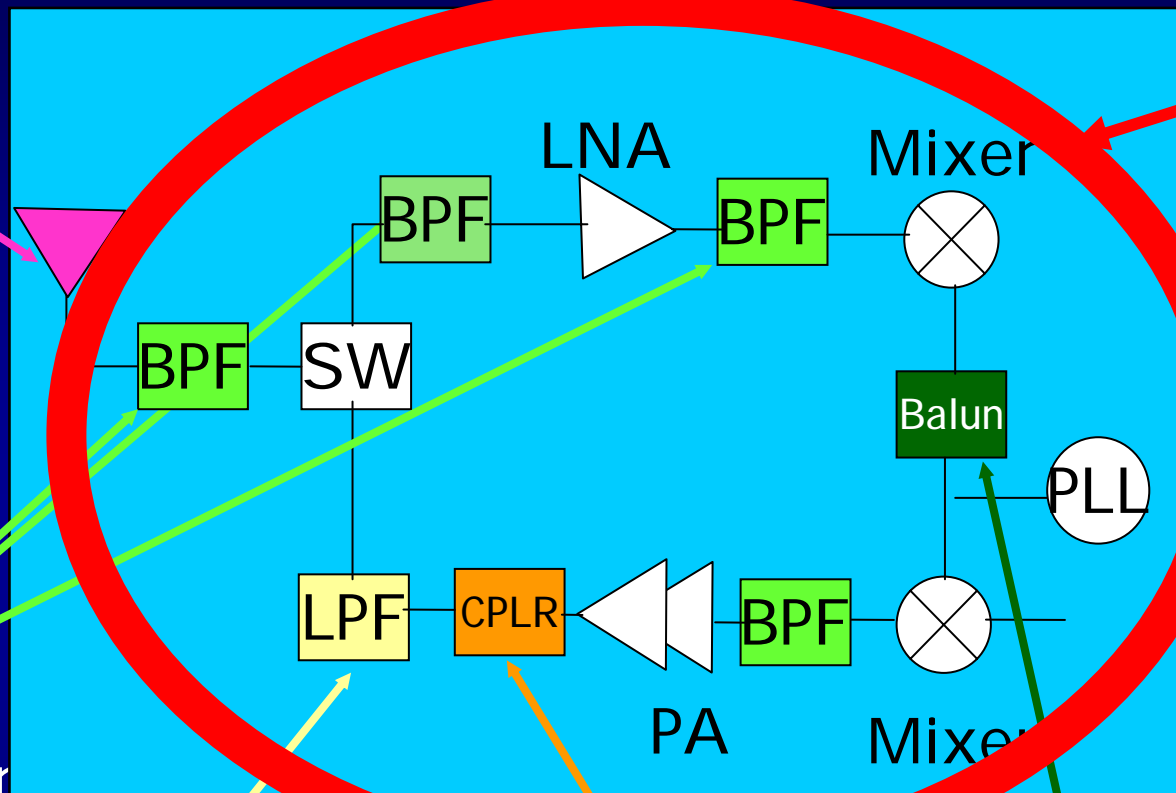
Low Pass Filter



Coupler



Balun

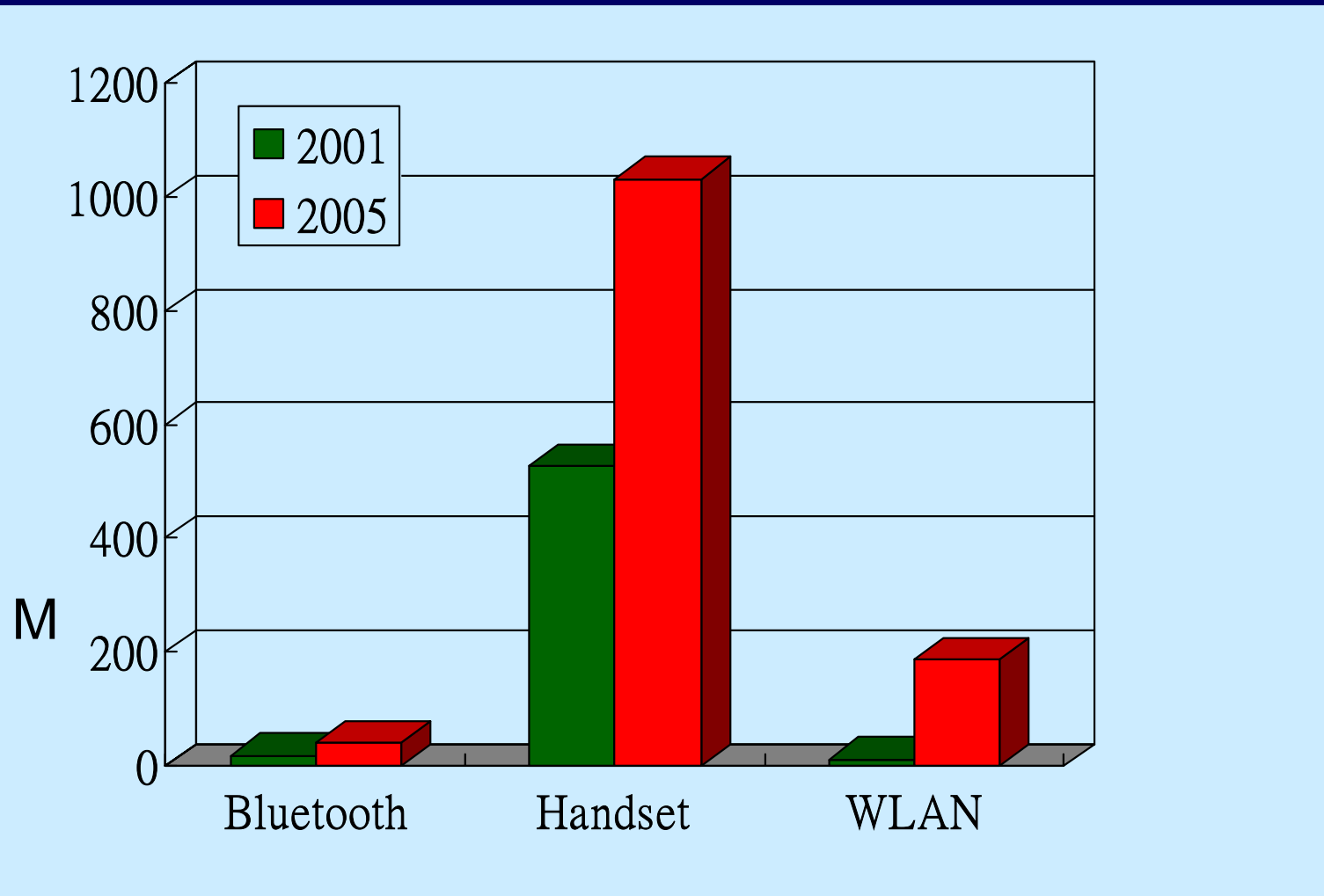


Module



Inductors

LTCC Market in Wireless Communication



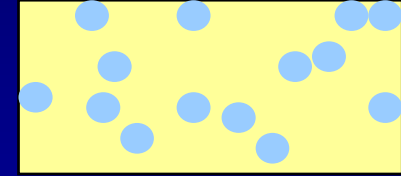
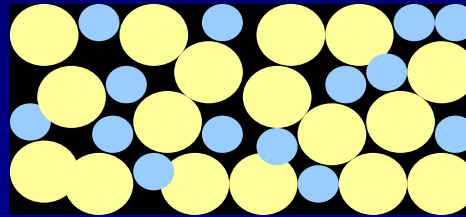
Design of LTCC Compositions

Green

Sintered

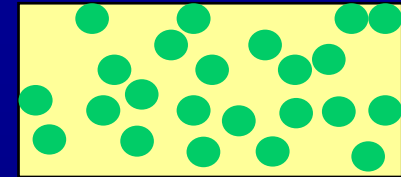
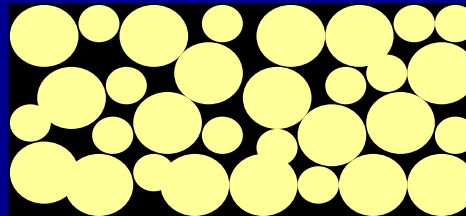
Type 1: Glass+Ceramics

e.g., DuPont 951



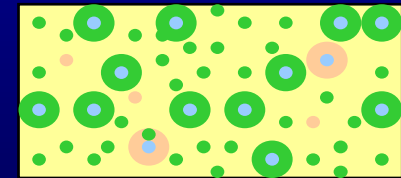
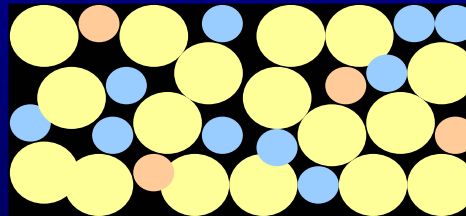
Type 2: Glass-Ceramics

e.g., Ferro A6



Type 3: Glass±Ceramics

e.g., Heraeus CT2000



Glass



Al_2O_3

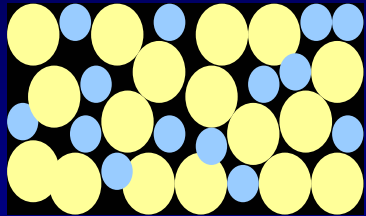


Crystalline phase



Filler

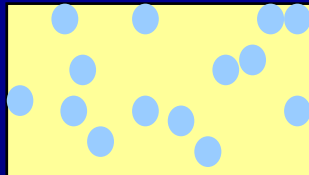
Type I: Glass+Ceramics



Glass: PbO, K₂O, B₂O₃, SiO₂
 V_{glass} : 60-70%

Ceramic Filler: Al₂O₃
 V_{Al2O3} : 30-40%

Sintering
 850~ 900 °C



Glass
 K=6-7
 Q= 100-150
 V_{glass}=60-70%

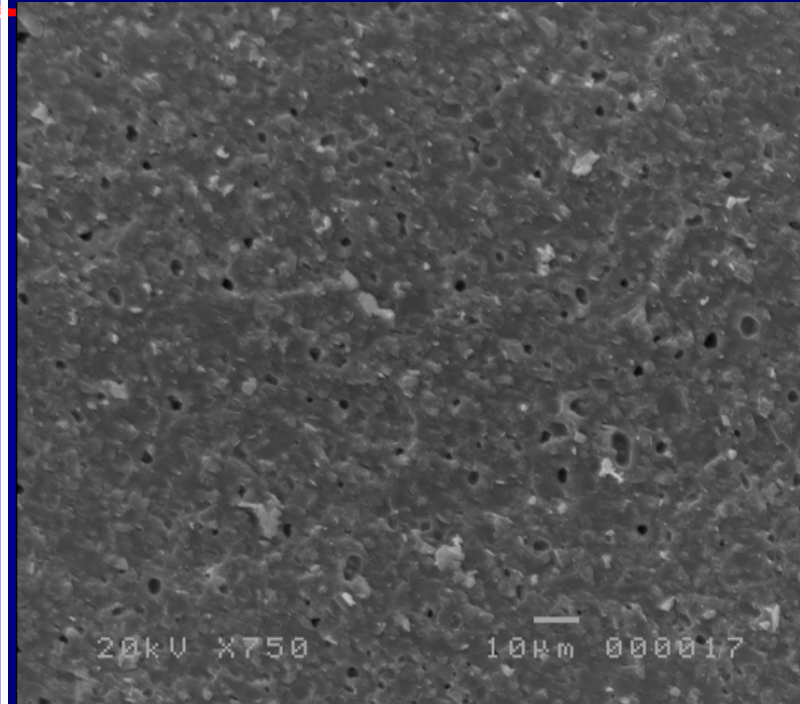
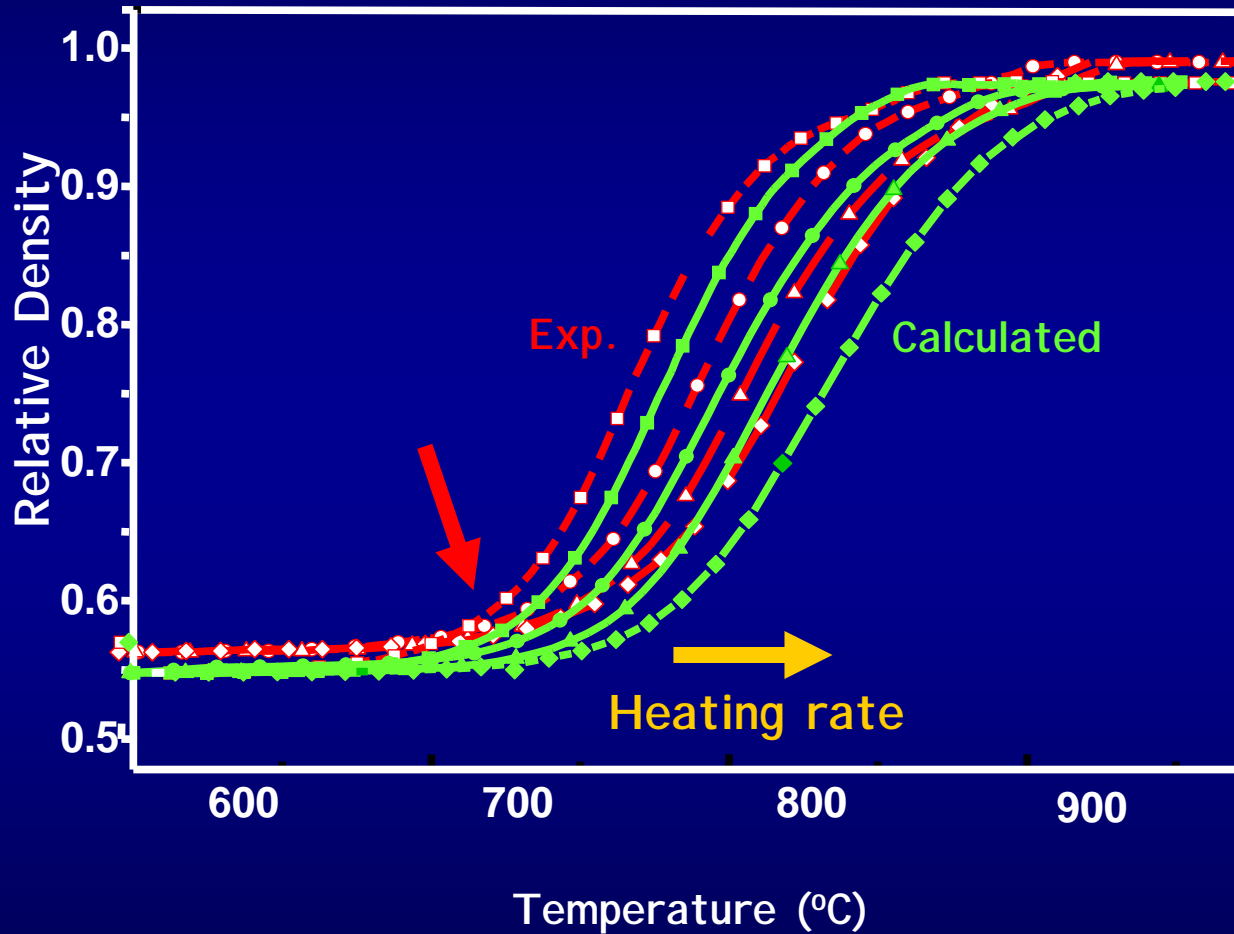
Al₂O₃
 K = 10
 Q = 10000
 V_{Al2O3} =30-40%

Dielectric Mixture

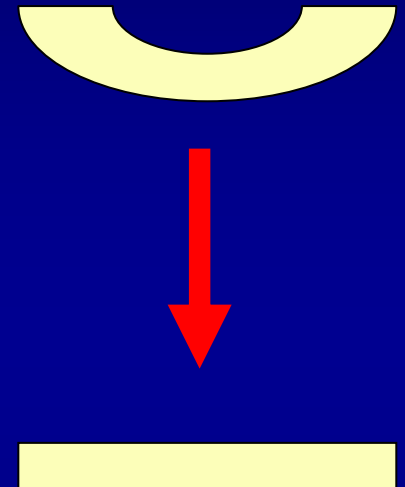
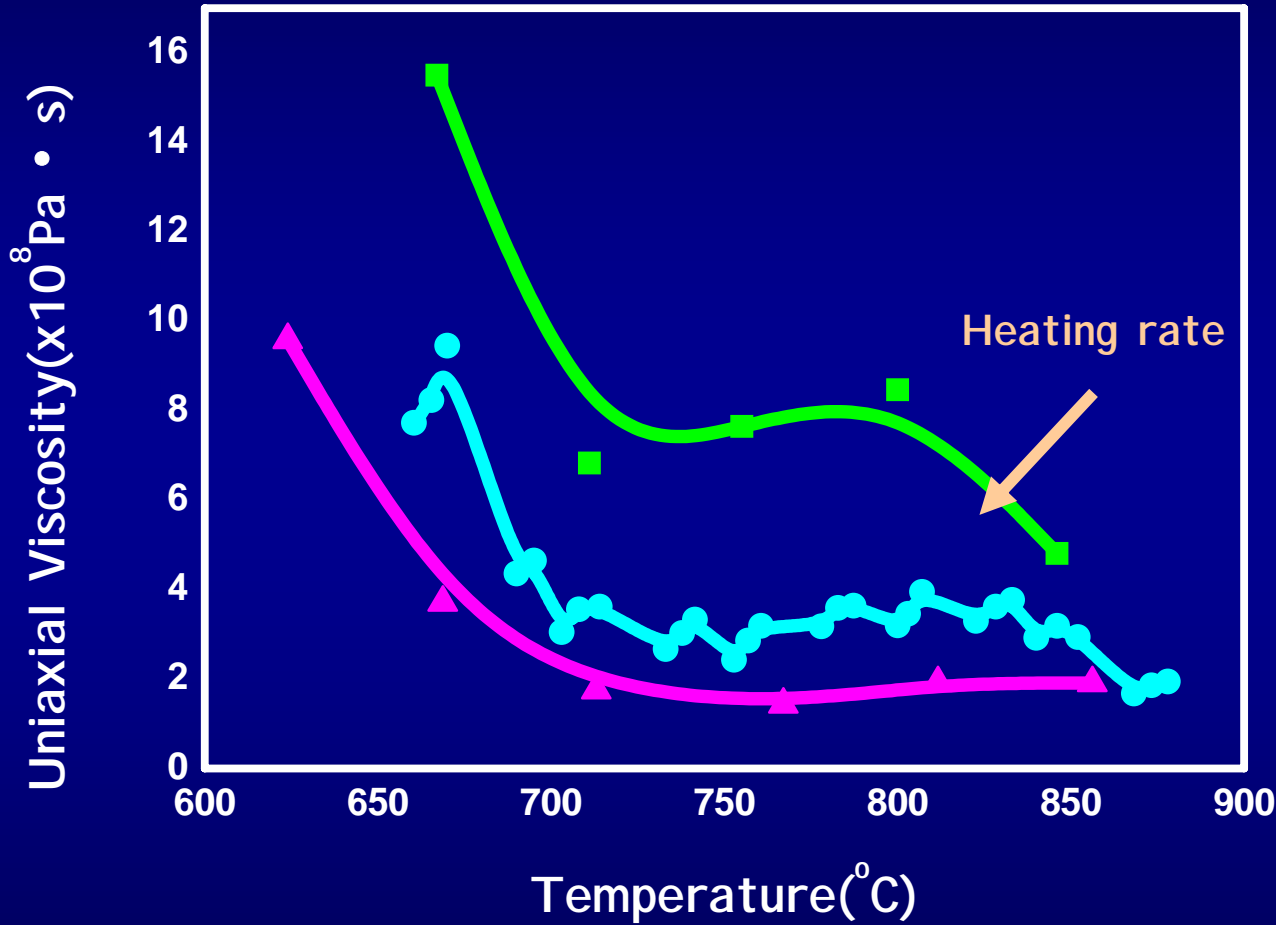
$$1/Q_m = (V/Q)_{\text{glass}} + (V/Q)_{\text{alumina}} \quad \mathbf{Q_m = 200-300}$$

$$1/K_m = (V*K)_{\text{glass}} + (V*K)_{\text{alumina}} \quad \mathbf{K_m = 4-8}$$

Densification of Glass+Ceramics

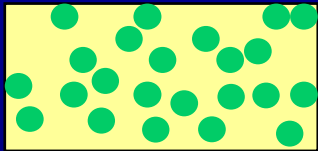
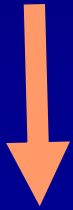
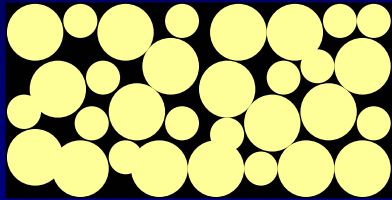


Uniaxial Viscosity (E_p)



Processing robustness
--“Fool-Proof” systems

Type II: Glass-Ceramics



Glass: CaO, K₂O, B₂O₃, SiO₂
 V_{glass} : 100%

Sintering
 850~ 900 °C

Residual glass: B-rich
 K=5-6
 Q= 100-150
 V_{glass}=20-40%

Wollastonite
 K = 5-6
 Q = 1000
 V_{Al₂O₃} =60-80%

Dielectric
 Mixture

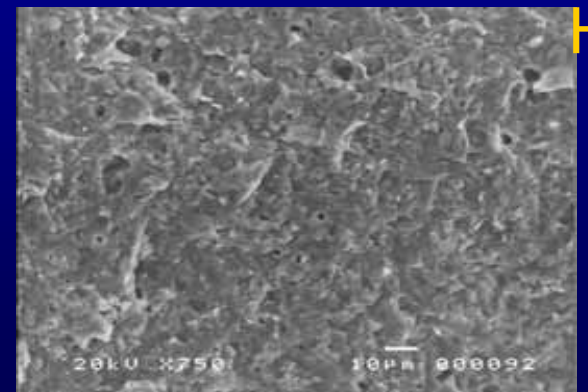
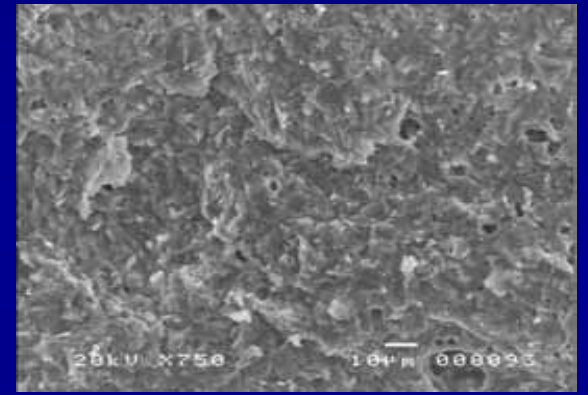
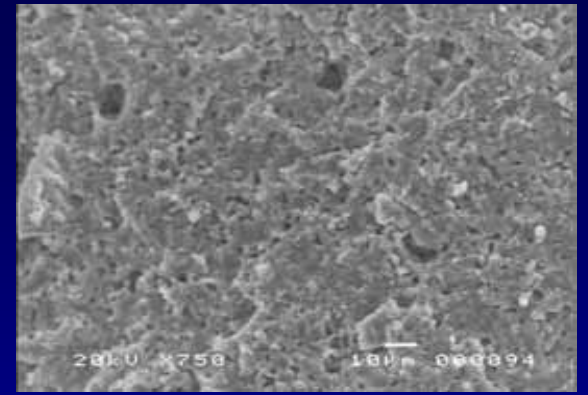
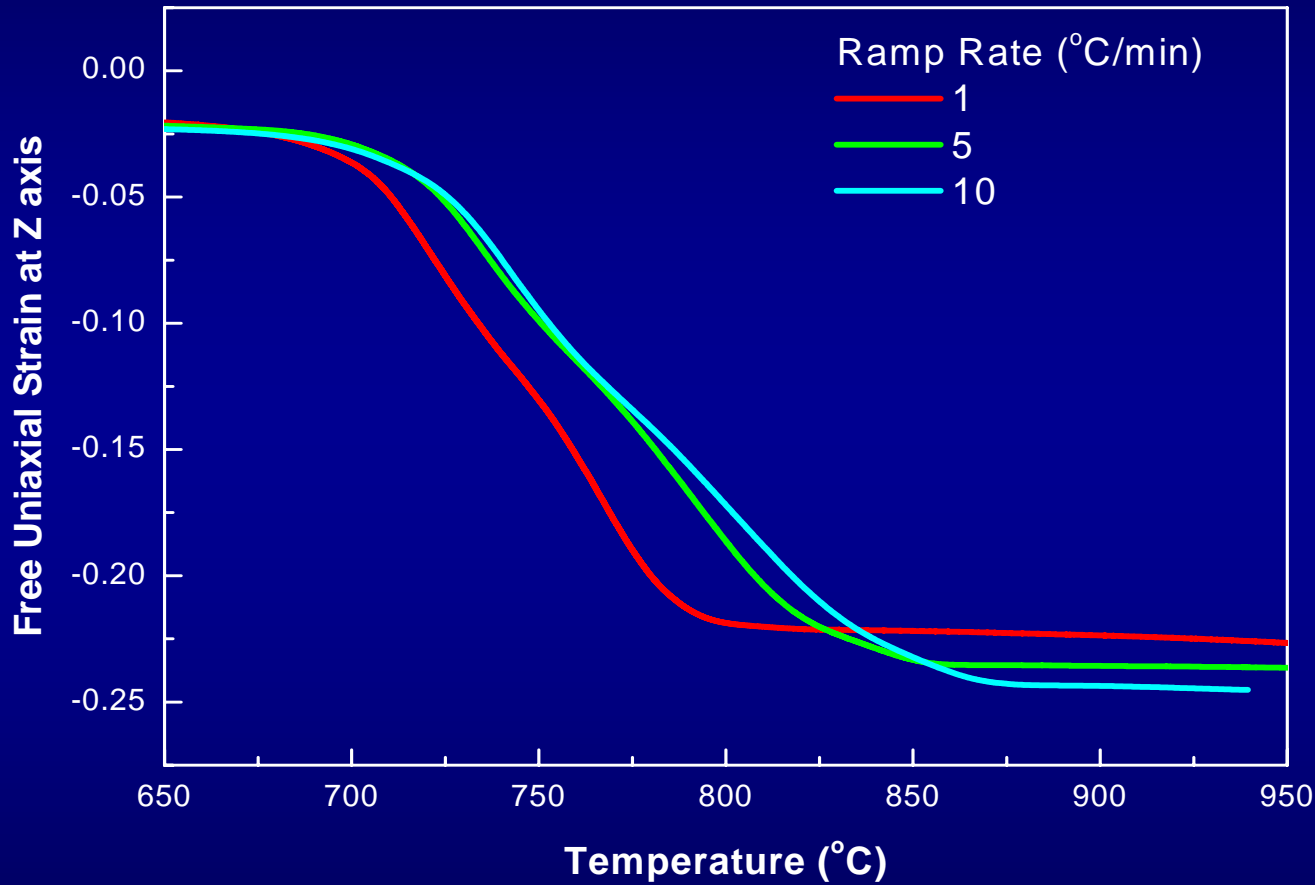
$$1/Q_m = (V/Q)_{\text{glass}} + (V/Q)_{\text{alumina}}$$

$$Q_m = 500-700$$

$$1/K_m = (V*K)_{\text{glass}} + (V*K)_{\text{alumina}}$$

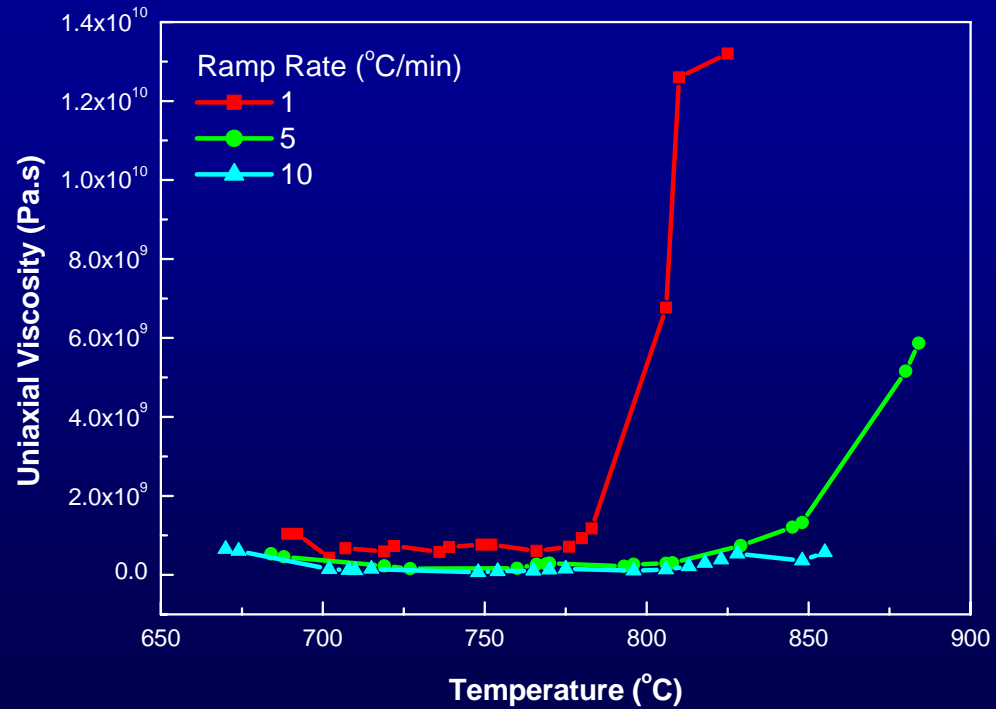
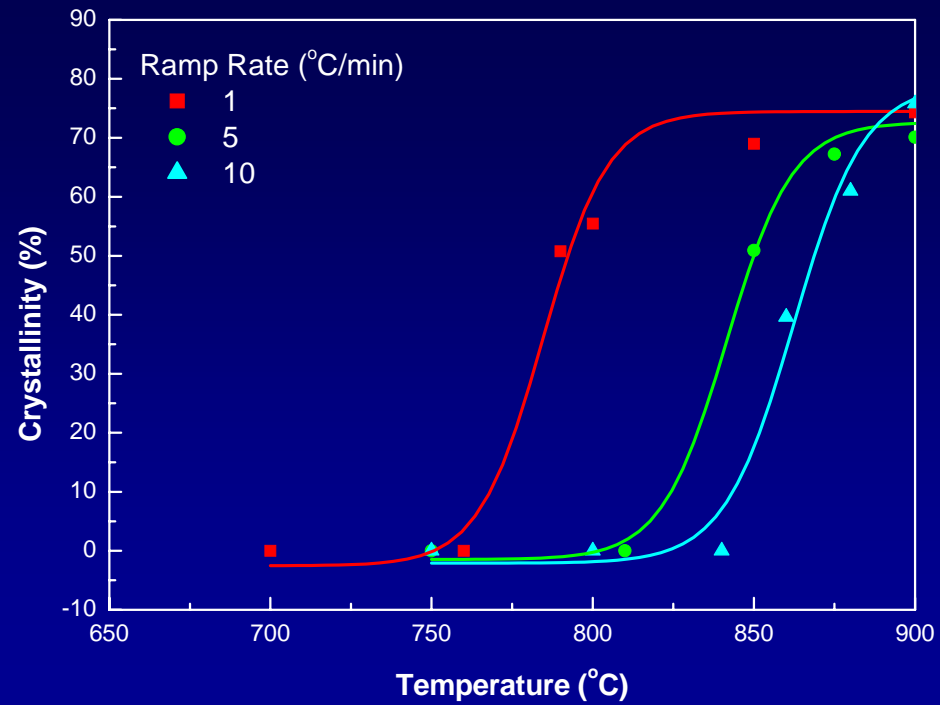
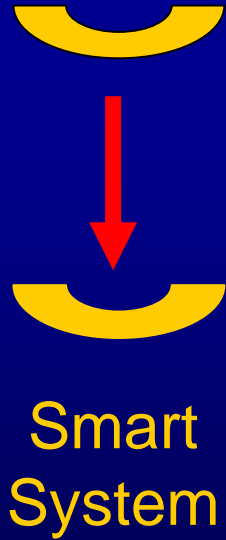
$$K_m = 5-6$$

Effect of heating rate on densification

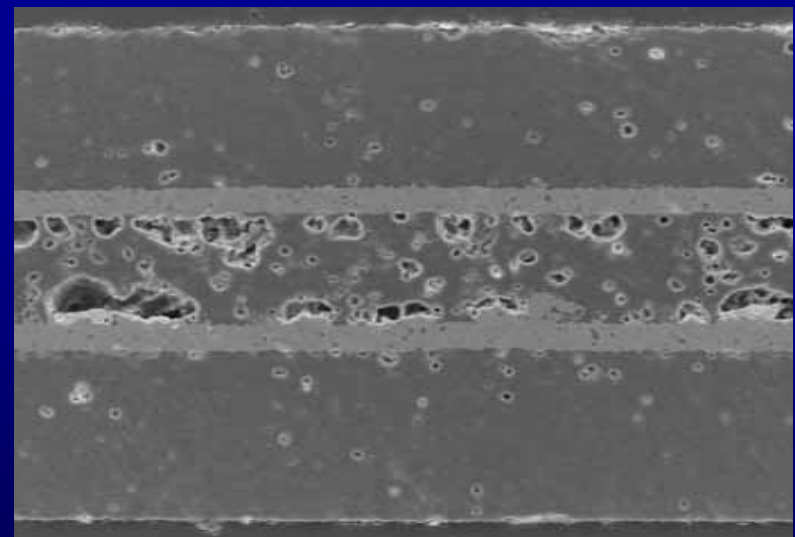
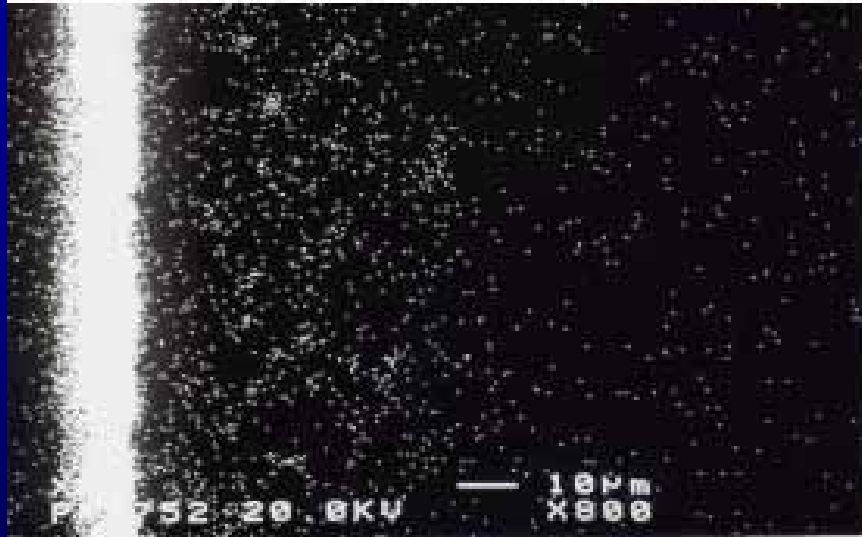
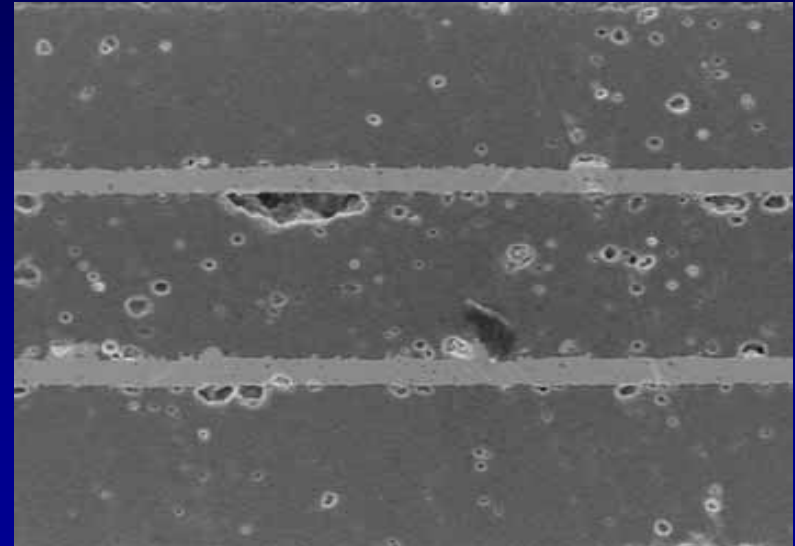
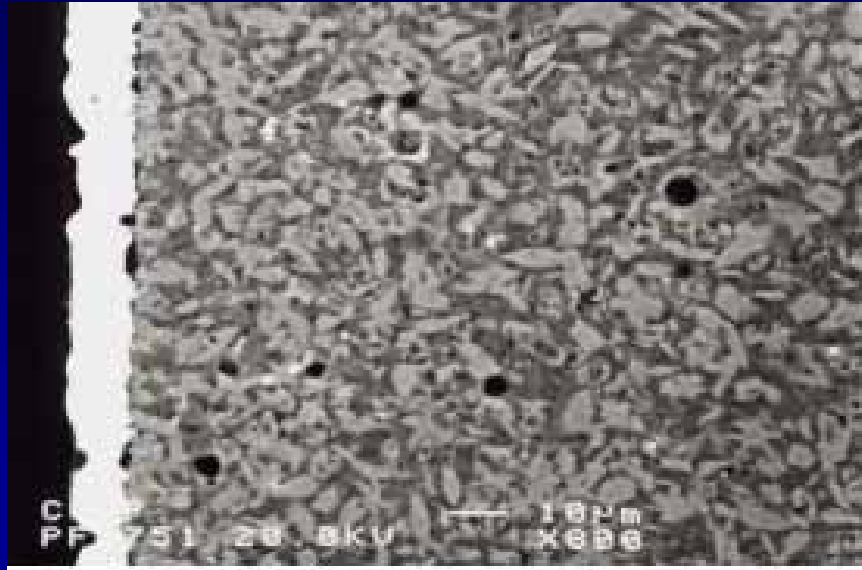


High

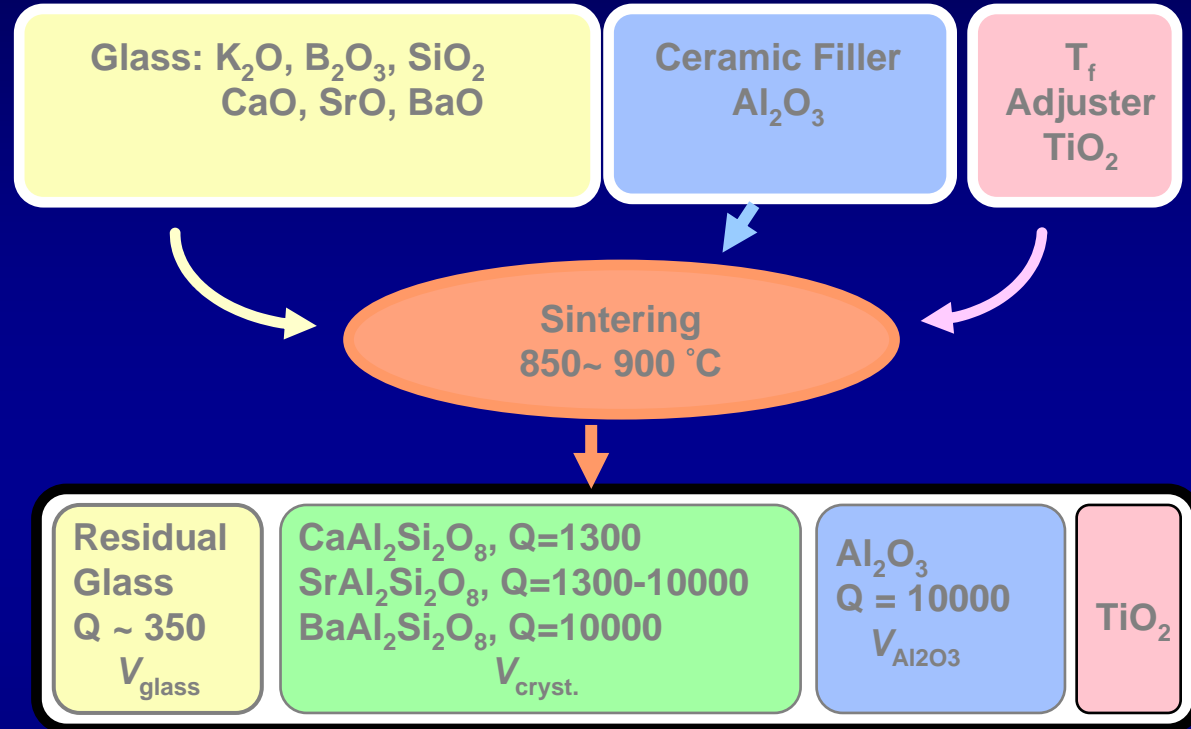
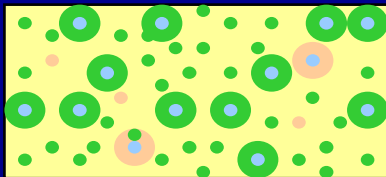
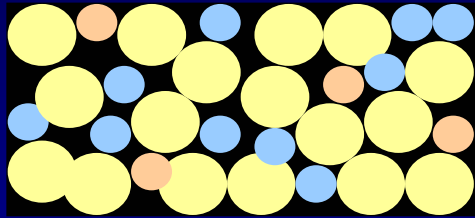
Effect of Crystallization on Viscosity & Densification



Interfacial Reaction between Ag and LTCC



Type III: Glass±Ceramics

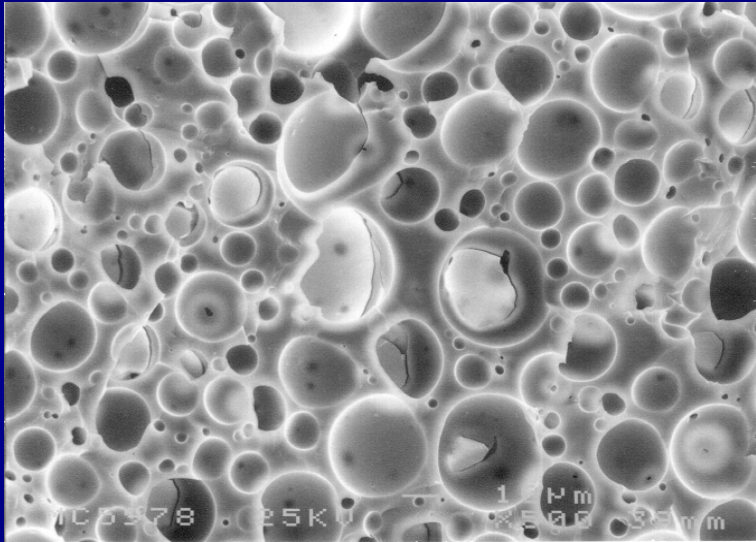


Dielectric Mixture

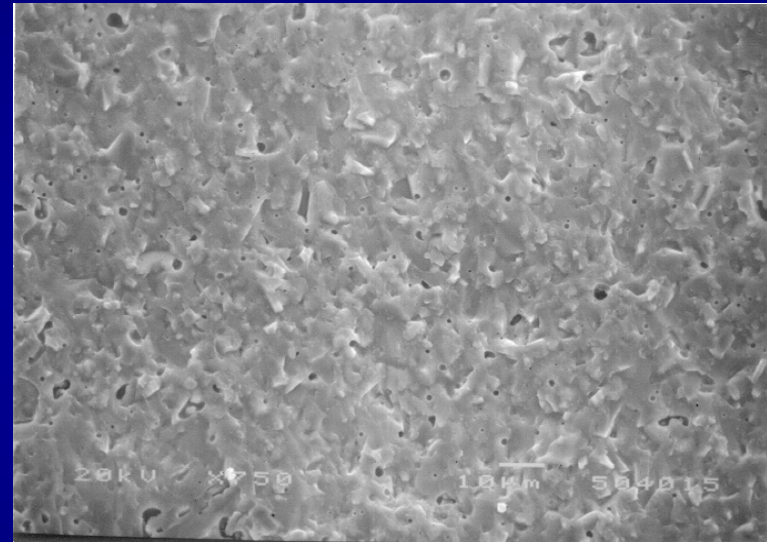
$$1/Q_m = (V/Q)_{glass} + (V/Q)_{alumina} \quad Q_m = 900-1200$$

$$1/K_m = (V*K)_{glass} + (V*K)_{alumina} \quad K_m = 8-10$$

Prevention of Bloating

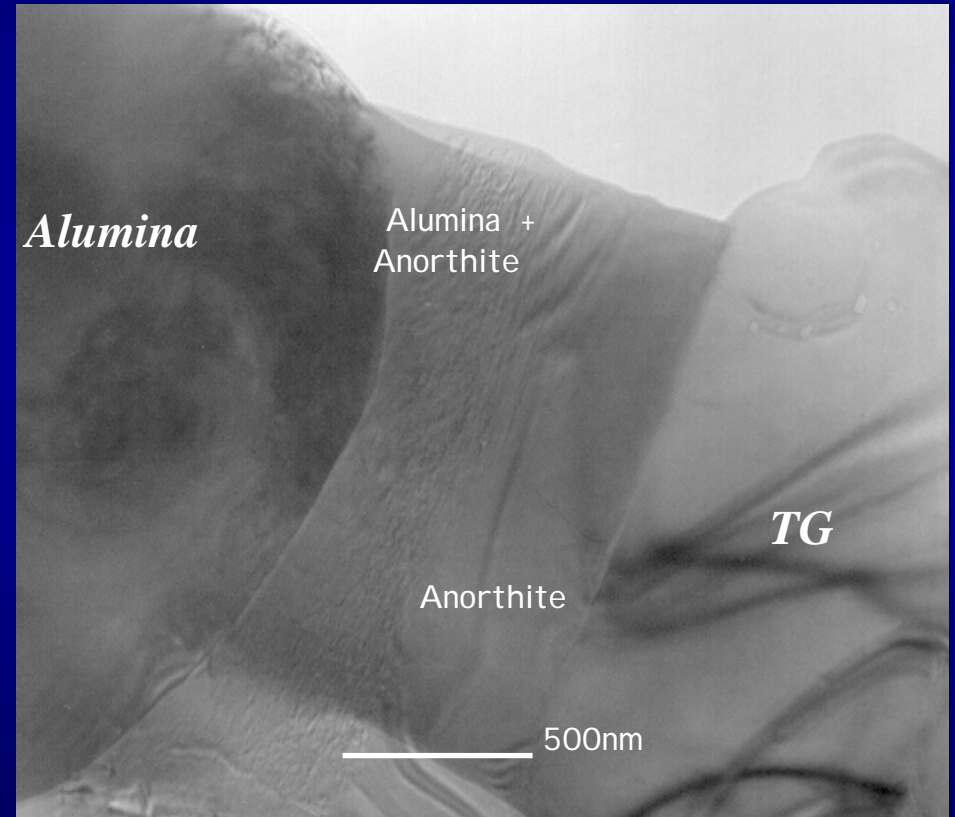
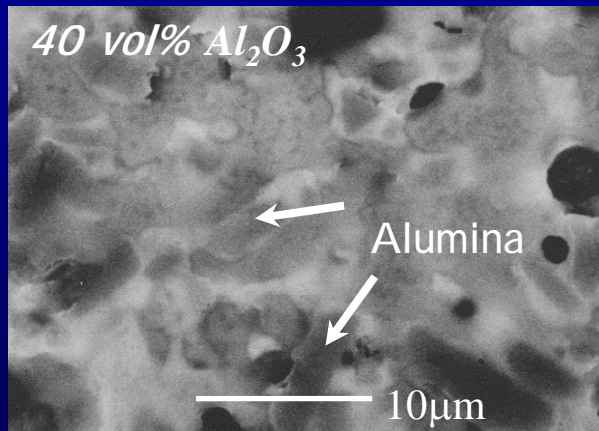
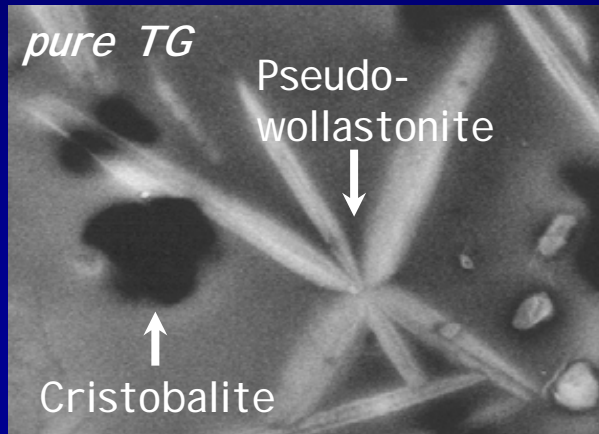


Pure glass

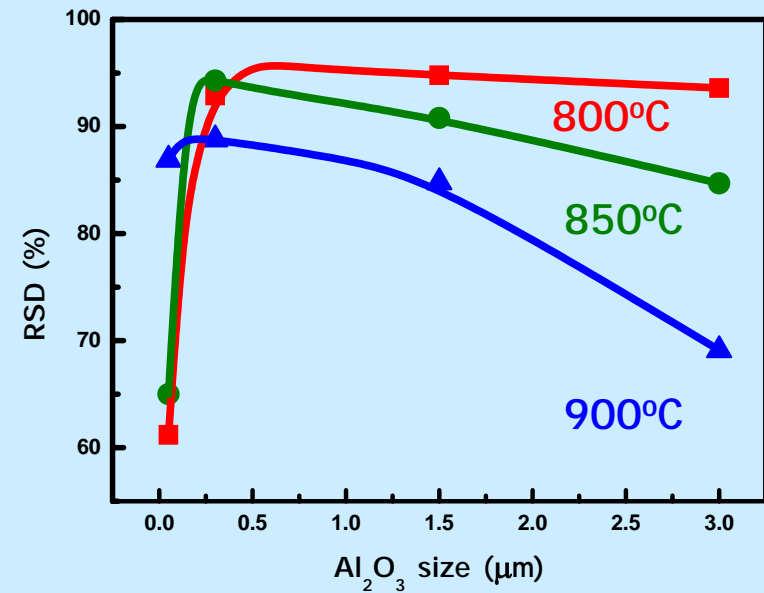
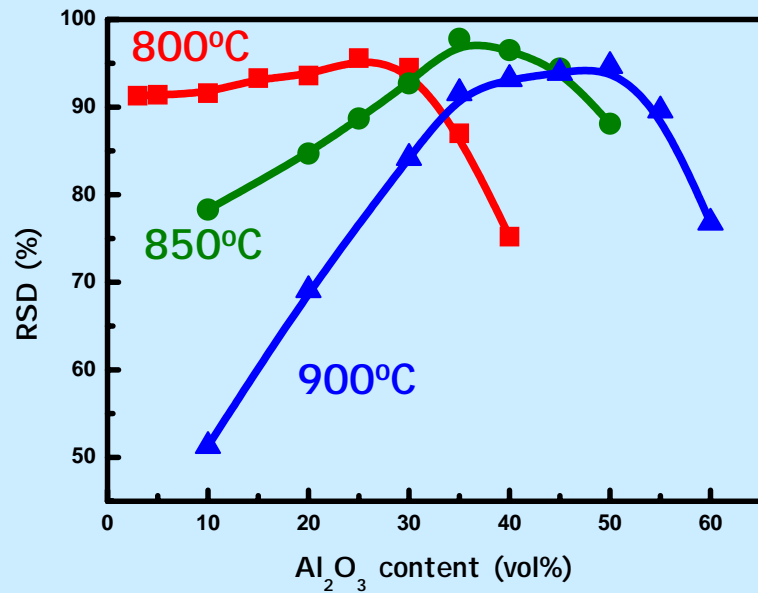


40 vol% Al₂O₃

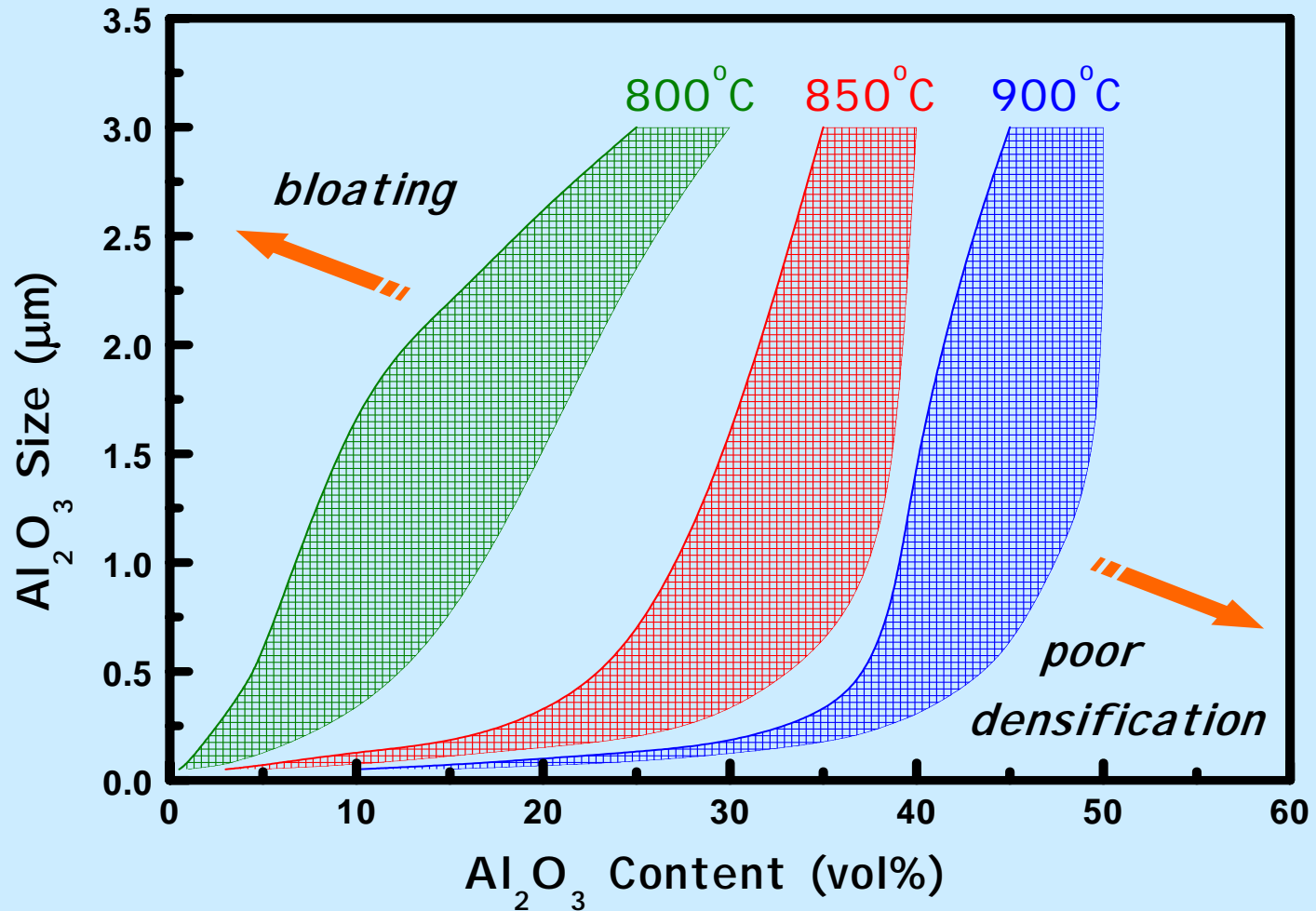
Effect of Al_2O_3 on Crystallization



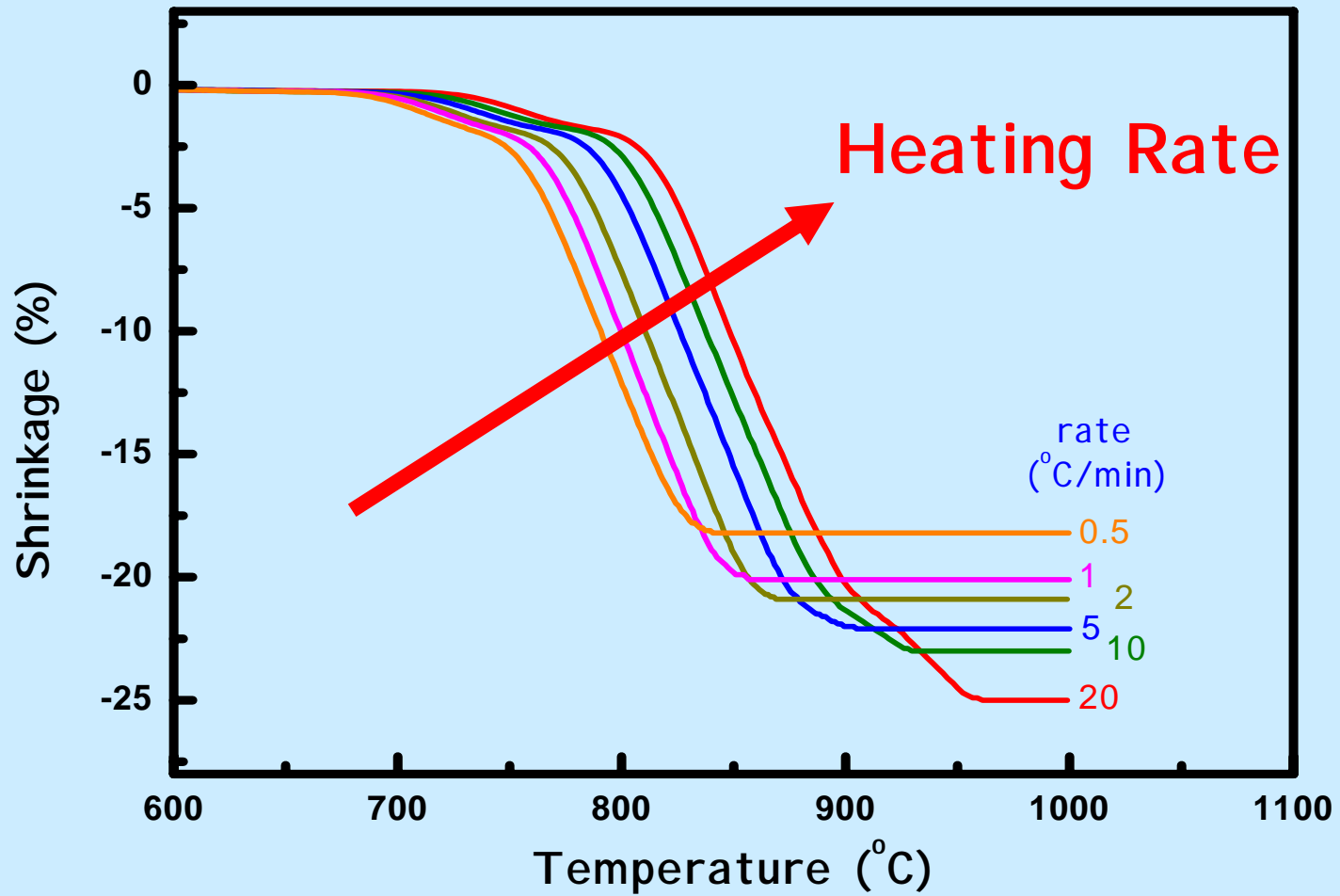
Effects of Alumina Content and Size on Densification



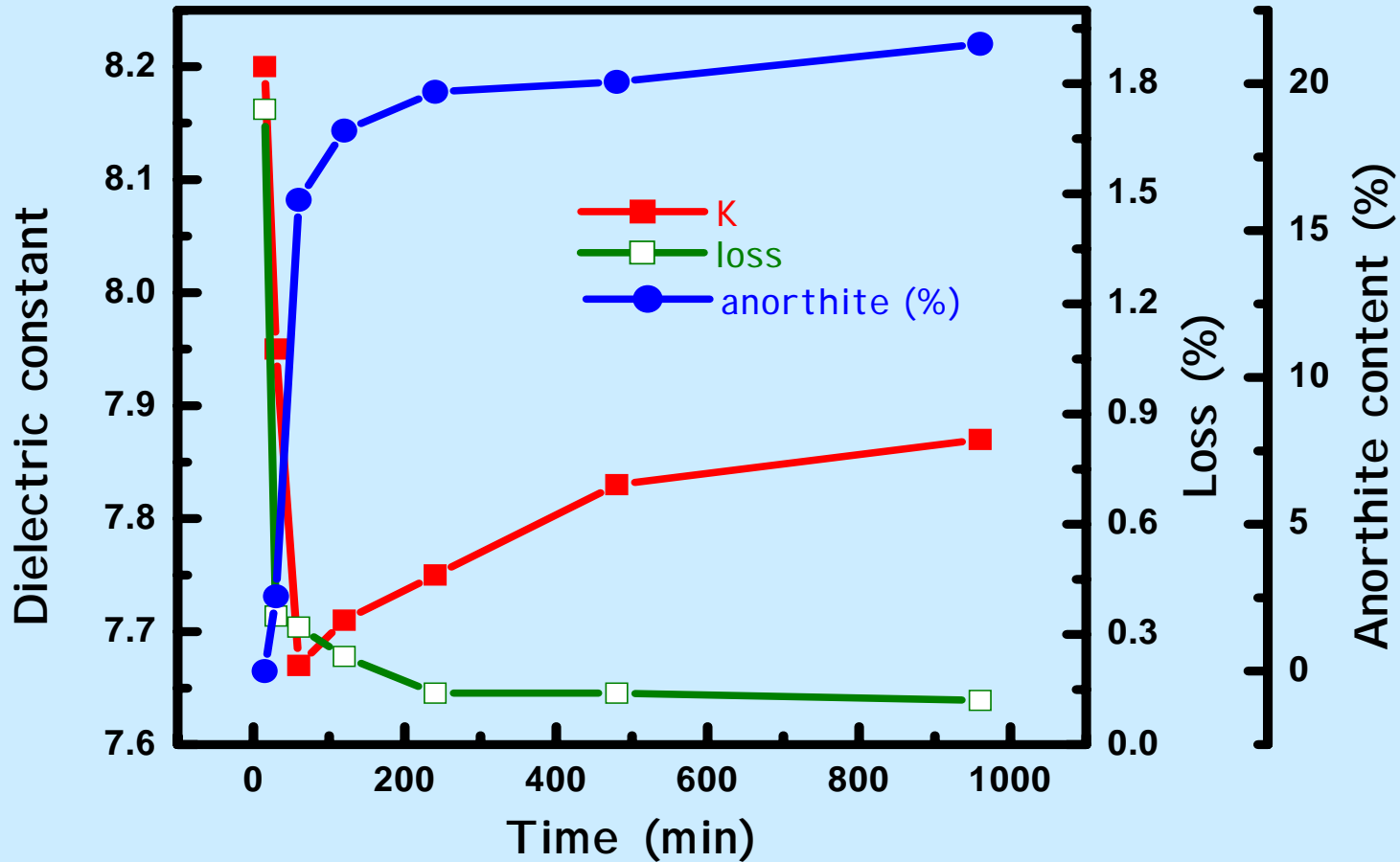
Effects of Alumina Content and Size on Densification



Effect of Heating Rate on Densification



Effect of Crystallization on Dielectric Properties



Glasses in LTCC

- * $K = 5-100$
- * $Q > 1000$
- * Low-fire : 850-900C
- * Non-crystallizable preferred
- * Lead-free
- * Insignificant reaction with Ag
- * Excellent leaching resistance