LTCC/LTCC-M technologies for packaging and module fabrication

Orion Electric Co., Ltd.

L-project team

Je Do Mun

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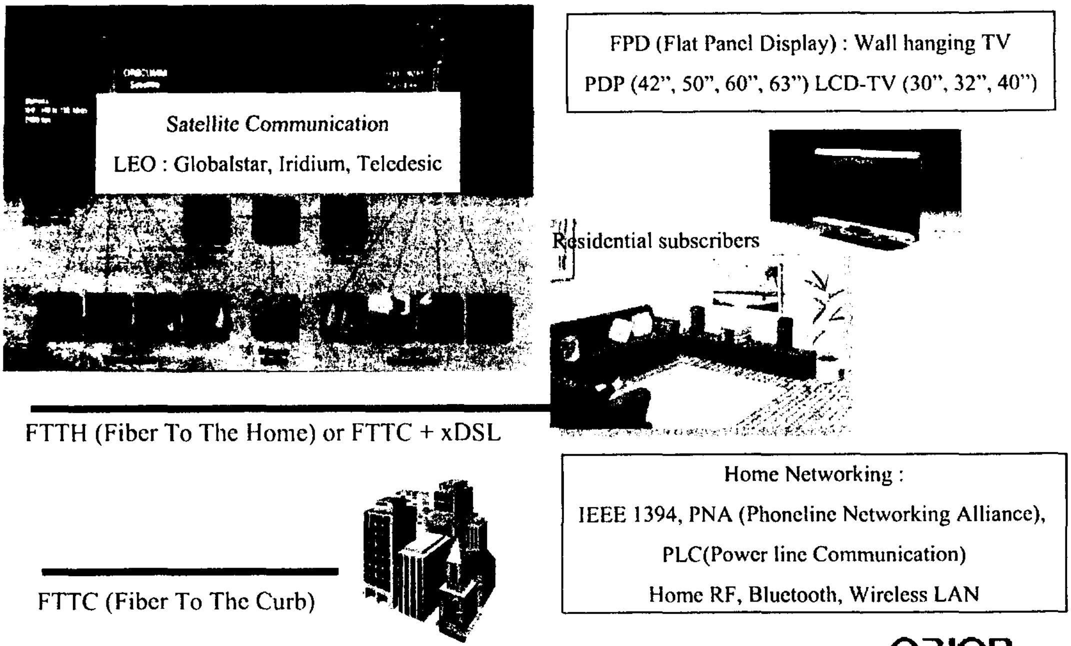
Strategic Electronic Systems



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Frequency/Products family

Frequency	Product family
800 – 900 MHz 1.8 –2.4 GHz	Cellular phone
900 MHz	Pagers
1.5 – 3 GHz	Wireless local loop
1.2 – 1.6 GHz	Global Positioning Systems
0.5 – 2 GHz (L-band)	Uplink for Globalstar (Low Earth Orbit) Uplink and Downlink for Iridium (Low Earth Orbit)
1.8 – 2 GHz	PCS
2 GHz	IMT 2000
2.45 GHz	Bluetooth™
2 – 4 GHz (S-band)	Downlink for Globalstar (Low Earth Orbit)
5 – 20 GHz	T/R modules for active phased array radars (C-, X-band)
20 –25 GHz	Industrial sensors (process control)
18 – 31 GHz (Ka band)	Uplink and Downlink for Teledesic (Low Earth Orbit)
40 – 60 GHz	Communication modules and digital radiolink for cellular infrastructure
70 – 80 GHz	Sensors for Automotive radars
90 – 100 GHz	Seeker system

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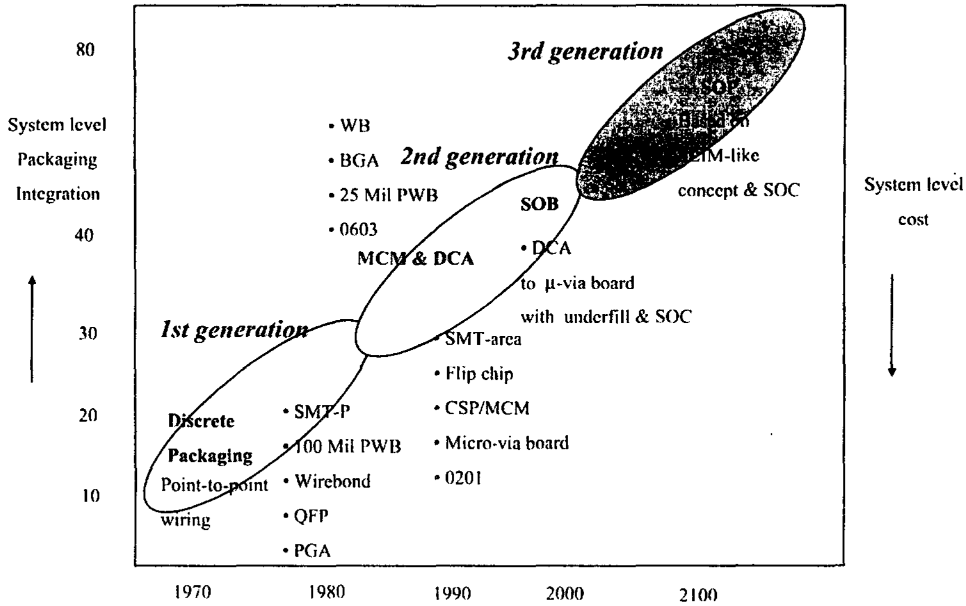
Three generation of microelectronics packaging



* Source : Rao Tummala "Microelectronic systems packaging technology for the 21st century", Advancing microelectronics, 26 (1999)

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Advantages of SOP (System-On-a-Package) technology

- Module or package size reduction
- Reduced signal delay
- Improved reliability due to reduced number of solder points for SMD passives attachment
- Improved electrical performance by reduced parasitic effect
- Low noise level due to eliminated soldering points for passive attachment
- Relative cheap manufacturing cost over SOC (System-On-a-Chip) devices for customer order based products

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Issues in LTCC SOP (System-on-a-Package) technology

- ❒ Method of achieving embedded passives with tight tolerance
- ❒ Cofiring of glass-ceramic materials having different dielectric
- ❒ Realization of Impedance Matching Circuit
- ❒ Analysis of embedded passives at high frequencies and parasitic effect
- ❒ Camber control (Shrinkage matching)

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Comparison of LTCC and HTCC technologies

- ❒ Dielectric constant
  7 - 10 (HTCC) 5 - 10 (Glass-ceramic)
- ❒ Conducting material*

Material	Resistivity (10^{-8} Ωm)	Melting point (°C)
Au	2.255	1064
Ag	1.617	961
Cu	1.712	1084
W	5.39	3422
Mo	5.47	2623

- ❒ Embedded passives : All R, L, C can be embedded in LTCC substrate
- ❒ Mechanical strength
- ❒ Thermal conductivity : 2 ~ 3 watts/mK for LTCC

* Kyocera announced in 2002 the development of low-resistance (Cu base) alumina ceramic multi-layer system

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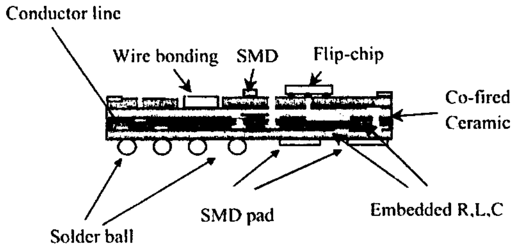
Characteristics of LTCC



LTCC module

- ❒ **Improved electrical performance**
  - Low dielectric loss
  - Controllable T_f by CTE control

    $T_f = -T_k/2 + CTE$

    T_f: Temp. coefficient of resonance frequency

    T_k : *Temp. coefficient of permittivity*
  - Embedded passives with less parasitic effect
  - Controllable CTE
- ❒ **Improved reliability**
  - Less solder points
  - Ceramic packaging (Hermetic packaging)
- ❒ **Inferior thermal and mechanical properties**
  - Weaker mechanical strength (than HTCC)
  - Lower thermal conductivity (than HTCC)

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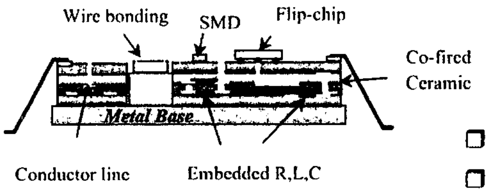
Characteristics of LTCC-M technology



LTCC-M module

- ❒ **Improved electrical performance**
  - Low dielectric loss
  - Controllable T_f by CTE control

    $T_f = -T_k/2 + CTE$

    T_f: Temp. coefficient of resonance frequency

    T_k : *Temp. coefficient of permittivity*
  - Embedded passives with less parasitic effect
  - Controllable CTE (matched to CTE of metal core)
- ❒ **Zero-shrinkage**
- ❒ **Improved reliability**
  - Less solder points
  - Ceramic packaging
  - Mechanical support by metal core
- ❒ **Cavity formability**
  - Good heat dissipation
- ❒ **Relative difficulty in singulation**

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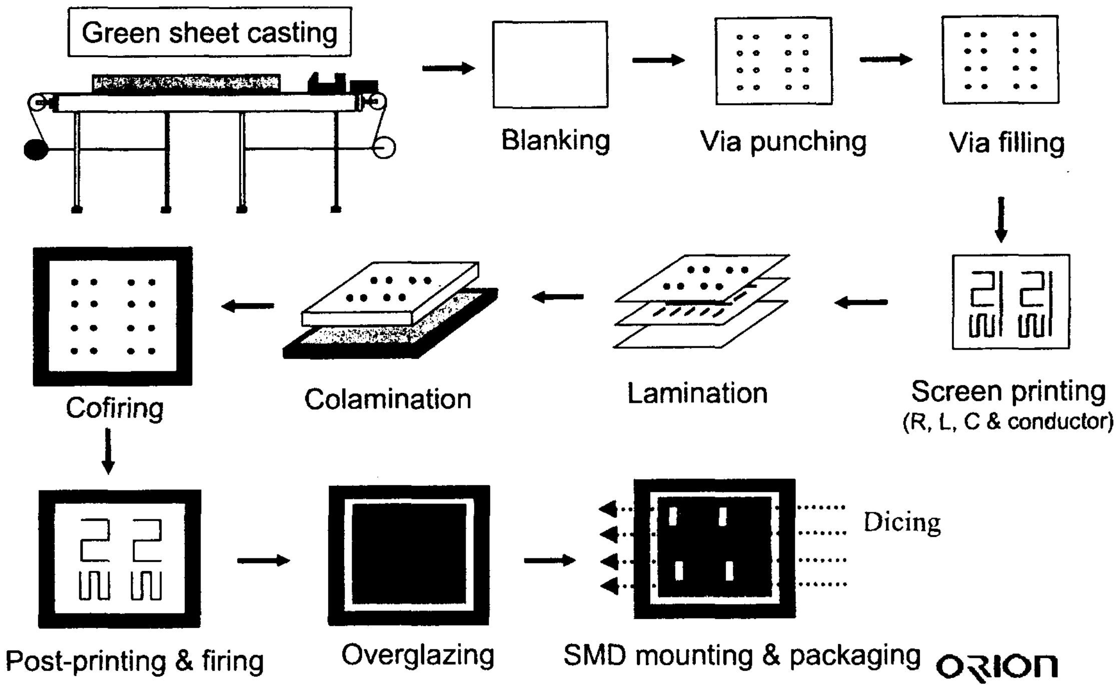
LTCC/LTCC-M Substrates Fabrication procedure



Comparison of commercially available green sheets

	851	951	A6-M	GCS78
Dielectric constant	7.3	7.8	5.9+/- 0.15	7.8
Dissipation factor	<0.3 % (@1 MHz)	<0.15% (@1 MHz)	<0.2 % (@10 MHz)	<0.3%
Green density (g/cm^3)	-	-	-	2.0+/- 0.2
Density (g/cm^3)	2.89	3.1	2.50	3.15 +/- 0.02
CTE (ppm/°C)	7.0	5.8	6	5.2
X-Y shrinkage	12 +/- 0.2 %	12.9 +/- 0.3 %	15.5+/-0.2 %	13.2+/-0.3 %
Z shrinkage	17 %	15 %	27%	
Fracture strength	250 MPa	320 MPa	>210 MPa	300 MPa
Thermal conductivity	2.2 W/mK	3.0 W/mK	2.0 W/mK	-
Breakdown voltage	>1000 volts/mil	>1000 volts/mil	>5000 V/layer	-

* Du Pont : 851, 951 Green tape

Ferro : A6-M

NEC : GCS 78

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Factors to consider in chip packaging and module fabrication

- Thermal design : thermal via, cavity structure
- Mechanical design
- Line definition
- Warpage (Camber) requirement
- Edge definition of the cavity / Cavity dimension
- Impedance matching
- Vacuum packaging (?) : outgassing rate of composing material
- Insertion loss
- Number of embedded passives
- Tolerance of embedded passives
- Reliability issues
- 1st and 2nd level connection

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Factors to consider in the realization of embedded passive

- Tolerance
- Degree of allowed surface modulation
- Position of embedded passives
- Thermal property (TCR, TCC, TCI)
- Breakdown voltage
- SRF (Self Resonant Frequency) of embedded capacitor and inductor

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Requirement for embedded passives

Application		Value range	Tolerance (%)	Other requirement
Digital application	Decoupling capacitors	0.01 - 0.1 μF	10 – 20	low series inductance
	Pull-up/down resistors	1 - 30 KΩ	10 – 20	
	Terminating resistors	20 - 100 Ω	1 – 10	
	Capacitors	10 - 100 pF	10 – 20	
	Filter resistors	1 - 10 MΩ	20	
Analog and Mixed-signal application	Resistors	10 - 100 MΩ	1 – 10	Tightly matched ratios
	Signal capacitors	10 pF - 10 nF	5 –10	Tightly matched ratios
	Decoupling capacitors	0.01 - 0.1 μF	10 – 20	
	EMI filter capacitors	1- 10 nF	10 –20	
	Choke inductors	1 - 10 μH	10 – 20	
RF and Microwave application	Signal inductors	1 - 20 nH	1 – 10	high Q and self-resonant frequency
	Signal capacitors	1 - 20 pF	5 – 10	high Q and self-resonant frequency
	Decoupling capacitors	0.01 - 0.1 μF	10 – 20	low series inductance
	Choke inductors	1 - 10 μH	10 – 20	high Q and self-resonant frequency
	Terminating resistors	20 -100 Ω	1 – 10	
	Signal resistors	10 -100 Ω	1 –10	Tightly matched ratio

* Source : R.C.Frye "Passive components in electronic applications : Requirements and Prospects for integration" IMAPS, **19** (1996)

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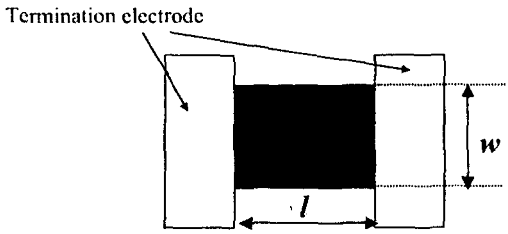
Embedded resistor



$$R = R_s\ l/w$$

- Interaction between embedded resistor and glass-ceramic of substrate
- Interaction of termination and resistor
- Particle size effect on resistance
- Effect of process parameters on resistance
- RF characteristic of resistance
- Thermal properties of embedded resistor

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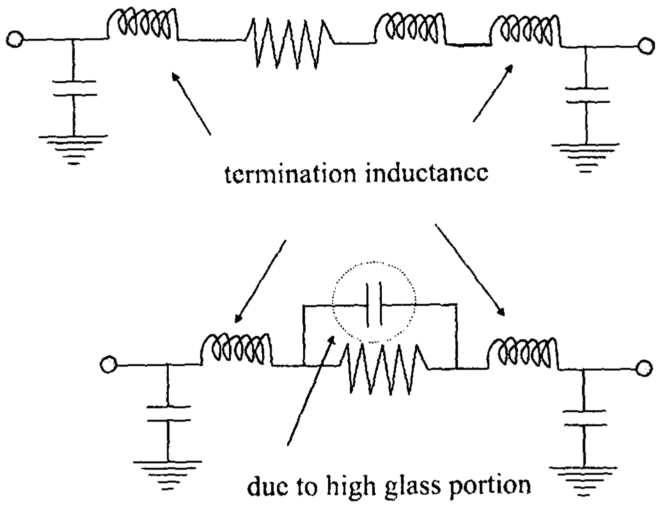
RF characteristic of embedded resistor



Low resistance resistor

High resistance resistor

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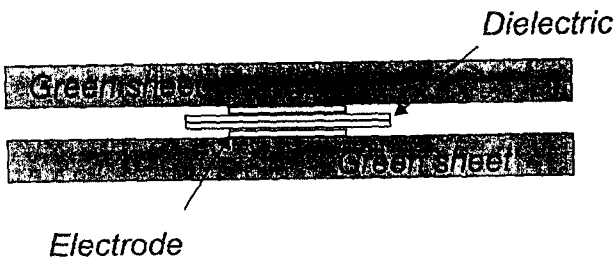
Embedded capacitor



C [pF] = 8.85 *KA/t*

- Interaction between electrode and dielectric layer
- Breakdown voltage
- Self resonant frequency
- Thermal properties of embedded capacitor

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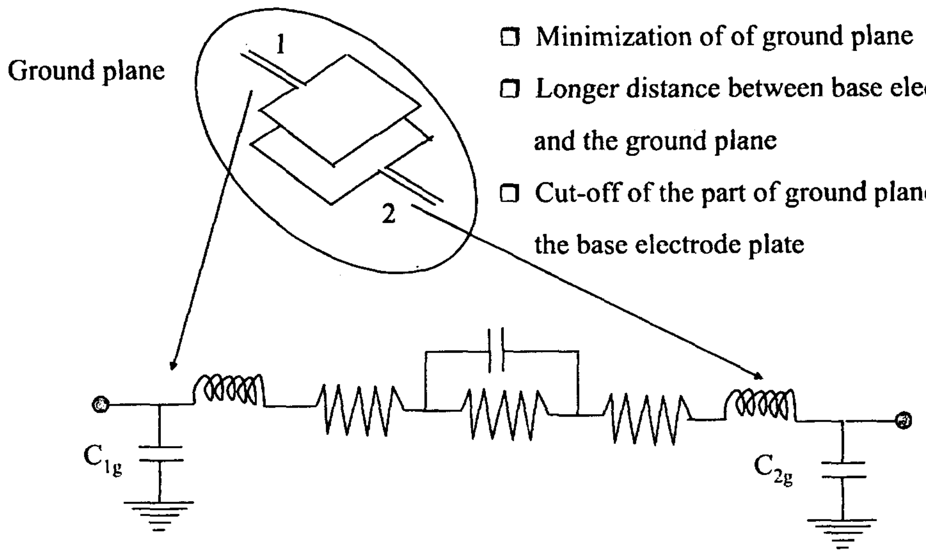
RF characteristic of embedded capacitor



- Minimization of of ground plane
- Longer distance between base electrode plate and the ground plane
- Cut-off of the part of ground plane facing the base electrode plate

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Embedded inductor

- Inductor shape : Loop, Meander , Spiral

For circular spiral

$L_o(nH)=0.03937\,\{a^2n^2/(8a+11c)\}$

$a=(D_o+D_i)/4 \qquad c=(D_0-D_i)/2$

$L\ (\text{with ground plane})=K_gL_o$

$Kg=0.57-0.145\ln(w/h)$

- Interaction between electrode and ferrite
- DCR
- Self resonant frequency and Q-factor (ωL/R)

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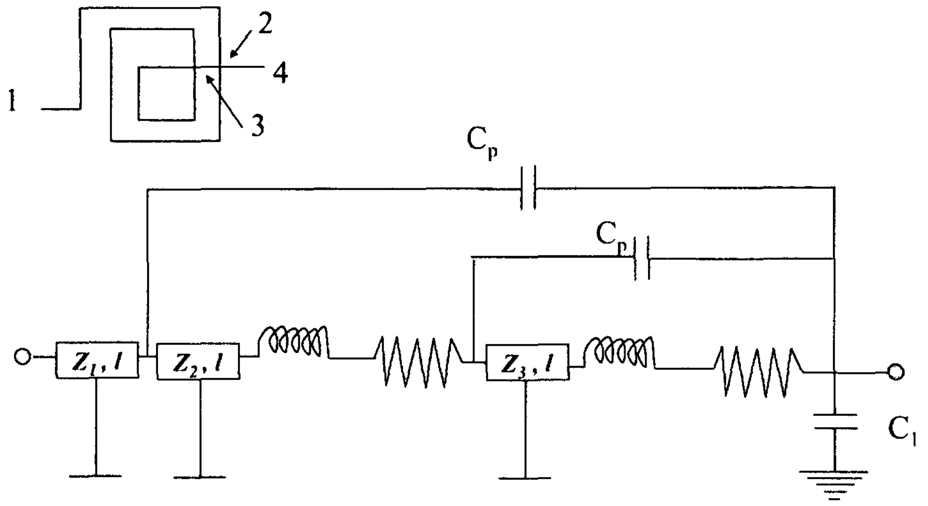
RF characteristic of embedded inductor



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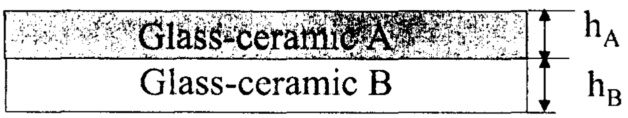
Importance of CTE matching in module fabrication



$$\sigma_A=(\alpha_B - \alpha_A)\,\Delta T \,/\, \{(1-\nu_A)/E_A + (h_A/h_B)(1-\nu_B)/E_B\}$$

$$\sigma_B=(\alpha_A - \alpha_B)\,\Delta T \,/\, \{(1-\nu_B)/E_B + (h_B/h_A)(1-\nu_A)/E_A\}$$

$$\Delta T=T_{high} - T_{low}$$

α_A : Coefficient of thermal expansion of glass-ceramic A
α_B : Coefficient of thermal expansion of glass-ceramic B
E_A: Young's modulus of glass-ceramic A
E_B : Young's modulus of glass-ceramic B
ν_A : Poisson's ratio of glass-ceramic A
ν_B : Poisson's ratio of glass-ceramic B

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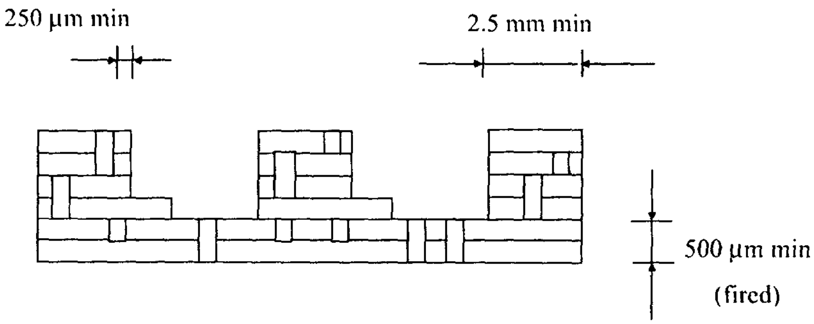
Example of Cavity Design in module fabrication

Usage of cavity : Chip Attachment / 3-D structure



from CTS microelectronics

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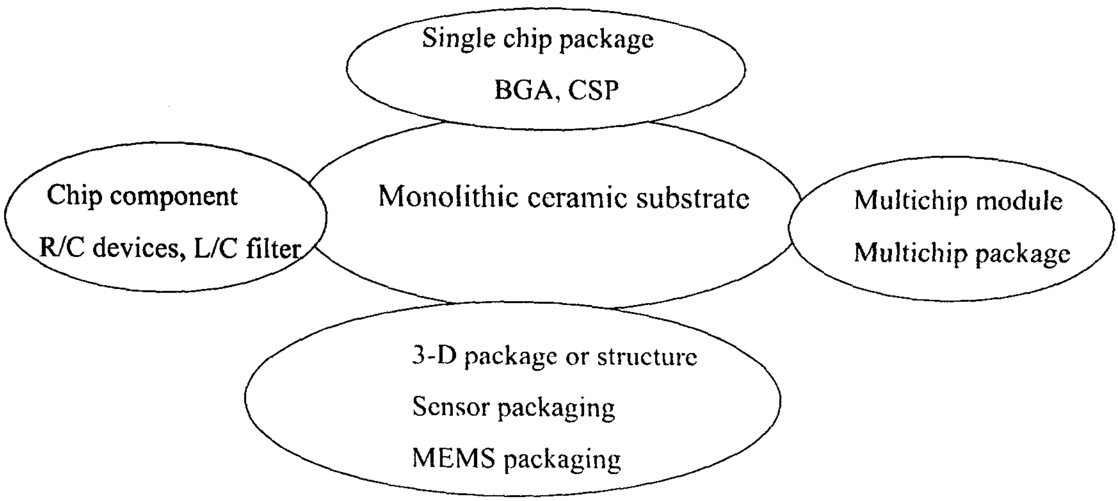
Applications of LTCC/LTCC-M technologies



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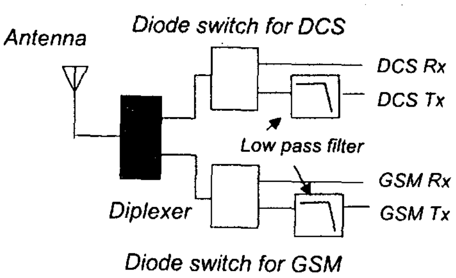
Murata's chip multilayer Antenna/Antenna Switch Module

❑ Chip Multilayer Antenna

- LTCC system
- Dim : 9.5 mm x 2.0 mm x 2.0 mm
- Operating frequency : 900 MHz - 2.6 GHz
- Application : Personal Digital Assistants, Pagers, Cordless telephone, WLAN
- Advantage : Space saving, reduced risk of antenna breakage,
  a robust mechanical design

❑ Antenna Switch Module

- LTCC system
- Dim : 6.7 mm x5.0 mm x 1.8 mm
- GSM/DCS (European dualband phone)
- 20 layers/23 embedded passives



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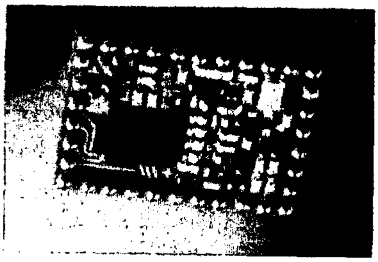
Bluetooth & RF devices fabricated by using LTCC tech.



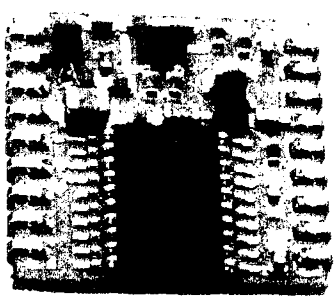
❑ Ericsson's Bluetooth radio transceiver

•Integrated antenna filter, Rx, Tx baluns

* Bluetooth : Device for voice and data communications between mobile appliances and between mobile and fixed appliances

Standardized communication protocols

2.4 5 GHz/ operation within 10 m



❑ National semiconductor's VCO / Synthesizer

- 8 layers
- 200 μm line and space, 150 μm via
- Resonator, Loop filter, 2 inductor, 4 capacitor
- Reduction in circuit size by a factor of four and cost by half

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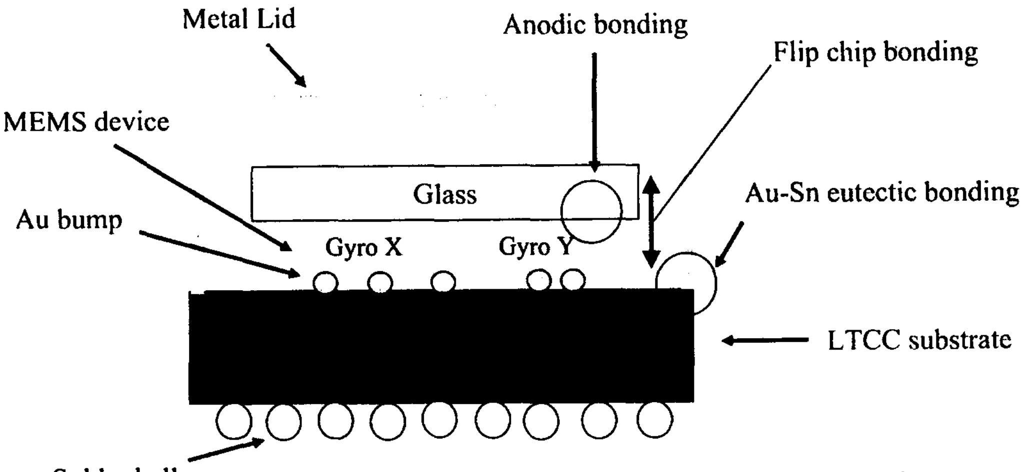
MEMS packaging



By Draper Laboratory

* Source : Advancing microelectronics Nov./Dec. 2000

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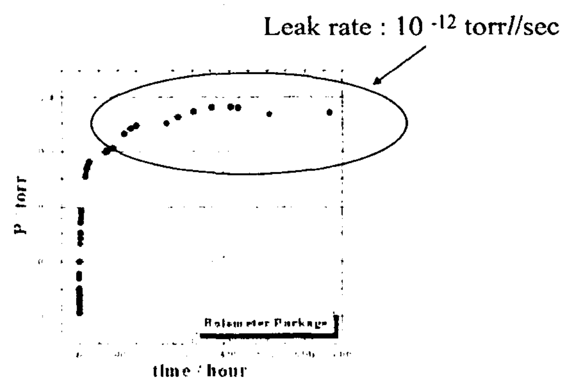
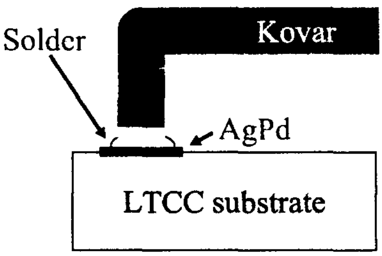
Hermetic Vacuum Packaging for MEMS device





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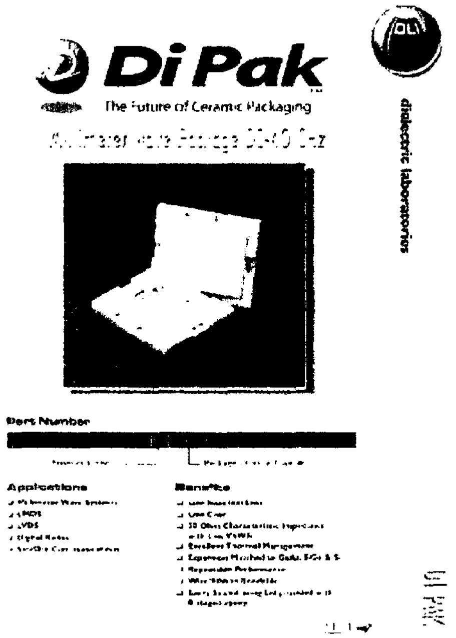
Di-Pak^{TM} Ceramic package (LTCC-M)



❐ *Advantages*

- Low insertion loss
- 50 ohm characteristic impedance with low VSWR
- Expansion matched to GaAs, SiGe and Si (CTE : 5.7 ppm/°C)
- Good thermal management (Cu/Mo/Cu)
  - Lateral thermal conductivity 208 W/mK
  - Vertical thermal conductivity 170 W/mK

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Telecommunication Module

... Subscriber module for FTTC (Fiber To The Curb) system...

❐ Technology

- LTCC-M technology
- Min. Camber requirement (< 100 μm/4"x4")
- Embedded R in LTCC-M Substrate (Resistor : 22 ea.)
- Laser trimming for high tolerance embedded resistor (1 %, 5 %)
- Flip chip bonding (2 SLIC ICs and 2 COMBO ICs)
  (SLIC : Subscriber Line Interface Circuit , COMBO : Combined Codec & Filter)
- SBB (Stud Bump Bonding) bonding
- SMD : Diode 2 ea., C:22 ea., R:6 ea.

❐ External Dimension

- Module size : 62 mm x 16 mm

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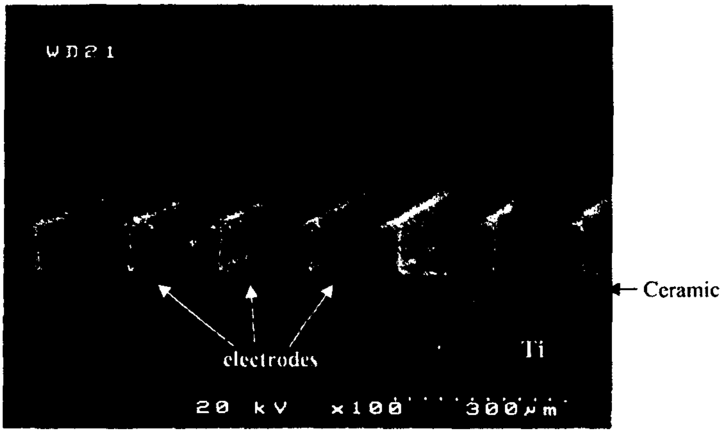
Cross sectional view of LTCC-M back panel



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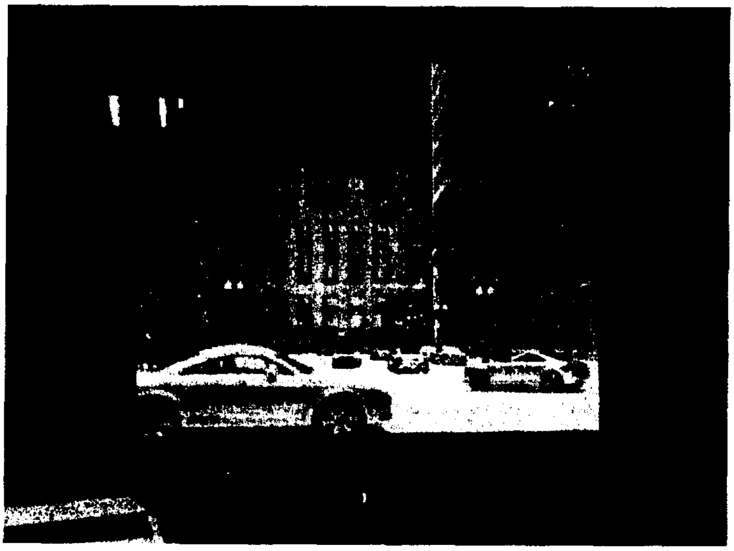
Light-up image of 25" XGA LTCC-M PDP



Presented in SID 2002 (Boston)

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Summary

- LTCC/LTCC-M technologies are a cost-effective SOP technology

- LTCC/LTCC-M materials have good RF characteristics and the materials can be used as excellent substrates for high band width applications

- Reliability of LTCC/LTCC-M package or module can be greatly improved by embedded passive technology and CTE control of the substrates

- To expand the application area, more development is needed in realization of embedded passives with tight tolerance

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