Hybrid Thick Film Technology

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Introduction

- Hybrid means composite. In the context of hybrid technology, we mean a mixture of integrated components: conductors, resistors, capacitors, etc., that are manufactured as part of the substrate - and discrete components that are soldered or bonded on top of the substrate.
- The traditional types of hybrid technology are thick film- and thin film hybrid technologies, that have been used since early in the 1960´s.

Introduction

- The main goal of using hybrid circuits , is saving space, volume and weight compared to ordinary printed circuit boards.
- However, we can also achieve superior high frequency properties and very high reliability.
- This makes hybrid circuits suitable for demanding
  - military systems,
  - space applications,
  - medical electronics,
  - as well as computers, telecommunication equipment, etc.

Thick Film Deposition and Film Formation

The deposition process of a film can be divided into three basic phases:

1. Preparation of the film forming particles (atoms, molecules, cluster)

2. Transport of the particles from the source to the substrate

3. Adsorption of the particles on the substrate and film growth

These phases can - depending on the specific deposition process and/or on the choice of the deposition parameters - be considered as either independent or as influencing one another. The former is desirable since it allows to control the basic steps independently and therefore yields a high flexibility in the deposition process.

THICK FILM HYBRID TECHNOLOGY

Substrates

Important properties of thick film substrate materials are:

- - Good dimensional stability during high temperature processing
- - Good adhesion between substrate and printed materials
- - High thermal conductivity
- - A thermal coefficient of expansion matching that of other materials in the circuit
- - High electrical resistivity that gives isolation between components
- - Low dielectric constant
- - Low dielectric loss tangent (for microwave circuits)
- - Good machinability
- - Low price.

No single material will satisfy all these requirements.

- Various types of ceramic are used as thick film substrate materials, with 96 % Al2O3 (alumina) as the dominant one.
- Alumina has many good electrical and mechanical properties, please refer to Table

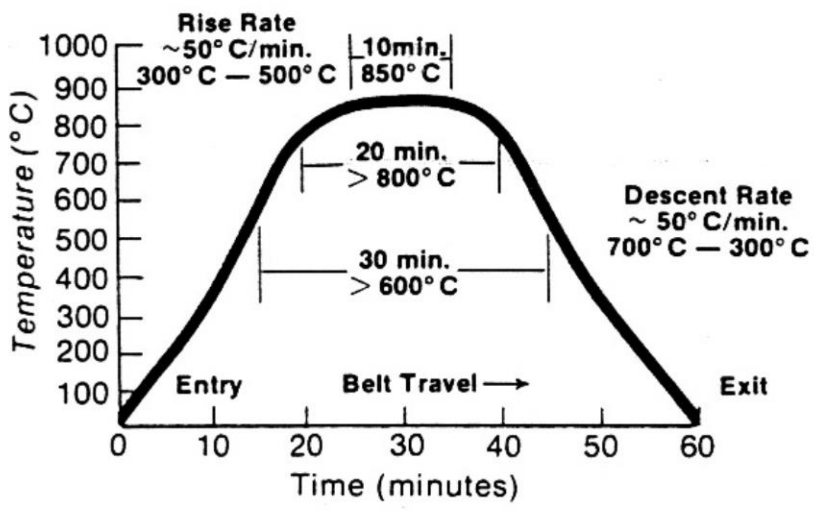
Material	Relative permit-ivity ε_r	Dielectric Loss Factor (at 10 GHz, 25°C), tan δ_ε	Specific Thermal Conduct-ivity K_{th} [W/cm °K]	Linear Thermal Expansion Coefficient (at 25°C) $\Delta l/l/\Delta T$ $[10^{-6}/°K]$	Temper-ature Coefficient of ε_ρ $\Delta\varepsilon/\varepsilon\Delta T$ $[10^{-6}/°K]$	Type	Remarks
Al_2O_3 ceramic (99.5% pure)	9,8	0,0001	0,37	6,3	+136	In	
Al_2O_3 ceramic (96% pure)	9,4	0,001	0,35	6,4		In	
Sapphire	9,4; 1,6	0,0001	0,42	6	+110 +140	In	Aniso-tropic
Quartz glass	3,78	0,0001	0,017	0,55	+13	In	
Corning glass	5,75	0,0036	0,012	4,6		In	
Beryllium oxide Ceramic (BeO) (98%)	6,3	0,006	2,1	6,1	+107	In	Dust is poison-ous
Semi-Insulating GaAs	12,9	0,002	0,46	5,7		Semi	
(High-resistive) Silicon ($\rho=10^3$ ohm cm)	11,9	0,015	1,45	4,2		Semi	
PTFE	2,1	0,0003	0,002	106	+350	P	
Polyolefin (Glass reinforced)	2,32	0,0007	0,005	108	+480	P	
PTFE	2,55	0,001	0,003	16-100		P	
Aluminium			2,2	23,8			For
Copper			3,93	17			comp-
Invar				1,5			arison

Materials for conductors, resistors, dielectrics

Conductors, resistors and dielectric materials are applied in paste form by screen printing and they are transformed/sintered by heating to high temperature, "firing". The pastes have three main ingredients:

- Functional element (metal-, alloy- or oxide particles)
- Matrix or "binder" (glass particles)
- Organic solvents and "temporary binder".

The organic, temporary binders are polymers that give control over the printing properties. They decompose and evaporate early in the firing process, together with the solvents. The glass particles melt in the firing process, adhere to the substrate, bind the active particles together and give stability for the circuit. The high firing temperature, typically 800 - 900 °C, see Figure, is important for the long term stability and reliability.



Typical temperature profile for thick film firing [8.1]

Conductors

<u>Conductors</u>

The conducting pastes should give:

- High electrical conductivity
- Strong adhesion to the substrate
- Excellent solderability for soldering of packaged components
- Reliable bondability for wire bonding of naked IC chips.

Price is also an important parameter.

Normally one conductor paste can not satisfy all these criteria, and it is necessary to make several conductor prints.

Conductors

- The most used conductor systems are gold, copper, alloys of palladium/silver, palladium/gold and platinum/gold, with properties shown in Table 8.2.
- Noble metal systems are used because the heat treatment takes place at above 800 °C, where other metals are ruined by oxidation.
- However, gold and platinum are expensive materials, so the material cost is an important factor in the final price of the circuit. Gold is very well suited as basis for bonding, but it is not suitable for soldering. This is because gold is very quickly dissolved in solder metal during the soldering process, and it gives a brittle intermetallic composition with poor reliability properties.
- Pure silver has a strong tendency for migration , which may cause reliability problems after some time.

Conductors

- However, silver/palladium gives little migration, it is excellent for soldering, and is well suited for making contact areas for printed thick film resistors. Therefore, this alloy is the most used as conductor material, although it has lower conductivity than the pure elemental conductors.
- Silver is also used in alloys with platinum.
- Copper has high conductivity and low price. However, strong oxidation in air at high temperature makes it necessary that copper must be fired in a neutral nitrogen atmosphere. That gives a more complicated and costly process and has impeded the use of copper conductors.
- Nickel is also used to some extent, but it has lower electrical conductivity than the other materials. T
- ypical thicknesses for the conductors are 5 - 10 µm after firing. The sheet resistivity is typically between 2 and 25 mohm/sq, please refer to Table 8.2.

Table Properties of thick film conductor systems [8.2]

Comparison of Parameters for Thick-film Conductors			
	AgPd	*Cu*	*Au*
Sheet Resistivity (mohm/❒)	25	1,8	2,5
Breakdown Current (mA/mm width)	3000	10000	10000
Thickness	10-20	15-30	5-15
Minimum With (µm)	150	150	50
Through-hole Diameter	0,4-1,5	0,4-1,5	-
Number of conductor layers	1-3	1-5	1-5
Substrate Area (cm^2)	0,2-100	0,2-200	0,2-50
Substrate Thickness (mm)	0,6-1	0,6-1	0,25-1
Tin-Lead Soldering Properties on Thick Film Conductors			
Parameter	*AgPd*	*Cu*	*Au*
Solderability	Good	Good	Unsolderable
Wetting	Good	Good-excellent	-
Leach Resistance	Fair-good	Excellent	-
Adhesion	Excellent	Excellent	-
Visual Quality	Good	Excellent	-

Resistors

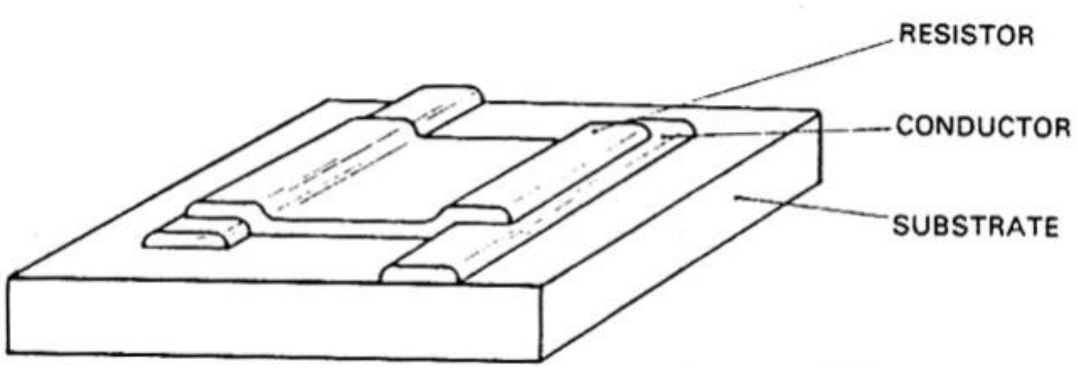
Important properties of thick film resistors are:

- Large range of available resistor values
- High stability
- Low thermal coefficient of resistivity, with little spread over the substrate
- Low voltage dependence of the resistance
- Good noise properties.

Resistors

- The resistor pastes consist of the same three main ingredients as the conductor pastes, but the active elements have lower electrical conductivity.
- They are most often based on various types of oxides of ruthenium: RuO2, BaRuO3, Bi2Ru2O7. In addition, oxides of iridium, rhodium and osmium are used. They may be produced with sheet resistance down to approximately 1 ohm/sq, and up to 109 ohm/sq, for a 25 µm thick print.
- The sheet resistivity is determined by the active material in the paste, the amount of glass matrix mixed in, and the details in the processing.
- We obtain termination of the resistors by printing a conductor underneath or on top of the ends of the resistor, see Figure 8.2.

Resistors



Thick film resistor with termination.

Table Typical properties of thick film resistors

Tolerances as fired	±10 – ±20%
Tolerances, laser trimmed	±0.5 - ± 1%
TCRs:	
5 to 100K ohm/sq (-55° to 125°C)	±100 - ±150 ppm/°C
100K to 10M ohm/sq (-55° to 125°C)	±150 - ±750 ppm/°C
Resistance drift after 1,000 hr at 150°C no load	+0.3 to -0.3%
Resistance drift after 1,000 hr at 85°C with 25 watts/in^2	0.25 to 0.3%
Resistance drift, short term overload (2.5 times rated voltage)	<0.5%
Voltage coefficient	20 ppm/(V) (in)
Noise (Quan-Tech):	
At 100 ohm/sq	-30 to -20 dB
At 100 Kohm/sq	0 to +20
Power ratings	40-50 watts/in^2

Dielectrics

- Dielectric materials are printed
  - to obtain insulation between various layers of conductors,
  - to produce capacitors, and
  - as passivating cover on top of the whole circuit.
- For insulation, low capacitance between conductors is desirable and we use materials with low dielectric constant.
- For capacitors, materials with high dielectric constant are used, to achieve high capacitance with little area consumption.

Dielectrics

- Important properties of dielectric materials:
  - High insulation resistance
  - High breakdown field
  - For insulators: Low dielectric constant
  - For capacitors: Suitable dielectric constant, low temperature coefficient and low voltage coefficient of dielectric properties
  - Low loss tangent
  - Low porosity

Dielectrics

- For insulation layers, aluminium oxide is the common functional element, together with glass. The glass melts and crystallises during firing at 850 – 950 °C, but it does not melt if heated again. The relative dielectric constant is typically 9 - 10, and breakdown field strength 20 V/µm.
- The dielectrics for high value capacitors consist of ferroelectric materials with relative dielectric constant up to above 1000,
- For small capacitors the pastes of magnesium titanate, zinc titanate, titanium oxide, and calcium titanate are used, with relative dielectric constant 12- 160.

Advantage of thick film technologies

- The most important advantages of thick film technologies are the following:
  - Low price.
  - Simple processes.
  - Quick production of prototypes and full production volumes.
  - is well suited for repair/modification of regular printed wiring boards.
  - Printed resistors can be made.
  - Additive technology, little waste and environmental problems.
  - Substrates: Regular printed wiring board laminates.

Disadvantage of thick film technolgies

- Important limitations of Thick film:
  - thick film circuits satisfy only moderate environmental requirements.
  - Only moderate complexity can be achieved.
  - High sheet resistivity in the conductors
  - Special design rules.
  - Limited solderability.
  - The materials have limited shelf life before they are used.
  - Limited availability (i.e. few producers)

Application of thick film

- **Thick-film technology** is used to produce electronic devices/modules such as surface mount devices modules, hybrid integrated circuits, heating elements, integrated passive devices and sensors.
- Thick-film circuits/modules are widely used in the automotive industry, both in sensors, e.g. mixture of fuel/air, pressure sensors, engine and gearbox controls, sensor for releasing airbags, ignitors to airbags; common is that high reliability is required, often extended temperature range also along massive thermocycling of circuits without failure.
- Other application areas are space electronics, consumer electronics, and various measurement systems where low cost and/or high reliability is needed.