Electrical characterization of thick film materials

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Abstract

The thick-film technology is one of the fundamental technologies for the production of circuit carriers for electronic modules. It is mainly used in areas with harsh environmental conditions, such as sensor or automotive applications. Basis of the thick film technology are glass-based pastes, which are screen printed on ceramic substrates and fired in a high temperature process at (500…1000) ° C. Such thick film pastes are commercially available from various suppliers as elements of paste systems, which mainly include compatible isolation, resistance and conductive pastes.

There are a number of requirements according the fired thick film characteristics, such as high breakdown voltage of isolation thick films or low noise performances of resistance thick films. However, the most requirements are concentrating on conductor thick films. They should guarantee excellent properties in terms of assembling (soldering, bonding) which are focused in a many publications. Simultaneously, they should also offer very good electrical characteristics that have not been completely investigated until today.

At Fraunhofer IKTS different measurement methods are developed and adapted to characterize the electrical performance of thick film structures. Already well known is the short term overload (STOL) measurement of thick film resistances, which determining the maximum power dissipation of the thick film structure. The basic concept of this measurement is adapted on conductive thick film structures like conductive tracks or vias. The investigations show correlations between geometrical thick film properties and the resulting thermal characteristics of the thick film structure. Results can be used to improve screen-printing layouts in terms of cost reduction (paste consumption) and thermal management (track width, via diameter), but can also help to improve paste compositions itself. The paper will give an overview of the used electrical measurement methods and present exemplary results.

Introduction

The thick-film technology is one of the three fundamental technologies for the production of circuit carriers. Basis of the thick film technology are glass-based pastes, which are screen printed on ceramic substrates and fired in a high temperature process at (500…1000) ° C. Thick film pastes are commercially available from various suppliers as elements of paste systems, which mainly include compatible isolation, resistance and conductive pastes.

For the characterization of thick film pastes existing according to her type various standards e.g. DIN or MIL standards. This standards include various optical, electrical and mechanical tests. A principle overview about these is given in Tab.1:

Tab. 1: Tests for thick film materials according DIN 41850

	Conductor pastes	Dielectric pastes	Resistor pastes
Paste properties	viscosity	viscosity	viscosity
	particle size	particle size	
Processibility	min. line width	dimensional stability	dimensional stability
	min. line space		
Paste specific values	sheet resistance	insulation resistance	sheet resistance
		dielectric constant	temperature behavior
		Break down voltage	noise index
		Dissipation factor	voltage dependence
		influence of humidity	drift behavior
			maximum power dissipation
Compatibility to	resistor pastes	conductor pastes	conductor pastes
	dielectric pastes	resistor pastes	dielectric pastes
Connection techniques	solder wetting	adhesive strength	adhesive strength
	leach resistance		
	wire bondability		
	shear strength of soldered and bonded connections		

It is possible to perform a basic characterization of the different thick-film pastes by using these standards. The test of connections such as Solder joints and wire bonds is described in detail in other standards.

The current work on IKTS show that the methods described in Table 1 are often not sufficient. It is clear that in particular the test methods for the characterization of the electrical properties are of high importance. It is necessary to develop them further. This paper would like to give an overview of the possible methods of measurement. The possibilities are explained using concrete measurements.

Electrical measurements

An overview over usual electrical tests is given in Tab. 2 and described as follows.

Tab. 2: Electrical tests

	typical voltage	typical current	pulse or measurement time	application	example for standard
ESD - electrostatically discharge	10 - 30 kV	1 - 10 A (short time)	ns	equipment security, characterization of thick film resistor	DIN EN 61000-4-2
breakdown voltage	500-2000 V	10 mA		characterization of thick film Isolation paste	DIN 41850
insulation resistance	10 - 1000 V	10 nA	min	characterization of thick film isolation paste	DIN 41850
STOL - Short term overload	100 V	1-10 A	5 s	maximum power dissipation of thick film resistor	MIL STD 883
High current capacity	10 V	1-100 A	ms-s	max. current load in combination with thermal characteristic	

Electrostatically discharge

These measurements are used to examine the immunity to electrostatic discharges of single components and systems. The basic principle is the simulation of an electrostatic discharge. There are a number of relevant standards. A non-exhaustive overview is given below:

Tab. 3: Standards for electrostatically discharge

DIN EN 61000-4-2	Electrostatic discharge immunity test
DIN EN 61340-5-1	Protection of electronic devices from electrostatic phenomena
DIN EN 61340-4-10	Test method for the protection of electrostatic discharge susceptible Items
VDE 0847-4-2:2009-12:2009-12	Electromagnetic compatibility (EMC) - Part 4-2: Testing and measurement techniques

There are often further additional standards in the form of company-internal testing routine. Mostly the measurement setups consists of a high voltage generator and a measurement gun. An example of this is shown in the following figure.

Fig 1.: Equipment for ESD Tests (Source Picture: www. emtest.de)

Test samples or the devices were touched with the measuring gun during the test. After that, high voltage pulses are applied with predetermined conditions. At this point, both the use of individual pulses but also pulse trains is common. Typically, test voltages and pulse durations are described in Table 2. Thereafter, the test samples are classified.

For thick film structures this is often carried out of the electrical resistor. The measured resistance is compared to an output resistance. The test samples or component is not passing the test if defined resistance changes are exceeded.

Breakdown voltage / isolation resistance

This both measurements using a similar measuring setup shown in Figure 2.

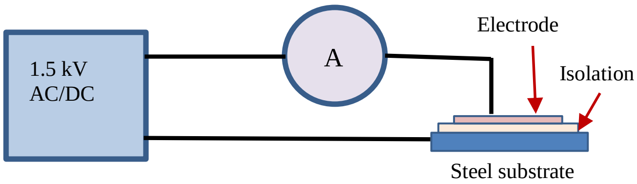

Fig. 2: Setup breakdown voltage / isolation resistance

The measurements are carried out between two electrodes. In the shown case an insulated steel substrate. The first electrode is contacted from the top. The steel itself forms the second electrode. The actual sample is the isolation layer shown in the picture. After connecting the two electrodes to the test instrument, the voltage is increased at a ramp. At the maximum value held for a predetermined time and then the sample is discharged with a ramp up to the zero voltage.

The test can be performed with DC voltage (current during charging of the capacitor) or AC voltage (current through capacitance). The breakdown voltage is reached when the current increases abruptly. The breakdown voltage is shown for some materials in its temperature dependence in Fig. 3.

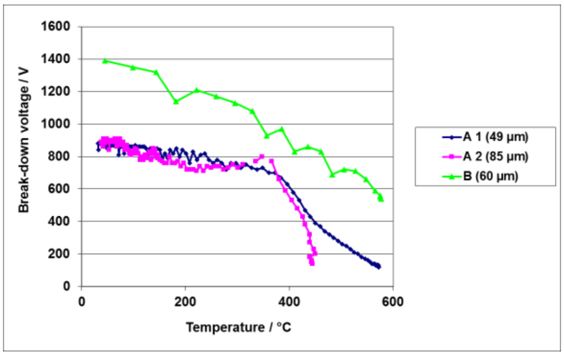

Fig. 3: Breakdown voltage

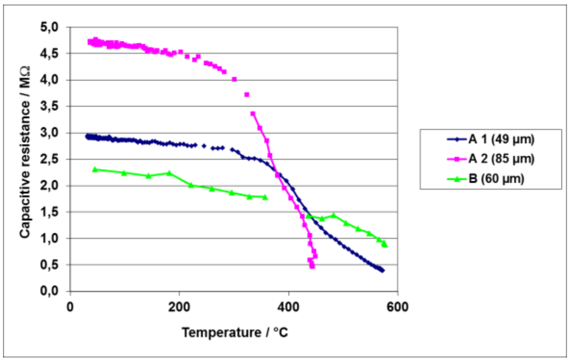

Fig. 4: dielectric characteristic of the material

The measurement of the insulation resistance is carried out with direct current. The measuring voltage is applied to the sample and after a predetermined time (charge time of the capacitor) the current is measured. The measured voltage must be less than the breakdown voltage. An example of such a measurement, including the effect of temperature is shown in the following figure.

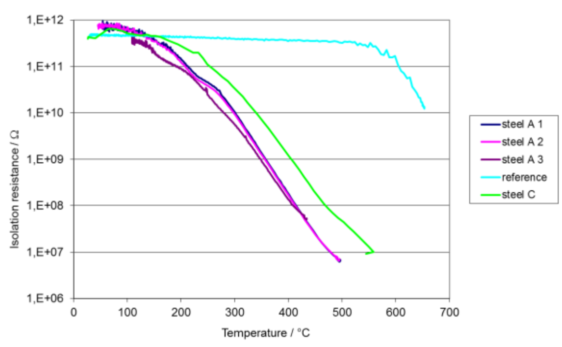

Fig. 5: Isolation resistance

Short term overload - STOL

STOL measurements are used, to determine the maximum power dissipation density of thick film resistors. There are standardized measurements. The test setup consists of a temperature controlled sample holder. On this, the test substrate is mounted and electrically contacted.

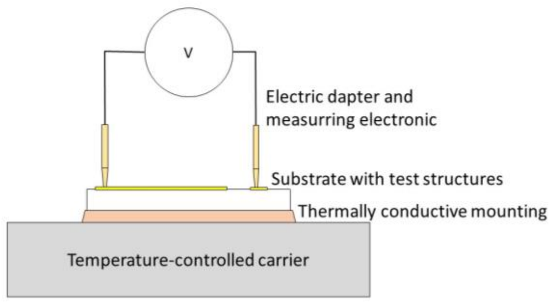

Fig. 6: STOL Test Setup

On the sample geometrically exact test patterns are printed and fired. Using the electrical connections, the resistance of the sample is measured in the cold state (R0). During the measurement the sample is loaded with a defined test voltage for a predetermined time.

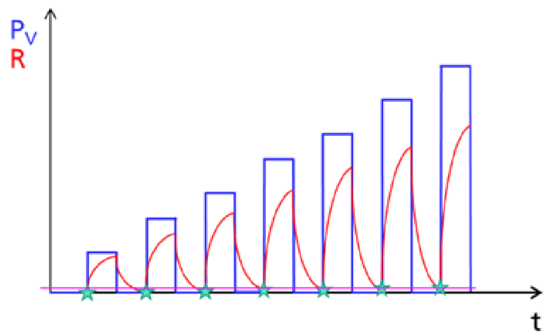

Fig. 7: STOL measurement

Test voltage leads to an applied power loss caused by the electrical resistance of the thick film. Through this, the sample is heated. A pyrometer or an infrared camera records this heating. At the same time, the electrical resistance of the sample in dependency of the sample temperature is recorded.

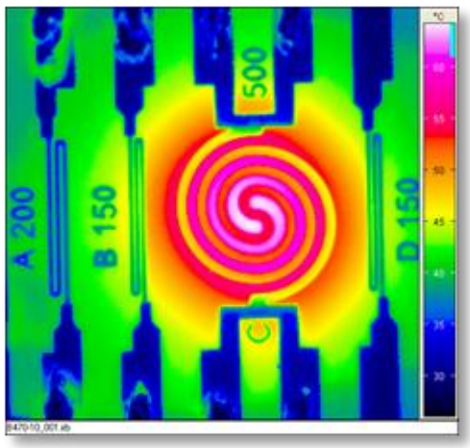

Fig. 8: Heated IKTS sample during STOL test

After a defined test time, the voltage is switched off and the sample cools. After reaching room temperature, in turn, the cold resistance of the sample is determined (Rx) and compared with the value of R0. This is followed by a repeated test cycle. However, this time with a higher test voltage and also by a higher power dissipation. This process is repeated until a rapid change of the resistance is detected.

The boundaries of the test must be defined in the context of the measurements. Typical values for this are in the range of (0.1 … 0.5) %. The usual test voltages and currents depend on the studied resistance decade and are summarized in Table 2.

The following figure shows an evaluation of such real measurements with different resistance patterns. Clearly visible is a permanent resistance change above 400 W for all resistors. This is caused by the damage of the resistors by the introduced power dissipation.

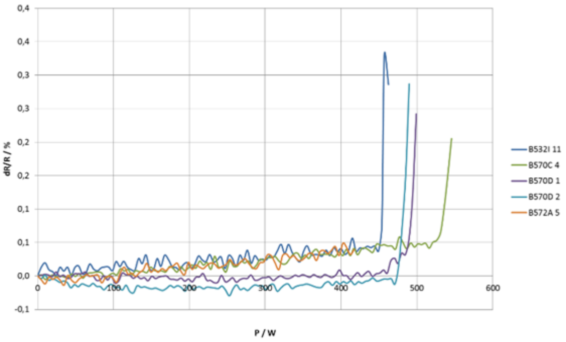

Fig. 9: Stoll measurements

After the determination of this specific power dissipation, it is possible to calculate the maximum power dissipation density for the examined thick-film paste. These values are in any case part of the respective pastes data sheet.

High current capacity

An important parameter of electronic circuits is the high current capacity of a conductor materials or electrical contacts. As opposed to STOL measurement is carried out in a much lower resistance region. In actual developments at IKTS this STOL measurements are developed further and a number of measuring systems were designed and realized.

In general, the basic test setup follows again Fig. 2. As seen in Table 2 the voltages are in a lower range than that of the STOL measurements. The currents used up to 100 A. Tests can be applied under continuous load or in pulsed mode.

The high-current measurements described below are used to determine the maximum current carrying capacity of conductor lines and vias. This is done in close connection with the heating of objects.

Conductor lines can be heated up to a defined temperature or even to destruction.

Furthermore, the comparison of different conductor materials each other is possible. A typical IKTS substrate is shown in fig. 10.

In the upper part of the substrate are located structures to characterize soldering and wire bonds. However, such studies are not the subject of this paper. In the lower part of the substrate different measurement geometries are available.

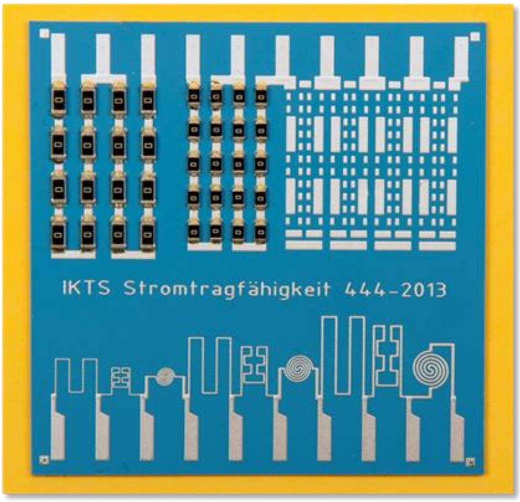

Fig. 10. IKTS test sample

On the substrate are shown varied line width in a range of 100, 150 and 200 microns. The three different geometries simulate different coverages on the substrate. By use of the test substrate described, various measurements are possible.

A possible investigation is the comparison of the heating of a conductor line with increasing pulse load. This is shown on the following figure.

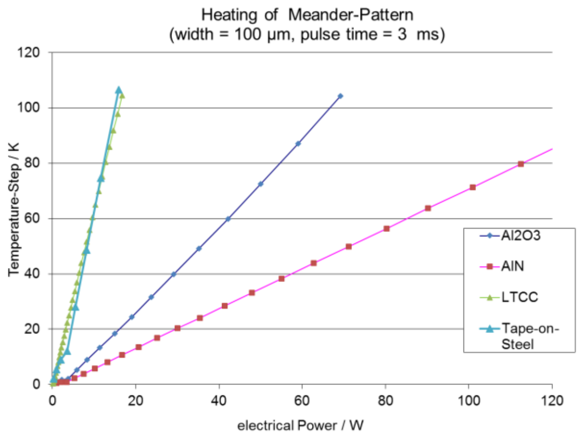

Fig. 11: High current measurements

It can be seen that with increasing current also increases the temperature. Comparison of different conductor widths can be used to improve track layouts to reduce paste consumption.

Furthermore, as the substrate material Alumina, AlN and LTCC are compared. Because of the different thermal conductivities each material shows different heating during the same test conditions. As known, the thermal conductivity of AlN is the greatest in this comparison. Therefore, the heating of the structure is the lowest.

Another example is given in the next picture. Here the substrate materials Alumina, AlN and LTCC are compared again. The line width for all samples is 100 micron. In addition the coverage of the sample surface is shown (indicated by L...Low, M…Medium an H…High coverage according to Fig. 10). Target of the investigation was to determine which current pulse loads are permissible not to exceed a maximum heating of 100K.

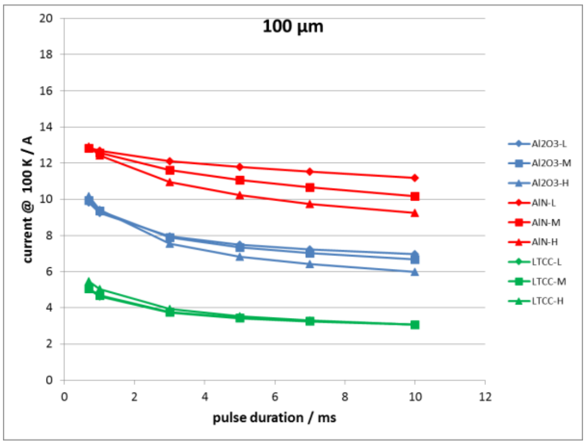

Fig. 12: Comparison of substrate materials

Again, it is clear that AlN shows the best values due to the very high thermal conductivity. For LTCC very low loads are permitted. Also clearly shown is the influence of the different coverages.

Summary

Characterization of thick film pastes can be carried out according various standards in dependency of the paste type.

The current work on IKTS shows that the test methods for the characterization of the electrical properties are of high importance. Results can be used to increase reliability of high power thick film structures or to decrease paste consumption.

In the paper gives an overview of different measurement methods. The function was described by means of selected measurements.