peters

Coating Innovations for Electronics

REPORT

Report 148: Carbon-conductive inks – Fields of application and potential for rationalisation and cost reduction

Authors: Dipl.-Ing. Rüdiger Dietrich, Dipl.-Ing. Johannes Tekath

Contents

LP 152608 E-2 / ref-148e.002

Introduction

The use of carbon-conductive inks constitutes a low-cost method of applying conductors and resistors to various types of plastic, polyester/polyimide films, conventional laminate, ceramics and other materials by means of the screen-printing process.

Carbon-conductive inks are used to substitute gold, manufacture resistors, cross-over conductors, shielding surfaces and in place of discrete resistors, etc. Expensive precious metal coatings very often can be dispensed with and in addition it is possible to replace double-sided plated-through hole circuits by single-sided printed circuit boards.

Thus these ink systems enable significant cost-saving and alternative concepts in the manufacture of printed circuit boards.

Permanent cost-saving is a must in the printed circuit board industry, like in all other industries. At the same time, however, the quality standards have to be maintained. With printed circuit boards that are produced in medium and large series', cost-saving proves a particular asset. These series', mainly for so-called "consumer electronics" are subject to the greatest price pressure so that cost-saving in the production process is one of the decisive factors for the economy and competitiveness of the end product.

Costs can be saved by replacing expensive raw materials by more economical ones and by a simplification of the production process. The employment of carbon-conductive inks in the production of printed circuit boards combines both the use of economical materials and the simplification/rationalisation of the production process.

The substitution of gold by carbon-conductive ink on contact points not only eliminates the necessity of using the extremely expensive raw material "gold" but also the labour-intensive plating process.

When double-sided, plated-through hole circuits are replaced by single-sided printed circuit boards with cross-over carbon conductors, the savings are even more substantial because, besides the cost for the wet processing in the course of the through-hole plating, also the separate treatment of the two printed circuit board sides can be disregarded. Furthermore, single-sided base material can be used instead of the double-sided copper-clad base material. Besides this cost-saving item and the simplification of the production phases, the use of carbon-conductive inks renders the production process safer.

If carbon-conductive inks are used to print resistors directly onto the base material the effort involved in assembling the printed circuit boards is reduced and in the case of multilayers it may even be possible to save on layers.

The following is a description of the fundamental character of carbon-conductive inks and a summary of their numerous possible applications. The information was established on the basis of laboratory and practical experience and is to render a possible problem-free introduction of carbon-conductive inks for the applications described. A model cost accounting based on a user operation indicates the extent of the cost savings.

Theoretical fundamentals

Screen-printing inks as well as carbon-conductive inks consist of one or more paint binding agents (polymers), solvents and fillers or pigments, respectively. In the paint production process the solid ingredients are dispersed into the liquid ingredients, i.e. they are distributed as finely and evenly as possible.

After application of the ink, the solvents evaporate and following a curing mechanism, which varies from paint system to paint system, a polymer film remains on the substrate into which the solids are homogeneously embedded. In the case of a carbon-conductive ink this lacquer coating is electrically conductive due to the formulated substances. Without these conductive substances the ink film is an insulator because the normally used fillers and pigments are non-conductive and the polymers with a volume resistance of > 10^{10} Ω x cm have insulating properties.

The concentration of the conducting particles must be high enough that a contact of the individual particles or a particle distance of < 10 nanometers enables the flow of current within the ink system. The concentration range in which the resistance drops significantly is called the percolation range [Fig 1].

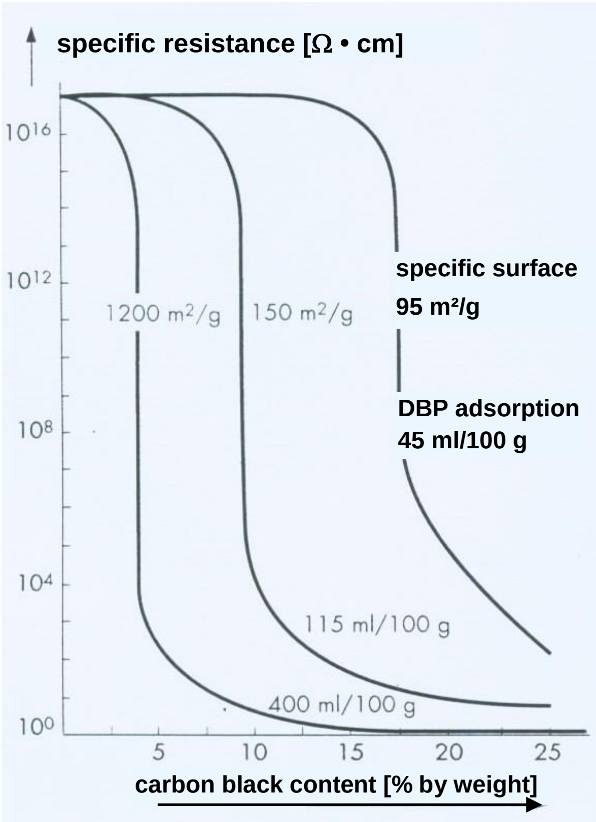


Fig. 1: specific resistance under the influences of specific surface and structure of different conductive carbon blacks in propylene as function of the carbon black content

The maximum concentration of the conducting particles is mainly dependent on their structure and the specific surface. Only so many conductive solids can be added to the paint as can be homogeneously embedded by the polymer. This is the only method of achieving a firmly adhesive, non-porous (dense) and closed lacquer coating.

Generally, first-grade conductors such as metal or precious-metal powder and carbon powder only can be used as conducting matters. Compared to carbon powders, metal or precious-metal powders yield conductances that are higher by about three tenth powers. This is mainly due to the higher specific conductivity of metals but also to the smaller specific surface of metallic powders so that higher concentrations in the lacquer are possible.

On the other hand, metal or precious-metal powders, among others, entail the problems of oxidation/corrosion and migration as in the case of the frequently used silver. Furthermore, the high material price of precious-metal powders adversely influences the cost accounting. It would go too far in this paper to illustrate all the advantages and disadvantages of each type of conductive ink, for this reason the following will deal only with carbon as a conductive substance accordingly.

In its elementary form, carbon occurs as monocrystalline diamond in stratified layers as graphite. Decomposition of organic matter with the exclusion of air or incomplete combustion results in carbon in a third amorphous form, either in coarse masses as coal or in finest dispersion as carbon-black (soot).

The individual character of soots is determined in particular by the specific surface and the structure. The specific surface of 80 to 1,200 m²/g decides the percentual amount of soot to be used. The structure is determined by the coalescence of the primary particles during the production process and is one of the decisive factors for the necessary packing density in the lacquer coating.

Since soots are produced synthetically, structure and specific surface can be easily controlled during the production process. From the large variety of different soot types available, the most suitable types for the production of conductive inks have to be selected on the strength of structure and specific surface.

On account of the more amorphous structure, however, an adequate packing density cannot be obtained with soots alone, so that graphites with a more stratified structure are added. The combination results in conductive inks which meet the aforementioned requirements in the cured lacquer coating, i.e. direct contact of the conducting particles.

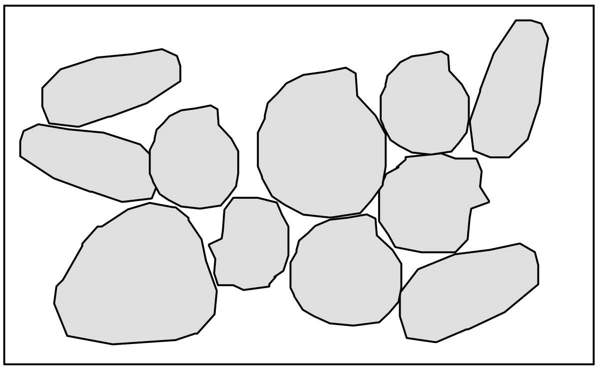


Figure 2: Packing density of soot and graphite particles in dried carbon-conductive ink

Generally, resistance values of 14 Ohm/☐ at a coating thickness of 25 µm can be obtained with carbon-conductive inks.

By selecting the suitable polymers, the following properties can be achieved:

- easy processing (1-pack system)
- good adhesion to different substrates
- high mechanical and chemical resistance
- nearly no change in resistance after soldering processes and/or after hot-air levelling
- favourable curing conditions, i.e. lowest possible curing temperature and short curing times

Use of carbon-conductive inks

In addition to the printed circuit board technology, carbon-conductive inks are also employed in other sectors of electronics/electrical engineering. By means of carbon-conductive inks, static electricity can be discharged from plastic components and other insulators, such as paint coatings. This application is mainly used in the housing industry (television and computer housings) with the paint being relatively fluid and sheet-sprayed onto the components.

Carbon-conductive inks for laminate keyboards

From a design point of view, carbon-conductive inks are used for the production of laminate keyboards. The entire conductor pattern and the contact areas are printed on plastic film, such as polyester or polyimide, using carbon-conductive inks. For this application, either two separate films are used or one film, the two sections of which are folded together. There is an insulating separator film between the two films and the entire laminate keyboard is masked by a printed cover foil.

The switch contact is effected by finger pressure on previously determined areas of the film at which the separator film is cut out. The contact is effected by touching of the upper and lower films and it is interrupted again as soon as the pressure is relieved. A service life of up to 25,000,000 switching cycles has been established in laboratory tests. This field of application is mainly related to keyboards for computers and control units as well as electronic games.

When selecting suitable carbon-conductive inks for this range of application, special attention must be paid to good adhesion to the substrates used, adequate elasticity as well as high abrasion resistance:

In printed circuit board technology, carbon-conductive inks can be employed for various applications:

Carbon-conductive inks as contact materials, substitution for gold

A partial gold plating on printed circuit boards is mainly effected for the purpose of protecting contact points such as edge connectors, tip contacts and sliding contacts from mechanical and chemical attacks in order to achieve a long service life. In the case of tip contacts. The use of carbon-conductive ink eliminates the need for gold plating.

This means substantial cost-saving because the following operations are required for a partial gold plating:

- covering the areas that are not to be gold plated
- electro-deposition of nickel
- electro-deposition of gold
- stripping of the plating resist (mostly in solvents)
- coating the areas that are not gold plated with solder resist for subsequent soldering processes.

If the same tip contacts are produced with carbon-conductive ink, it is sufficient to overprint the contact areas with carbon-conductive ink and to protect the rest of the printed circuit board with solder resist. The cost saving is achieved not only by saving gold but mainly by shorter and simpler production phases.

The tip contacts produced by means of carbon-conductive ink are safely protected from environmental influences and corrosion and guarantee a safe contact. The German Federal Post Administration specifies a load of 1,000,000 contacts for tip contacts. Long-term tests have proven that carbon tip contacts are capable of more than 25,000,000 contact cycles, which is equivalent to a life expectation of over 100 years.

Carbon-conductive inks for sliding contacts, regulators

With their increasing abrasion resistance carbon-conductive inks conquered a further field of application as sliding contacts, for instance for automotive applications. Within the scope of the necessary cost reduction expensive gold contacts are also being replaced by printed carbon-conductive ink sliding contacts in this sector. With optimum process parameters up to 125,000 contact cycles can be realized.

Tip contacts without metal base
With the aforementioned process it must be ensured that the metal area operating as the tip contact is completely covered with carbon-conductive ink in order to avoid corrosion and thus contacting problems. This requires a relatively high level of screen-printing precision. This production phase can be simplified even more substantially by printing this contact area onto the base material using carbon-conductive ink only.

In the layout design, the conductor is routed just close to the contact into an area that will be covered with solder resist later. From this point, the conductor is continued as a carbon-conductive ink print and the contact is also printed with carbon-conductive ink.

This process simplifies the production even further and, at the same time, makes it safer because, compared to the covering of copper contacts, the precision level required in screen-printing does not have to be so high and the contact areas are safely covered by a solder resist insulation.

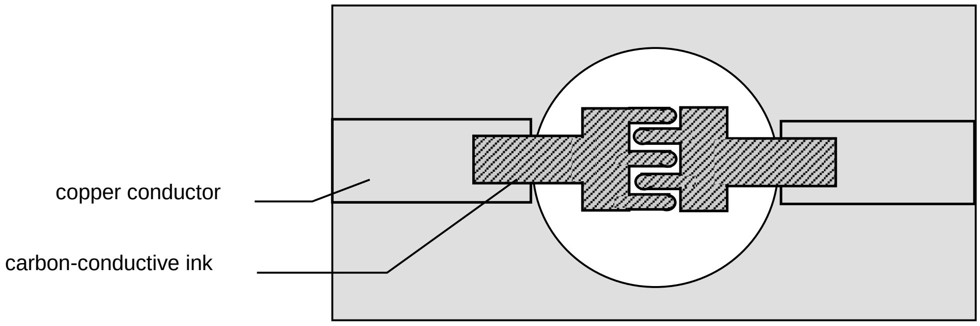


Figure 3: Tip contacts without metal base

Carbon-conductive inks as components
Used as components carbon-conductive inks can considerably contribute to the miniaturization of a pcb.

Carbon-conductive inks can be printed as resistances on outer and inner layers. Moreover, they can assume the function of a potentiometer or are conditionally suitable for shielding purposes.

Further advantages are:

- improved layout design
- single-sided assembly, thus one-time reflow soldering
- low inductivities on account of short network connections
- all resistances required are created at the same time.

Carbon-conductive inks as etch resists
The use of carbon-conductive ink as an etch resist is an alternative process for the two procedures described before. In this process, the entire conductive pattern including the contact areas are printed on copper-clad base material using carbon-conductive ink. The uncoated copper is removed and the finished circuit with carbon-conductive ink-protected conductors and contact areas is available.

Besides the careful adjustment of the etching baths to the conductive ink used, patent rights have to be observed with respect to this process.

Carbon-conductive inks for the production of cross-over conductors
The technically most interesting application for carbon-conductive ink, which, at the same time, has the greatest cost-saving effect, is the production of cross-over conductors. This process, also

called CCP (**C**rossover **C**onductive **P**aint), allows the replacement of a double-sided, plated-through hole printed circuit board by a single-sided board with carbon contacts. Such a printed circuit board is built up as follows:

To begin with, a single-sided copper printed circuit board is produced. Instead of hole and plated-through holes, a contact area is provided for at the interconnection points to the next layer. The printed circuit board is then insulated by means of a lacquer suited as an insulating lacquer (for instance solder resist), with the exception of the tip contacts and the contact areas. It must be ensured that the insulation print is absolutely non-porous and the edges of the copper conductors are covered. Depending on conductor configuration and spacing, the solder resist may have to be printed twice with an intermediate drying cycle. In order to achieve a safe edge covering, base material with 17.5 µm copper is normally used for this technique because edge protection is thus ensured more easily.

In the next operation, the carbon-conductive ink is printed onto the solder resist between the corresponding contact areas. At the same time, also the tip contacts are defined by means of the print. The following operation is another insulation print over the cross-over carbon conductors and the contact areas. In a final operation, the tip contacts can be protected by a peelable solder resist.

From a design point of view, attention has to be paid to the fact that the conductivity of carbon-conductive ink is not as high as that of copper conductors. Thus, the conductor length is limited by the resulting resistance. There are possibilities, however, to produce much longer conductors as described below.

Carbon-conductive inks as anti-migration agents

The previously described cross-over conductors can also be produced with silver- conductive ink instead of carbon-conductive ink. On account of the considerably lower electrical resistance of silver-conductive inks, much longer conductors can be printed with an identical overall resistance compared to the carbon-conductive ink. The use of silver-conductive ink, however, entails the problem of silver migration, i.e. applied voltage and increased air humidity result in a silver migration that may lead to short-circuits. This problem, however, can be solved as follows:

The silver-conductive ink is printed over the insulation lacquer as a cross-over conductor. Contrary to the previously described process with carbon-conductive ink, the silver conductor is not routed onto the contacting area but ends just short of the contacting point. A wider carbon conductor is then printed over the silver conductor and the contacting area. This leads to the following results:

- on account of the lower resistance of the silver-conductive ink, a longer cross-over conductor can be selected
- the complete covering of the silver conductor with carbon-conductive ink eliminates silver migration
- from a design point of view, the higher resistance of the carbon-conductive ink must be considered only for the areas between the silver-conductive ink and contacting area

Manufacturing heating elements with carbon-conductive inks

For applications such as heated mirrors in automobile electronics, a layer of carbon-conductive ink can be printed on the relevant parts which heats up when exposed to electric current. This is an economical method of heating wing-mirrors. However, when selecting a suitable carbon-conductive ink care must be taken that the resistance does not change with the increasing number of heating phases such that a heating effect is no longer achieved. We recommend conducting pre-tests involving artificial ageing (tempering at planned operating temperature).

Design notes for the use of carbon-conductive inks

Substitution of gold on contact points

This is the simplest and least problematic application for carbon-conductive ink. The following notes merely serve the purpose of proving additional safety in production.

Overprinting of copper tip contacts

In order to avoid copper corrosion, the contact area must be completely covered with carbon-conductive ink. If possible, the contact points should not be arranged in a meander configuration, because overprinting of these areas would make excessively high demands on the screen-printing precision. Semi-circular tip contact areas which can be securely overprinted have proven to be successful. In any case, the carbon-conductive ink print should be effected prior to the solder resist print so that the transition point - uncoated copper/copper overprinted with carbon-conductive ink - is under the solder resist.

Printing of sliding contacts

On account of their high graphite content carbon-conductive inks exhibit good sliding properties. Nevertheless, some items must be observed to ensure that the carbon-conductive ink can fulfil the requirement for several million circuit cycles:

- The material must not be abrasive and the slider not be sharp-edged.
- If the slider passes areas that are free of carbon-conductive ink damage to the edges of the carbon-conductive ink may result. This can be avoided by printing a suitable dielectric into the gaps between the solder resist and carbon-conductive ink to compensate the height difference. The following diagram demonstrates the realisation of this solution:

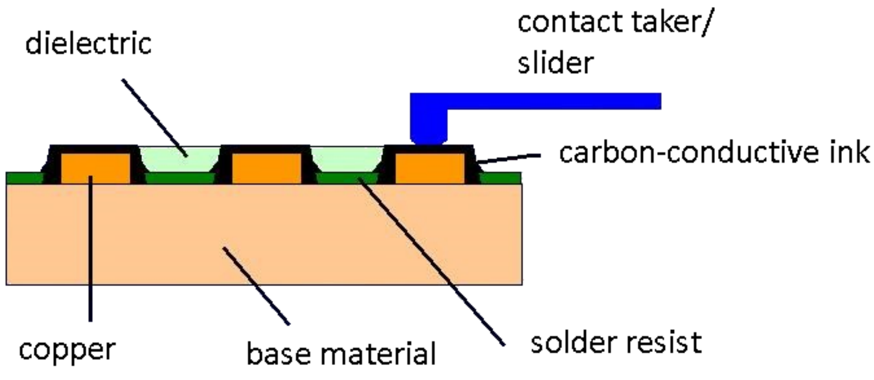


Figure 4: Printing of sliding contacts with carbon-conductive inks

The printing process of the carbon-conductive ink must be optimised in such a manner that a layer thickness tolerance of ± 5 µm is not exceeded.

Overprinting of contact fingers

When using carbon-conductive inks as contact materials for contact fingers it must be observed that only limited contact cycles can be realised. However, dependent upon the feather contacts used generally approx. 20 cycles are possible.

Tip contacts without metallic substrate

In this process, two major items must be observed:

- The transition point of the copper conductor to the carbon conductor must be securely covered by a solder resist insulation.

- The carbon area must clearly overlap the copper conductor so that, even in case of print misalignment, the copper conductor is positively contacted. An overlap ping distance of 1.5 mm has proven ideal in practical operation.

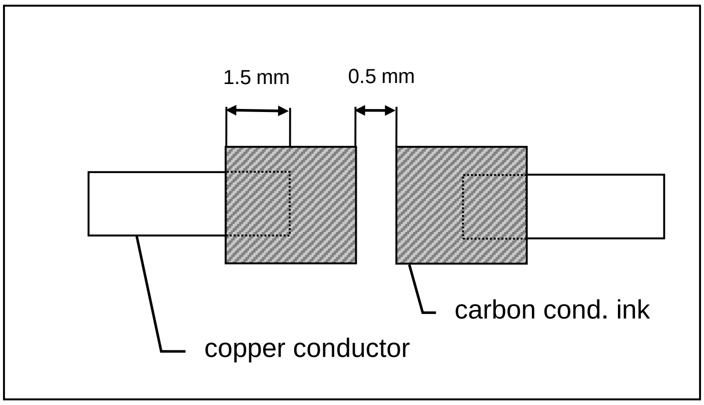


Figure 5: Tip contact without metallic substrate

Cross-over conductors

When producing cross-over conductors, the conductivity of the carbon-conductive ink is of particular importance. The maximum permissible resistance of a conductor and the specific resistivity of the carbon-conductive ink are the decisive factors for the conductor length. If the conductivity of the carbon-conductive ink is not sufficient for the desired conductor length, a silver-conductive ink can be printed underneath the carbon-conductive ink, as described above, thus minimising the overall resistance of the conductor or enabling the production of a longer cross-over conductor.

The fundamental considerations are identical for both alternatives:

To begin with, the resistance for the carbon-conductive ink has to be specified. As mentioned above, resistances of 14 Ω//☐ can be reached with carbon-conductive inks. However, this value depends on the coating thickness and the processing parameters, such as drying. The stated resistance refers to a coating thickness of about 25 µm. As the coating thickness may vary when overprinting the insulated copper circuits and the processing parameters also influence the resistance, the design should assure a resistance that is higher than the 14 Ω/☐ mentioned.

Usually the resistance is measured across the diagonal of a 1 cm² area. Because there is no standardised method for measuring the resistance of conductive inks at present, we recommend changing the above mentioned measuring method and measuring the resistance parallel over a 1 cm² area.

As far as the design is concerned, this results in the ability to approximately calculate the resistance for the intended conductor width and thus the conductor length by dividing the area.

The following principle can be used to measure resistances with a square footprint (resistance/square):

- The resistance is defined as:

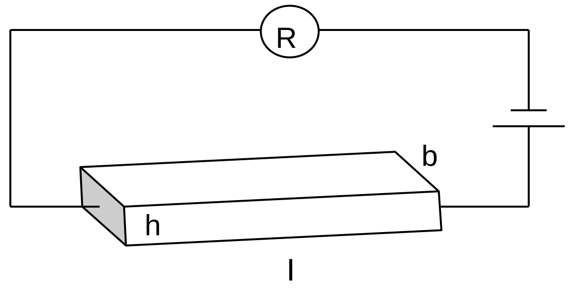
$$R = \rho \cdot \frac{l}{A}$$

ρ = specific resistance $\left[\frac{\Omega \ cm^2}{cm} \right]$

l = length of resistance [cm]

R = resistance [Ω]

A = cross-section area [cm²]



b = width of resistor [cm]
h = height of resistor [cm]

- where:
  $A = b \cdot h$
- thus the following applies:
  $R = \rho \cdot \frac{l}{b \cdot h}$

- In case of a square surface of the resistor the following applies:
  b = l, that means, $\frac{l}{b} = 1$.
- and the result is:
  $R = \rho \cdot \frac{1}{h}$

With square surfaces the resistance of the carbon-conductive ink – at a given coating thickness (as a rule approx. 25 µm) – is a material constant.

This quantity is called layer resistance and is expressed in the unit Ω/☐ or Ω/square.

In case of simple non-square geometries the layer resistance is expressed and described by a corresponding multiple (e.g. 3-square, etc.).

In order to enable a continuous control of the conductive ink print during production, a measuring length should generally be integrated on the outer edge of the printed circuit board. Corresponding steps should be taken in the layout phase. Basically, the concept of the measuring length is not of importance, but a nominal resistance with acceptable tolerances must be specified for this measuring length which makes it possible to conduct spot measurements of the conductivity during production and to take immediate corrective action.

Since the technology of providing cross-over conductors with carbon-conductive ink is mainly employed in mass production, particular emphasis should be placed on designing the printed circuit board in such a manner that reliable production is possible. In order to achieve this security, a well-known manufacturer of such printed circuit boards, has established, among others, the following in-house design rule.

General construction advice for the use of carbon-conductive inks

- minimum carbon conductor width: 1.0 mm
- distance of conductive ink conductors parallel to each other: 0.5 mm
- distance of conductive ink conductors to punched contours: 1.0 mm with pure carbon conductors
- distance of conductive ink conductors to punched contours: 1.0 mm, if insulated copper conductors were overprinted with carbon-conductive ink

- distance to perforated contours: 1.6 mm with pure carbon conductors
- distance to perforated contours: 2.1 mm if insulated copper conductors were overprinted with carbon-conductive ink
- Interface with polymer paste > 0.3 mm on all sides.

As already stated in chapter “Carbon-conductive inks as anti-migration agents”, a carbon-conductive ink can also be employed as an anti-migration agent for silver-conductive ink. In such applications, special care must be taken that the silver conductors are completely covered with carbon-conductive ink. This aspect is of particular importance when designing the printed circuit board.

The following illustration shows a possible layout for such a circuit.

- insulation distance > 0.3 mm on all sides
- pay attention to minimum differences in height (thin copper and build-ups)

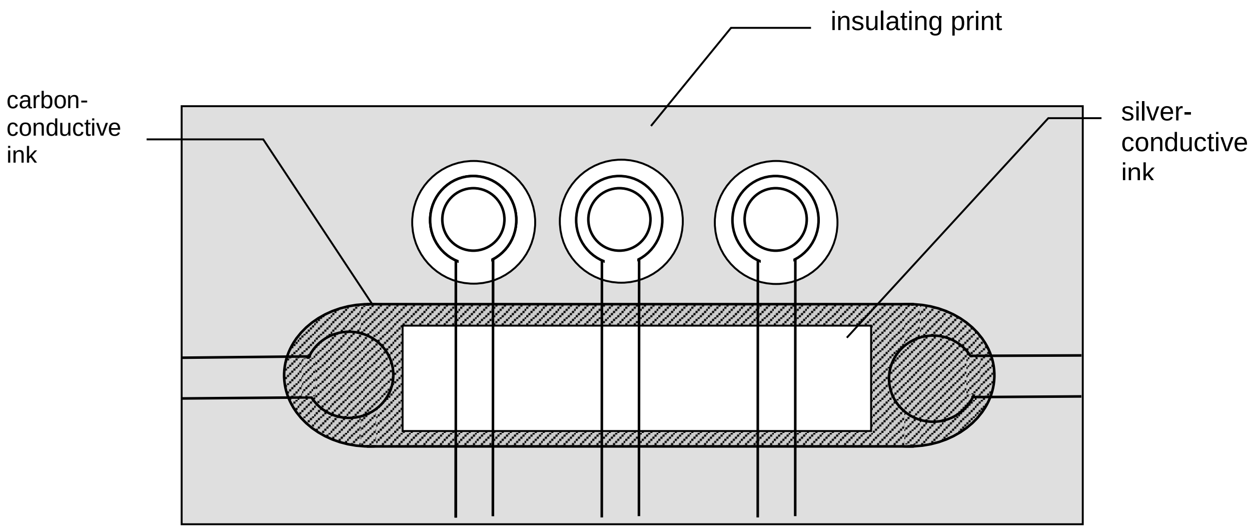


Figure 6: Printing over cross-over conductors

Use of carbon-conductive inks as passive components

Resistance pastes are available in components in the range of 14 Ω/☐ up to 1 MΩ/☐. Each resistance can be adjusted by mixing the carbon-conductive inks with special insulating pastes.

When designing the layout the following construction characteristics should be observed:

- The Cu landing areas should have a minimum size of 500 x 400 µm.
- The width of the carbon-conductive ink should be at least 450 µm otherwise the screen printing edge blurring tolerance is reached.
- The distance between Cu pad – Cu pad should be at least 1 mm.

For guidelines on calculating the area please refer to chapter “Crossing conductors”.

Adjustment of resistances by means of laser trimming

If the requirements on the exactness of the resistances are very high the resistance value can be corrected upwards by reducing the conductor profile. This is effected by means of so-called laser trimming.

By collateral cutting and abrasion of the previously cured carbon-conductive ink the current track is narrowed and the resistance value increased.

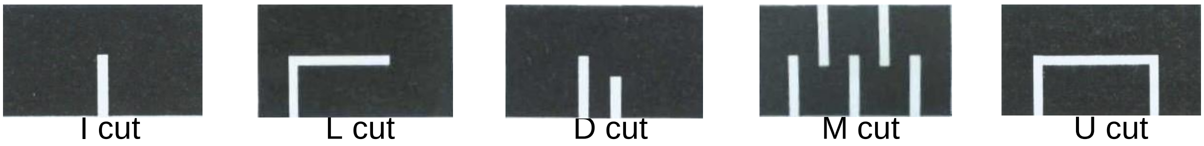


Figure 7: examples of laser trimming cuts

There are various trimming cuts that differ in the trimming exactness, trimming time and the change in the current noise, however which we shall not expand upon here.

Processing

When processing carbon-conductive inks, particular attention must be paid to some parameters in order to ensure that the construction-specified resistances of the carbon areas or conductors are achieved.

Applying carbon-conductive inks by screen printing

Carbon-conductive inks are usually highly thixotropic ink systems. To achieve the viscosity necessary for processing, these inks must be carefully mixed prior to their application. After mixing, a significant reduction in viscosity is noticeable which guarantees easy printing. If the ink is left to stand its thixotropy will increase again which is why it is recommended to remix the ink after longer breaks in processing.

Naturally with regard to the screen printing parameters the recommendations of the specific ink manufacturers should be observed. Generally, however, polyester fabrics 43-80 to 55-65 (43–55 T acc. to old nomenclature) or corresponding steel meshes with a screen tension of at least 18 N are suitable for most applications and squeegees of 75 - 90 Shore-A hardness with angular cuts have proven to be ideal. In this respect a squeegee angle of approximately 75 - 80° should be observed.

Coating thickness of carbon-conductive inks

The conductivity of a carbon-conductive ink is always dependent upon the overall cross-section of the conductor (width x height). For this reason, in addition to the specific resistivity of the ink, our technical reports, also indicate the layer thickness to which this value refers. As a rule, the specific resistivity is related to a coating thickness of 25 to 30 µm. In practical operation, very often a compromise has to be found between coating thickness and desired definition because the finer the selected screen fabric, the better the definition and the identification of details. The coating thickness, however, decreases.

The compromise eventually adopted depends on the application in question. Generally, printing should always be as coarse-meshed as possible because the thicker the ink coat, the lower the resistance and the more non-porous and dense the film.

Dilution of carbon-conductive inks

The conductivity of a carbon-conductive ink not only depends on the screen fabrics but also on its solids content. The solids content indicates how much percent by weight of the ink remains on the printed circuit board after drying. This value is decisive for the specific properties of the carbon-conductive ink because the conductivity specified in the technical report refers to the dried coating.

However, the solids content of the lacquer can be modified by the user by adding thinner. The more thinner added, the lower the solids content and also the coating thickness of the dried ink. This will increase the resistance. There are two reasons for diluting the ink in the production cycle:

When changing over from a coarser to a finer screen fabric, the ink normally has to be diluted a little in order to ensure an equally good printing of details. Attention must be paid to the fact that not only the finer screen fabric but also the addition of thinning agent result in a thinner ink coat and thus a higher resistance. Therefore, it is mandatory to compare the theoretical resistance with the actual resistance achieved.

In many cases, a screen-printing ink has to be diluted in the course of the production process because the viscosity has increased due to the evaporation of solvents on the screen. This dilution normally does not create any problems because merely the evaporated amount of solvent is replenished. Thinning agent should never be added „by instinct“, but in a controlled manner using a viscosimeter until a specified nominal value is reached.

Changing the resistance by mixing with insulating paste

In order to achieve higher resistance values, some carbon-conductive inks can be adjusted by admixing special insulating pastes. Such admixings are possible in any ratio so that a specific increase in resistance can be achieved by means of a corresponding admixture.

The following diagram illustrates an example of how the resistance values change by admixing the carbon-conductive ink with insulating paste:

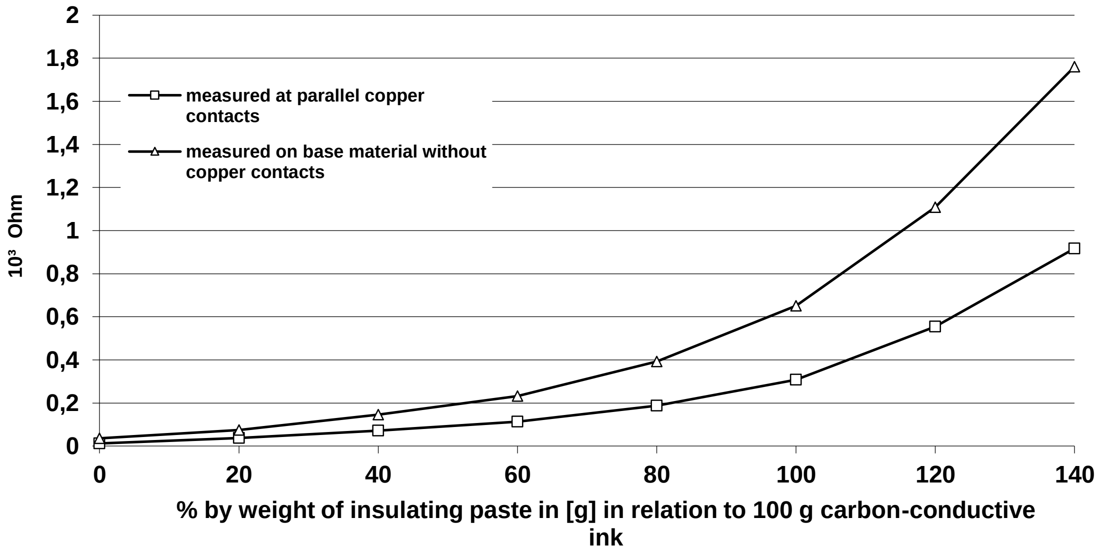


Figure 8: Modifying the resistance values of a carbon-conductive ink by admixing insulating paste

Drying of carbon-conductive inks

Most carbon-conductive inks are dried thermally. As the resistances indicated refer to a fully cured coating, the drying conditions, i.e. both temperature and drying time, have to be strictly observed.

Drying in the drying oven

In many printed circuit board productions, the circuit boards are first deposited in stackers and then cured together. With his procedure, attention must be paid to the fact that, at the beginning, the temperature of the drying oven drops considerably and, in addition, the cold mass charge has to be heated. As the curing time is related to the curing temperature, the heat-up period of the oven has to be added. According to our experience, the curing oven will return to the curing temperature about 10 minutes after the feeding of the cold stacker.

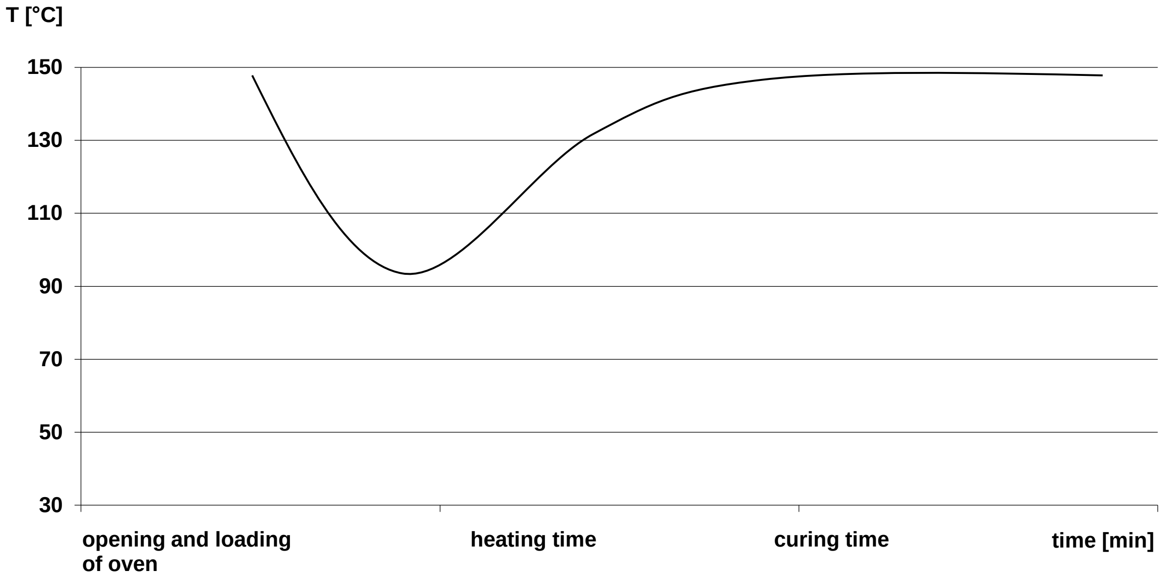


Figure 9: Temperature flow in the drying oven after loading

IR drying

Special solvent combinations in some carbon-conductive inks render a curing by means of IR radiation possible. Advantages in comparison to a convection dryer are a considerably faster curing and the achieved reduced process times as well as an increased process safety compared to a batch process. Particularly the dependence of the resulting resistance upon the curing temperature leads to varying values on account of different oven temperatures.

The process safety in case of an IR cure is < 2 Ω/☐ resulting resistance.

The curing result depends to a large extent on the IR dryer used and/or its lamps. Therefore, the optimum temperature profile of the equipment should be determined by means of pre-trials.

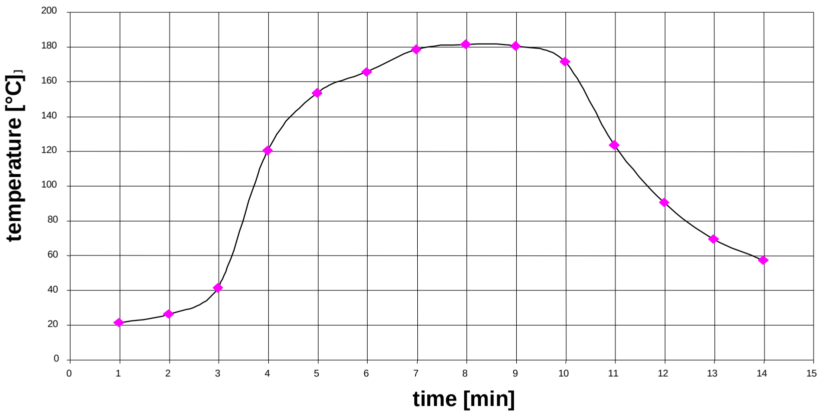


Figure 10: Model IR temperature profile for a carbon-conductive ink

Moreover, when curing carbon-conductive inks it must be observed that they are not cured together with 2-pack epoxy resin lacquers (solder resists) in one oven. During the curing process decomposition products may escape from the epoxy resin lacquers that retard the curing of the carbon-conductive ink and/or effect a change in the resistance.

Overprinting of carbon-conductive inks

Besides good mechanical properties, most carbon-conductive inks also have very good chemical resistances. This good chemical resistance, however, is not the only decisive factor when considering whether the carbon-conductive ink area and conductors should be protected by an additional lacquer coat. Even if the chemicals do not attack or destroy the conductive ink film, substances may diffuse into the conductive ink and increase the resistance.

For this reason it should be determined whether carbon-conductive inks must be protected from environmental influences by means of a solder resist and from flux in the soldering process by means of a peelable solder mask.

These peelable solder masks used as protective lacquers, however, must be particularly suited for the use on carbon-conductive inks in order to avoid an increase in the resistance as a result of an interaction between the protective lacquer and the carbon-conductive ink.

UV or UV-sensitive 2-pack lacquers are especially suited as solder resists. As peelable solder masks only lacquers exclusively developed for this purpose can be used.

Cost comparison

The use of carbon-conductive inks for the production of tip contacts and cross-over conductors simplifies the production of printed circuit boards because this eliminates the otherwise necessary wet process (plating). Furthermore, a better automation of the production becomes possible. These reasons result in substantial cost savings.

A cost calculation is naturally different for every production plant. The cost comparison mentioned before is based on the production cost calculation of a big German manufacturer of printed circuit boards. A simple pcb in “print and etch technology” with a solder resist print is used as factor 1. A selective gold plating, for example, effects an increase in costs to the factor 2.6.

Example 1:	
printed circuit board with selective gold plating:	approx. factor 2.6
printed circuit board with carbon tip contacts:	approx. factor 1.2
Saving	approx. 54 %

Example 2:	
double-sided, printed circuit board with plated-through holes and selective gold plating:	approx. factor 3.2
single-sided printed circuit board with cross-over conductors and carbon tip contacts:	approx. factor 1.4
Saving	approx. 56 %

This cost comparison proves that the production cost can be reduced by more than 50 per cent when carbon-conductive inks are employed.

Closing remarks

In the course of the last decades, the use of carbon-conductive inks for the application described has increasingly prevailed in the printed circuit board industry and will increase considerably for individual new applications. When employing conductive lacquers, the items mentioned have to be considered in layout and production. The adaptation of these recommendations will render possible the application of carbon-conductive inks without any problems and thus contribute to the realization of a substantial saving of costs.

Bibliography

/1/ Werner Jillek, Gustl Keller: Handbuch der Leiterplattentechnik, Volume 4
in collaboration with 31 co-authors, among others Werner Peters, Rüdiger Dietrich, Michael Müller and Dr. Manfred Suppa (all staff members at Lackwerke Peters), Eugen G. Leuze Verlag, Bad Saulgau, 2003, ISBN 3-87480-184-5

/2/ Karl-Heinz Näser: Physikalische Chemie, 18. Auflage,
VEB Deutscher Verlag für Grundstoffindustrie, Leipzig

/3/ VDE 0111: (DIN 57.111) Isolationskoordination für Betriebsmittel

/4/ EPP 2/97 Boards in Carbontechnik, Hubert Beck, Metalex

/5/ SMT 8/96 Entwicklungstrends bei modernen Leiterplatten, Heinz Bleiweiß,
Siemens AG, Karlsruhe

/6/ Horst Ferch: Pigmentruße, aus der Reihe „Die Technologie des Beschichtens“,
Vincentz Verlag, Hannover, 1995, ISBN 3-87870-426-2

/7/ Lackwerke Peters GmbH & Co. KG: Technical Reports on carbon-conductive inks

Lackwerke Peters GmbH & Co. KG
Hooghe Weg 13, 47906 Kempen, Germany

Internet: www.peters.de
E-Mail: peters@peters.de

Phone +49 2152 2009-0
Fax +49 2152 2009-70

peters
Coating Innovations for Electronics