PROJECT NO: COOP-CT2005 - 018271

SPRAYTEC

Low cost thermally sprayed and structured conductive layers for power electronic printed circuit boards

Co-operative Research (Craft)

Horizontal Research Activities Involving SMEs

Publishable Final Activity Report
Date of issue of this report: July 2009

Start Date: 15th November 2005

Duration: 36 Months

Version 03

Project Co-Ordinator: Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. on behalf of Fraunhofer-Technologie-Entwicklungsgruppe (TEG)

Project co-funded by the European Commission within the Sixth Framework Programme(2002-2006)

Dissemination Level	
PU Public	X
PP Restricted to other programme participants (including the Commission Services)	
RE Restricted to a group specified by the consortium (including the Commission Services)	
CO Confidential, only for members of the consortium (including the Commission Services)	

1 PROJECT INFORMATION

PROJECT NO: FP6-018271

CONTRACT NO: COOP-CT-2005-018271

TITLE OF PROJECT*:* ***SPRAYTEC***

Low cost thermally sprayed and structured conductive layers for power electronic printed circuit boards

COORDINATOR: Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V.

SME EXPLOITATION MANAGER: Contech

***SME CONTRACTORS*:**

1 PNC Natryskiwanie Cieplne Powłok s.c., Poland
2 Lifco Industrie, France
3 Contech Electronic GmbH & Co KG, Germany
4 P4Q Electronic S.L., Spain
5 Technosert Electronic GmbH, Austria
6 Sirio Panel SPA, Italy

***OTHER ENTERPRISE / END USER CONTRACTORS*:**

7 Infineon Technologies AG, Germany
8 Hella KGaA Hueck & Co., Germany
9 APtronic AG, Germany
10 Metallisation Ltd., UK
11 Würth Elektronik GmbH & Co. KG, Germany

RTD PERFORMER CONTRACTORS:

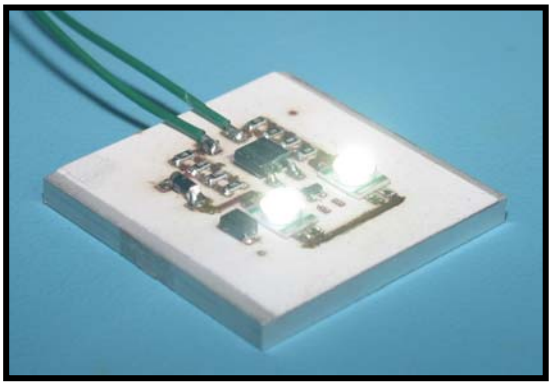
12 Fraunhofer-Technologie-Entwicklungsgruppe (TEG), Germany
13 Pera Innovation Ltd., UK
14 Zentrum für Aufbau- und Verbindungstechnik GmbH, Germany

2 PROJECT EXECUTION

2.1 Motivation

Nowadays, electronic modules on **P**rinted **C**ircuit **B**oards (PCB) are glued to the heat sink (e.g. FR4). Although thermally conductive glues are used, the thermal resistance of the junction limits the achievable power density of the modules. Thus the heat-sinks, which are essential parts of the module's housings, have to be dimensioned much bigger than needed solely by the dissipated power. Higher thermal conductivity at the PCB / heat-sink junction would therefore allow to significantly reducing the size of such modules, saving space, weight and material.

State of the art in manufacturing of the module substrates for PCBs is done by gluing the different material – slices (Aluminium and Alumina) together. Gluing the different layers is the start of the process of manufacturing module substrates.



In SprayTec, thermal spraying will be used to replace the gluing - process in the manufacturing of module substrates by direct thermal spraying of the materials one after another. The adhesive characteristics of layers sprayed onto materials such as ceramics and metals will be improved. Also the manufacturing process time will be reduced by using of thermal spraying technology.

Thermal sprayed coatings are used extensively for a wide range of industrial applications. The technique generally involves the spraying of molten powder or wire feedstock, the melting being achieved by oxy - fuel combustion or an electric arc (plasma). The molten particles are accelerated by the flame, followed by impacting onto a properly prepared substrate, usually metallic. To adapt this process to spray the substrates of PCB's, several barriers like the implementation of the right materials or the adjusting of the PCB manufacturing process have to be overcome through the help of the European consortium.

2.2 Project objectives and achievements

The overall objective of the SPRAYTEC project is to develop low cost thermally sprayed and structured conductive layers for power electronic printed circuit boards and to gain an understanding of thermal spraying principles as well as materials for printed circuit boards. The industrial benefit of thermal spray coatings is the achievement of cost – effective production of high thermally resistant PCBs.
The technology of APS (***A***tmospheric ***P***lasma ***S***praying), PureCoat™ and HVOF (***H***igh ***V***elocity ***O***xy-***F***uel-spraying) allows tailoring of components or specific areas to counteract damaging effects, prolonging the life of new parts or providing cost effective repair of worn parts. Thermal spraying also allows use of cheaper substrate materials such aluminium and is a flexible technology for the spraying of different layer materials to provide a cost effective product with high thermally resistance.

The understanding of the thermal spraying principle, the use of applicable materials and suitable processes for thermal sprayed of PCBs has been build up by the SME partners. Especially detailed knowledge and the influence of the different parameters like layer thickness, layer porosity, sealing of copper and ceramic layers have been gained and opened new markets for the SME.

The main requirements from customers to the new PCBs are a high dielectric strength, high thermal conductivity and good thermal shock resistance.
The figure on the right shows the layer composition of the new PCBs.
Aluminium was chosen as substrate material to get better heat abstraction and alumina has best characteristics for the isolator layer. The copper layer for the circuit path is applied by lift-off technique of steel masks. Hence the resultant reduction of copper consumption is also one big benefit of the SprayTec technology.

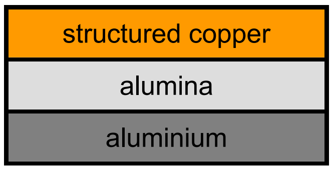


Fig.: layer composition of the new PCBs

Due to the different coefficients of expansion between aluminium and ceramic, an additional bonding agent interlayer is used to reduce the thermal stresses and to obtain better adhesion values.

In the development of the technology, thermal sprayed PCBs provide a cost efficient and fast solution, with low start up costs and fast lead times to prototypes. In addition, quick turnaround can be achieved and low cost changes are possible, hence there is high design flexibility. In the process of thermal sprayed layers the use of plastic materials is reduced to a minimum, thus the thermal sprayed PCBs are especially suited to high temperature applications. Only ceramic and metals are be processed. Costly and time consuming sticking and soldering processes are replaced

by thermal spraying method. With this method, coatings with low porosity and high thermal shock resistance were realised.
Furthermore, new test methods to verify the capabilities of thermal sprayed PCBs have been developed. The significantly improved thermal conductivity and the use of smaller heat sinks enhanced the usability for high temperature applications in the power electronic market.

The SME partners built up detailed knowledge about thermal sprayed PCBs by understanding the requirements and possible enhancement of the customer needs in sectors such as automotive and power electronics including the knowledge of the industrial implementation of the SprayTec technology.

The greatest benefits will be for SME partners, which can use the new thermal sprayed power PCBs to improve their power electronic components in various areas as functionality, module size, module weight and different design.

The close collaboration of the partners enabled the development of a new PSU (**P**ower **S**upply **U**nit) and a new LED panel for automotive lighting.

It turned out that the SprayTec technology is more suitable to high temperature applications like the IMS (**I**nsulated **M**etal **S**ubstrate) technology than to assembling technologies like DBC (**D**irect **C**opper **B**onding). The joining techniques contrary to the thermal sprayed PCBs differ primarily in the lamination processes of the copper and dielectric layer by gluing and costly etching processes.

Following table shows the project results in comparison to conventional power PCBs.

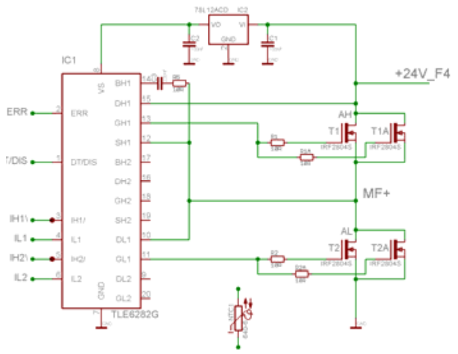
Feature	**aimed change**	**achieved change**
Thermal conductivity	+60%	+ 25%
Increased adhesion	+50%	✓
Weight power PCBs	- 30%	✓
Costs of materials compared to IMS technology	- 20%	- 90%
Production cost compared to DBC process	- 60 %	- 80%

2.3 Work performed

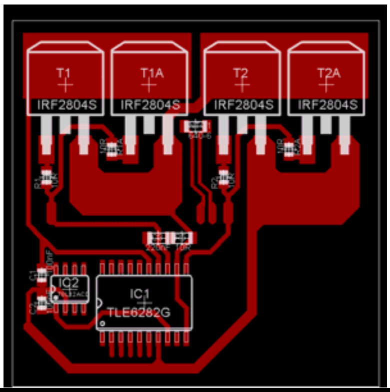
The project started with a detailed scientific characterisation of the spraying technology, the characterisation of the suitable materials for the different layers and the definition of the market requirements on the thermal sprayed PCBs.

To fulfil the market requirements of thermally sprayed PCBs, the required tests and tests methods have been defined.

To perform different test methods optimally, special masks were developed and designed for laser cutting of thin steel. These masks were placed on the samples with ceramic layer. The structured copper layer was sprayed by lift off the masks.

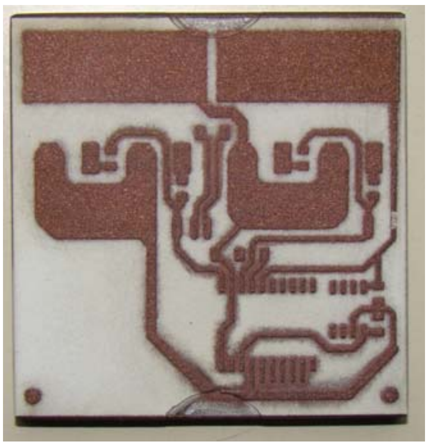


Step 1: Designing the electronic circuit



Step 2: PCB Design

Step 3: Manufacturing of steel mask



Step 4: copper sprayed finished PCB

Fig.: Designing of a circuit for a MOSFET assembly

The process, as is shown in figure above, starts with the PCB layout design which is turned into a steel circuit mask and a second mask.

Following tests have been performed in accordance of IPC-TM-650:

- microsections of sprayed samples for layer thickness measurements, structure analysis by microscopy
- adhesion test of
  - dielectric layer <-> substrate
  - dielectric layer <-> copper layer
- surface roughness tests
- dielectrical breakdown tests [ASTM - D149]
- thermal conductivity tests
- temperature storage and temperature cycle tests

2.4 Thermal spraying processes

Thermal spraying is a general term to describe all methods in which the coating is formed from melted or semi-melted droplets. In thermal spraying the material is in the form of powder and is fed into the flame produced by a spray gun, where it melts and the formed droplets are accelerated towards the substrate to be coated. The thermal and kinetic energy of the flame can be produced either with burning mixtures of fuel gas and oxygen, or by using an electrical power source.
Based on the energy source, thermal spray methods can be divided into a few main groups: plasma spray methods, flame spray methods, high velocity oxy-fuel methods, electrical arc methods and cold gas methods.

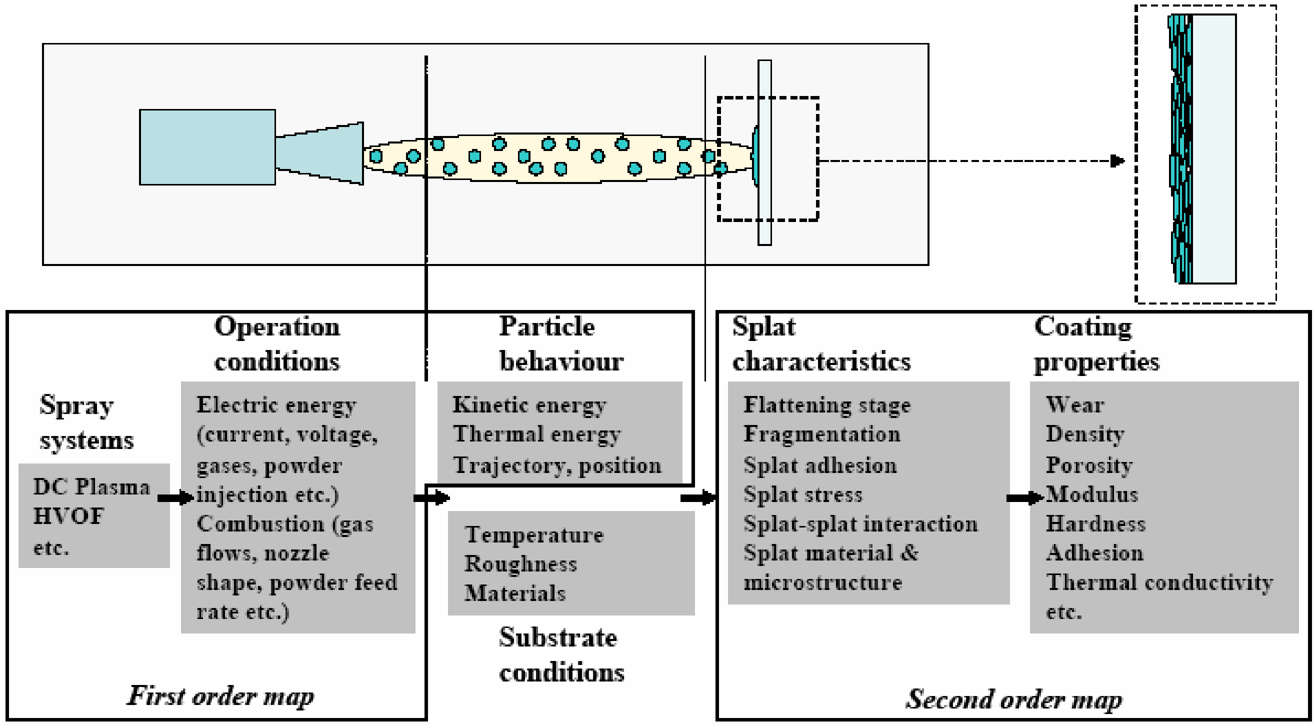


Fig.: Thermal spraying principle and influences[1]

In thermal spraying the coating is built up from the lamellas formed by rapid solidification of the melted or semi-melted droplets attached to the substrate. A typical structure for the coating is a pancake – like lamellar structure, where the flattening degree and adhesion between the lamellas, together with the coating material itself, define the main properties of the coating. In SprayTec two spraying methods are applied – APS and PureCoat™.

[1] Erja Turunen. "Diagnostic tools for HVOF process optimization" ESPOO 2005, VTT PUBLICATIONS 583

2.4.1 Atmospheric Plasma Spraying (APS) technology

Atmospheric Plasma Spray (APS) is a method where the energy is based on the plasma produced by ionising an inert gas, typically mixture of argon and hydrogen or helium, between the anode and cathode of the spray gun. Due to the high energetic ionized plasma, the temperature of the plasma is very high, as high as 10000°C. The speed of the plasma is approximately 400 m/s. Due to the high process temperature, APS which enables good melting of the ceramic particle is often used to produce a ceramic coating.

2.4.2 PureCoat™ technology

Purecoat™ is an arc spraying process that uses a wire feedstock melted by an arc. Because of this it is not possible to produce unmelted particles. This thermal metal spraying process has been developed which is reported to be able to give coatings of near high velocity oxy-fuel (HVOF) quality at less than half the cost. The process, known as Purecoat™, has been developed in the UK by Metallisation Limited, in collaboration with six other companies in Europe. The Purecoat™ process uses a computer-designed spray head which solves clogging and oxidation problems encountered with conventional metal spraying in the open air. It produces coatings of a quality close to that of the feedstock metal.

2.5 Completed test prototypes

All sprayed samples were soldered with reflow technology construction units on the copper layer. All samples were soldered by the steps:

1. structured copper layer with steel mask
2. surface finishing
3. solder stop lacquer
4. solder paste printing
5. mounting of components
6. reflow / vapour phase soldering

Like other lamps, high – power LEDs generate heat. The SprayTec technology places importance on heat management by selecting material compositions with good heat dissipation. This assures that the LED modules remain below the critical temperature zone and operate at full capacity throughout their lives. The company Technosert designed a layout to make soldering tests, thermography tests and breakdown voltage tests with sprayed and mounted samples.

Thermal spraying of a test structure for LED mounting:

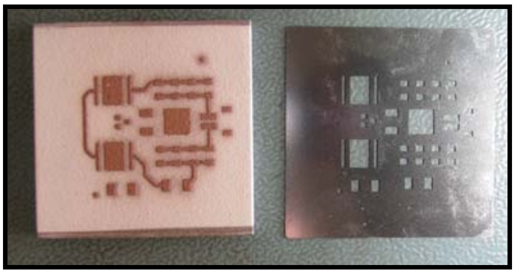


Fig.: sprayed copper layer and solder steel mask

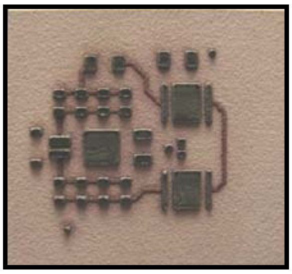


Fig.: after solder paste printing

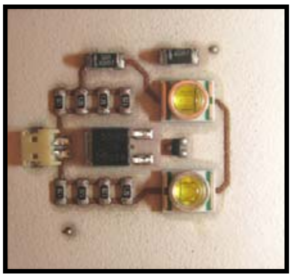


Fig.: mounted high-power LEDs

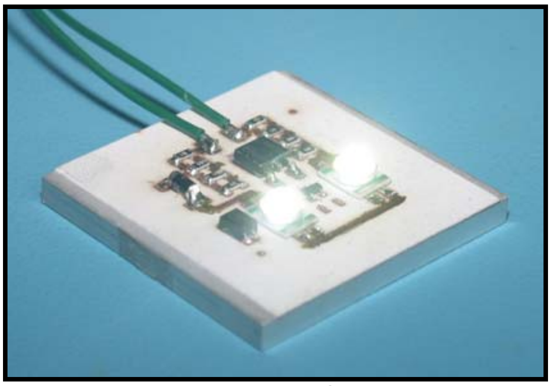


Fig.: Thermal sprayed PCB in operation

Project partner APtronic designed a layout to make soldering tests and breakdown voltage tests with sprayed and mounted sample. The following pictures show the adjustable current sink:

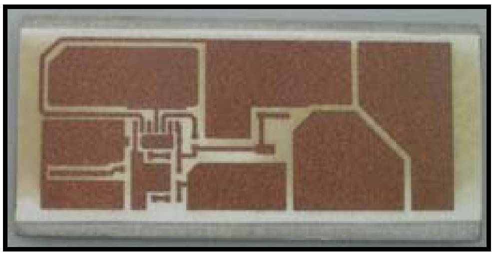


Fig.: thermal sprayed copper layer

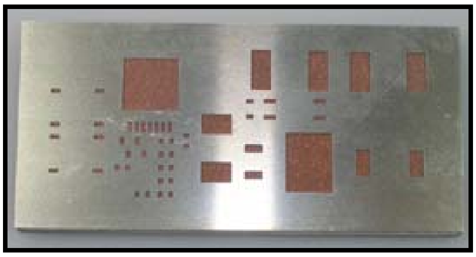


Fig.: 300µm steel mask for soldering paste printing

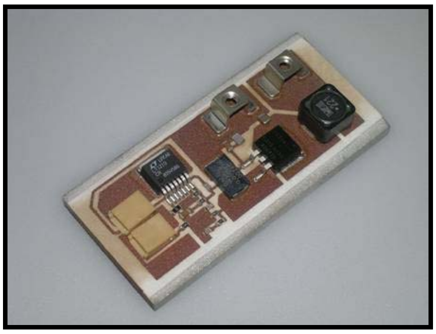


Fig.: assembly current sink

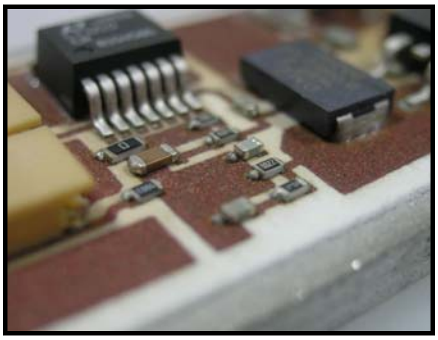


Fig.: assembly current sink in detail

Further realised LED application designed by consortium partner Technosert from Austria.

Fig.: Aluminium angle assembly with 6 high power LEDs

The table on next page shows temperature values at different positions on the sample. The measurements were accomplished with the following parameters: long time test with 4 x 27 - resistances, parallel connected Rges = 7,00, temperature 24 – 27°C.

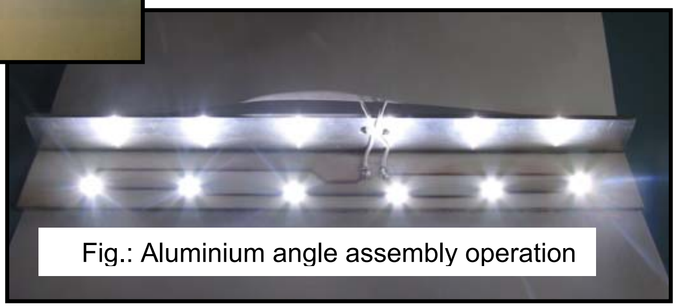
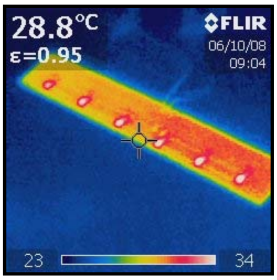
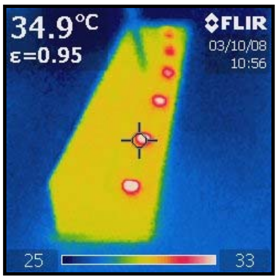
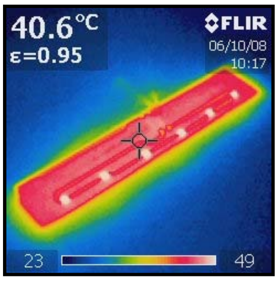


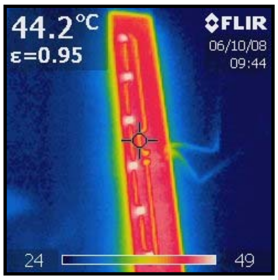
Fig.: Aluminium angle assembly operation

All pictures are taken with IR camera during the tests.









All samples show very good heat dissipation into all directions.

3 PLAN FOR DISSEMINATION AND USE

Exploitable knowledge and its use

Within the project knowledge was created that is going to be used after the project for the benefit of the SME partners. The most important aspects are summarised below.

In preparation for exploitation, the consortium formed an exploitation committee, lead by APtronic, Contech, Technosert and P4Q and assisted by the other SME consortium members like Würth Elektronik who have understanding of the market, applicable regulations and the existing client base.

The major target of this project is creating a business for the SME partners by selling the technology (Automotive, Aerospace, rail, lighting technology). Although the end users within the consortium (APtronic, Sirio Panel, P4Q, Technosert, Contech) will use the technology themselves, the consortium has to also take the opportunity of selling the technology / system to the industry outside the partnership. It is also possible for the SME partners to create a spin off / legal entity in order to market the technology together. Currently the company APtronic started a pilot project with app. 300 pieces of a working product. Metallisation is willing to produce the hundreds of samples for this pilot project and will profit from sales of machines.

At the end of the project there was a discussion with all project partners regarding application fields for the developed product. As an interesting field to use the PCB's the LED technology was mentioned. Fraunhofer made a market analyse in particular the market for the LED technology which was presented at the final management meeting. An increasing market for LED technology is predicted for the future. Regarding cost benefit & cost effectiveness for the manufacturing of PCB's by using thermal spraying method the company Metallisation analysed the costs for the production. The manufacturing is competitive to existing manufacturing techniques.

Dissemination of knowledge

During the project a high number of dissemination activities took place. Besides published papers and articles the technology was also presented on congresses (FED Congress 2007 & IMAPS Conference 2007). Partners visited trade fairs to promote the new product to the following sectors: automotive, electronic engines, consumer electronics. Articles about the new products have been published in professional journals.

More trade show presentations and end – user experts workshops are planned once APtronic developed the working prototype to a completed product in 2009. A further presentation will be held by Fraunhofer at the SMT 2009 in Nuremberg.