Development of technology for deposition of thick copper layers onto ceramic substrates applied in power electronics

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Abstract

The basic element of the design of a power module is a metallized ceramic substrate. In this work, the formation of metallization coatings by the method of thermal transfer of metallization pastes (Mo-Mn-Si + binder) for alumina and aluminum nitride ceramics was carried out. The fixing of the metallization coating on the ceramic substrate was performed by firing at a temperature of 1320 °C. The subsequent deposition of the copper layer was carried out by the method of cold gas-dynamic spraying (CGDS) followed by annealing of the deposited coating. For high-quality adhesion, the optimum annealing temperature was 1000 °C.

Keywords

- ceramics
- metallization coating
- aluminum nitride
- copper
- adhesion

Key findings

- The technology of a two-layer metallization coating on ceramic substrates made of aluminum nitride and oxide was developed.
- The resulting copper coatings are characterized by a strong adhesive bond with the base and low electrical resistance (at the level of 3·10^-6 Ohm-cm).
- For high-quality adhesion, the optimum annealing temperature was 1000 °C.

1. Introduction

Cold gas dynamic spraying (CGDS) is a relatively new modification of cold spraying techniques that uses converging-diverging (De Laval) nozzle at a supersonic velocity to accelerate different solid powders towards a substrate on which they are plastically deformed. This deformation results in adhesion to the surface. CGDS is one of the innovative cold spraying processes with fast-growing scientific interests and industrial applications in the fields of aerospace, automotive and biotechnology. Cold spray research and development efforts have doubled during the last decade and along with new industry applications and novel demands provide both a strong body of knowledge and market pull to identify and address these roadblocks [1, 2]. Due to the high strain rate deformation of particles in (CGDS), in situ investigation is challenging. Metallurgical bonding is one of the main adhesion mechanisms of particles during coating buildup [3]. The properties of the kinetically deposited coating layer are significantly affected by the microstructure of the coating. The most powerful influencing factors in microstructural evolution of kinetic-sprayed coating layers are instant generation of thermal energy and high-strain, high-strain-rate plastic deformation at the moment of particle impact [4]. Heat treatment of the 316 L austenitic steel coating improves its mechanical properties [5]. In [6] the microstructure of the coating obtained by cold gas-dynamic spraying was investigated. A Cu-Al-O-Zn powder blend was sprayed onto a copper substrate to restore a worn copper contact wire. The coating thickness was 1–2.5 mm. Improved adhesion
strength was achieved through substrate surface prepro-
cessing with coarse Al₂O₃ particles.

To obtain the pattern of an electronic power module, ceramic substrates should be metallized. Therefore, con-
ducting layers, over 300 µm thick, are deposited by differ-
ent techniques to form multilevel metallization [7]. While
in production and operation, the metallized structures of
power modules are exposed to thermal and mechanical
stresses.

The research objective is to optimize the technique of
thick copper layers deposition onto ceramic substrates
used in power electronics.

We considered the use of finely-dispersed PMVD-0,
PMVD-1 and coarse PMC-1 copper powders for their sput-
tering by gas dynamic cold spray technique (GDCS).

After preliminary experimental studies of gas dy-
namic cold spray technique (GDCS), we made a choice
of PMC-1 copper powder (GOST 4960-2009) as the most
appropriate, affordable and cheap.

The basic element of the power module structure is
considered to be a metallized ceramic substrate with the
power semiconductor crystal, which is used for imple-
menting two main functions: firstly, for electrical isola-
tion of conductor buses patterned on the power semi-
conductor crystal, which is used for imple-
menting two main functions: firstly, for electrical isola-
tion and strength pa-
raters at the level of world’s brands, such as MARUVA
(Japan), LEATEC (Taiwan), ClecGroup (China), CeramTec
(Germany).

The substrates are produced by slip casting tech-
nique followed by annealing of aluminum-oxide ceram-
ics at 1650 °C and aluminum-nitride ceramics at
1850 °C.

2. Experimental

Metallized coatings (MC) formation was tested by the heat
transfer of two metallization pastes compositions for alu-
minum-oxide and aluminum-nitride ceramics.

Pastes compositions:
A. Mo-Mn-Si+Ta₂O₅+ZrO₂+TiH₂+binder.
B. Mo-Mn-Si+ binder.

The organic binder for the metallization pastes con-
tains: ethylcellulose-100, α-terpineol, dibutylphthalate and
oleic acid.

Surface preparation is considered to be one of the main
stages of metallized coating formation on ceramics. Ce-
ramic substrates had been mechanically polished before
metallization to obtain alignment and surface roughness of
Rₐ = 0.15 µm.

MC bonding on the ceramic substrates was achieved
via its annealing. In this regard, nitrogen-hydrogen
through- and pusher-type furnaces were used. The furnac-
es consist of 5 mullite muffles, which are 90 cm long. The
muffles are located in series to provide a continuous
channel with 3 temperature ranges. Annealing was carried
out with 30 minutes exposure at 1320 °C.

The GDCS technique is based on acceleration of
1–150 µm particles with a supersonic gas flow up to the
speed of 500–1200 m/s. The particles colliding with an
obstacle tend to bond on it without melting [14, 15].
Meanwhile, the substrates are not strongly affected by
temperatures.

Sputtering was carried out on VK-96 aluminum oxide
substrates with the dimensions of 30×29×0.3 mm, and
with a Mo-Mn-Si sublayer being 10–20 µm thick. PMC-1
copper powder was used for sputtering.

Formation of metallized coatings from copper pow-
ders was carried out according to typical GDCS diagrams
with the use of a planar contracting-expanding nozzle
with 3.05×3.05 mm critical cross section and
9.5×3.05 mm exit geometry. The rate of powder con-
sumption from a dispenser was set to 0.1 g/s. The dis-
tance of sputtering was equal to 30 mm; the nozzle scan-
ning velocity against the substrate varied from 5 to
50 mm/sec. Air was chosen as a carrier and working gas.
The deposition was conducted on the GDCS ITAM SB RAS
test installation. The substrates were split into two
batches after sputtering. Then annealing was carried out
in the hydrogen medium at different temperatures to
determine the optimal thermal mode.
3. Results and discussion

Since the products obtained are operated in air, the resistance of the coatings in aggressive media (acids or base solutions) was not determined. It is also known that semiconductor devices with these products are operated at low temperatures (not exceeding 125 °C). For this reason, the thermal stability of coatings was not studied. The most important performance characteristics of coatings are adhesion resistance and low electrical resistivity.

The key parameters were determined after annealing as follows: the measured values of adhesion and intrinsic resistance were compared with the same parameters for DBC-substrates produced in Germany and China (Table 1). 1000 °C appeared to be the optimum annealing temperature for adhesion. The best results are peculiar to DBC-substrates with the lowest resistance, which is close to the resistance of pure copper. The substrates with thick copper layers sputtered by the GDCS technique are characterized by the key parameters close to the values of DBC-substrates, despite the use of copper powder to obtain the copper coatings.

4. Conclusions

The technology of applying a two-layer metallization coating on ceramic substrates made of nitride and aluminum oxide was developed. Initially, a layer of molybdenum-manganese-silicon was deposited on the surface of the substrates by burning in a nitrogen-hydrogen medium for 30 minutes at a temperature of 1320 °C. At the second stage, a layer of copper was deposited by the CGDS method with a flat Laval nozzle. The working gas was air. After deposition, annealing was carried out in hydrogen atmosphere. The optimal annealing temperature was 1000 °C. The obtained coatings are characterized by a stable adhesive bond of the copper coating with the base (the adhesion value exceeds 60 MPa) and low electrical resistance (at the level of 3·10⁻⁸ Ohm-cm).

Supplementary materials

No supplementary materials are available.

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Conflict of interest

The authors declare no conflict of interest.

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