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Influence of the densification parameters on screen-printed component properties

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Abstract

Standard screen-printing is a very versatile technology for the elaboration of thick films and hybrid circuits. However, in order to obtain components with particular properties such as gas sensors, varistors, PZT-based pyroelectric sensors, super-thick copper pads, etc., a better control of the layer compacity is necessary. This has been made possible, thanks to the preparation of specific inks and thanks to the development of new fabrication processes. Most examples will be drawn from our own experience.

Keywords: Densification; Sensors; Varistors; Films; Ferroelectric properties

1. Introduction

Standard screen-printing technology has been principally developed for hybrid circuits manufacturing. The advantages are well known: versatility in the conception, miniaturisation, mass production at low cost, etc. This technology may also be used to elaborate other thick-film components (chemical and physical sensors, heating resistors, varistors, capacitors, etc.). Moreover, the development of inks specific to the required application is relatively simple, at least at the laboratory level. However, a good control of the ink composition, screen-printing parameters, drying and firing process, is often necessary to obtain a layer compacity adapted to the desired properties. For example, porous layers will be preferentially used to develop catalytic and semiconductor oxide gas sensors. Conversely, conductors, varistors, dielectrics, etc. need compact layers. Thus, because of the poor densification generally obtained with the standard process, the original solution proposed herein is to add a new step to the standard screen-printing process, by applying uniaxial or isostatic pressure onto the oven-dried layers at room temperature. Besides pressure application, other possibilities to increase the compacity of films containing a small amount of inorganic binder are to add a temporary eutectic phase and/or to fire at a peak temperature close to the melting point of the active material.

In this paper, we present the basis of the standard screen-printing process and of the modifications introduced to enhance the densification of the films. We then focus on the correlations between the compacity and the component properties. Examples, mostly drawn from our own experience, deal with gas sensors, varistors, PZT-based pyroelectric sensors, super-thick copper pads, etc.

2. Processing and densification of thick films

2.1. Ink preparation

While conductive, resistive and dielectric pastes are commercially available, fabrication of our own inks may be necessary for specific applications. The latter contain two main constituents: about 60–80 vol.% of inorganic materials, which give the required electrical and mechanical properties to the film, and about 20–40 vol.% of a temporary organic vehicle, which controls the rheological properties of the ink.[1] The organic part contains ethylcellulose, terpineol, dibutyl phthalate and butyl carbytol. The inorganic fraction consists of a powder of active material(s) such as semiconductor ox-

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ide, varistor, PZT, metal, etc. which normally will determine the characteristics of the component.

A controlled concentration of inorganic binder (glass frit, fusible phase, etc.) is usually added to ensure the cohesion and/or the compacity of the layer and its adherence to the substrate. However, a particular attention to the influence of the inorganic binder on the required electrical properties of the layers must be paid. When the electrical properties are mostly dependent on those of the active material, a significant amount of glass frit will obviously modify the electrical performance of the layers. The effect may be beneficial: in resistors, for example, both resistance and TCR can be adjusted, by selecting an optimal concentration of glass frit. Conversely, in varistors, the addition of glass frit destroys the non-linear effect.

2.2. Screen-printing

Thick layers of some tens to hundreds of micrometers are obtained by a transfer of the ink through a screen onto the substrate. The final thickness of the layer depends strongly on the screen, the thickness of the emulsion, the settings of the screen-printing machine (squeegee pressure and speed, screen–substrate distance, etc.) and the ink viscosity.

2.3. Drying

The samples are dried for 20 min at 120 °C in an oven to eliminate the solvents. It is important to emphasise that the lack of compacity of the films mostly originates from the removal of this volatile part.

2.4. Pressure application (optional)

Because of the poor densification generally obtained with the standard process, it is not easy to manufacture screen-printed capacitors or varistors whose performances are comparable to those of ceramic components.

The original solution proposed herein is to add a new step to the standard screen-printing process, by applying uniaxial or isostatic pressure up to 5×10^8 Pa onto the oven-dried layers at room temperature. In both cases, 30% reduction of the thickness of the oven-dried layer is obtained. A densification close to that of ceramics may thus be expected.[2]

2.5. Firing

Unpressed or pressed samples are fired in a conventional belt furnace at peak temperature from 850 to 1100 °C. In the whole furnace, the atmosphere is either dry air or nitrogen containing 5–10 ppm oxygen. For higher temperature (up to 1450 °C), a laboratory prototype furnace has been specially designed to control the temperature profile. A particular attention has to be given to the strong chemical interactions between the layers themselves and/or between the films and the substrate, which can occur during firing.

Densification of the layers is of course dependent on the firing temperature cycle. Besides pressure application, addition of small amount of inorganic binder and/or a temporary eutectic phase and firing at a peak temperature close to the melting point of the active material are expected to increase the compacity of thick films.

3. Gas sensors

Screen-printed chemical sensors have been developed for the last 20 years, using different detection principles: semiconductor, catalytic, solid electrolyte, etc.

3.1. Semiconductor oxide gas sensors

The design of a semiconductor gas sensor is shown in Fig. 1a. Interdigitated gold electrodes and a platinum resistor are screen-printed on each side of an alumina substrate. The sensitive layer is then deposited above the electrodes and fired at 850 °C. Sometimes it is desirable to deposit a porous membrane on the sensitive layer for protection or filtering purposes.[1] Finally, the sensor is connected on a socket with Pt wires (Fig. 1b).

A glass binder is often needed for the reasons discussed previously. The addition of only 2 wt.% of CaBAlSi glass frit ($CaCO_3$, B_2O_3, Al_2O_3, SiO_2) to 10 wt.% Pd-doped SnO_2 leads to a reduction by a factor of about 20 of the response towards 1% CH_4.[1] The collapse may have two reasons: the inhibition of the sensing properties of tin oxide and/or that of the catalytic activity of palladium. Response to CO is also reduced by addition of CaBAlSi to SnO_2.[3]

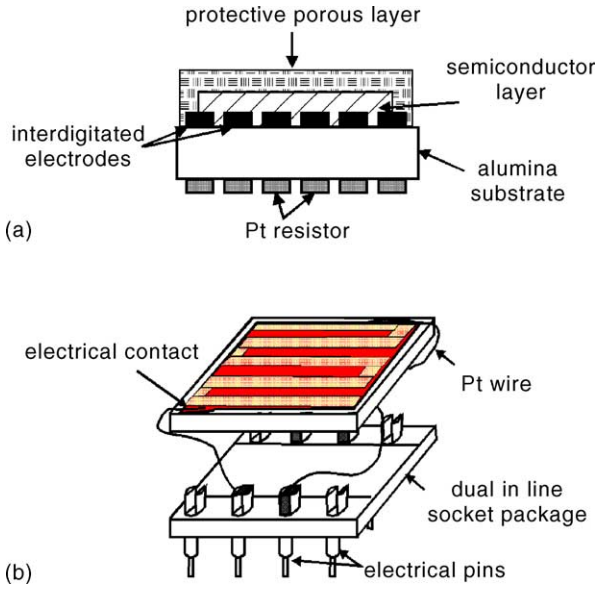

Fig. 1. Typical design of a screen-printed semiconductor gas sensor: (a) cross-section; (b) sensor mounted on a socket.