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Performance of LTCC embedded SiC gas sensors.

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Abstract

A novel approach to encapsulation/packaging of SiC field effect transistor gas sensors for high temperature applications, such as exhaust and fuel gas emissions monitoring, based on direct co-firing of sensor devices and Low-Temperature Co-fired Ceramics (LTCC) has been investigated. Structural (SEM, EDX, XPS), electrical (I/V, C/V) as well as gas sensing characterization of packaged devices has shown that the “one-step” packaging process forms a hermetic package with retained transducer functionality and gas sensing characteristics without the need for any separate die attachment, (wire) bonding, and/or sealing of the package. Long-term stability testing at elevated temperatures of packaged devices has also shown promising results.

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1. Introduction

Recent need for electronics capable of working at high temperatures and in harsh conditions has turned the industries interests towards wide band gap semiconductors such as Silicon Carbide (SiC). Structures manufactured on SiC single crystals are able to work in temperatures above 500 °C. However SiC field effect based devices for operation above 300 °C has so far had very limited commercial success, the reason behind which being limitations introduced by packaging and metal contacts [1], [2].

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The packaging of semiconductor devices for reliable operation in high temperature and harsh environment applications is not straightforward, involving prevention of undesired interdiffusion, coefficient of thermal expansion (CTE) matching of the semiconductor, substrate, die attachment, and contact/bonding materials and selection of high corrosion resistance materials, e.g. to prevent the often observed mechanical failures and/or device contact degradation.

Several ways of packaging have been investigated resulting in moderate success. Still die mounting, wire bonding and hermetic encapsulating and miniaturization pose a challenge when designing devices for high temperatures. [3]–[6]

Low Temperature Co-fired Ceramic (LTCC) is a well-established packaging technology offering low resistivity conductors, multilayer designs and resistance to harsh environments including temperatures up to 600 °C. Recent developments in tape preparation methods have allowed Heraeus GmbH to introduce a novel LTCC tape with virtually no planar shrinkage [7]. This has opened new possibilities of co-firing bulk materials as presented in [8]–[11].

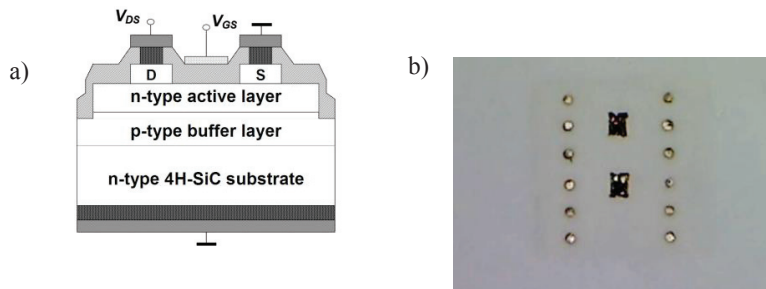


Figure 1. a) Displays a cross-sectional sketch of the layout of the SiC MOSFET gas sensor device used in this study. [2] b) Displays a picture of the SiC sensor device integrated in the LTCC package.

In this work the LTCC “one-step” process of direct co-firing has been used for encapsulation/packaging of SiC based MOSFET gas sensors (see Figure 1a) [12], forming the complete, packaged sensor (Figure 1b). Such approach abolishes the needs for separate carrier structures, die attachment and/or bonding procedures, potentially lowering the packaging price and increasing the reliability.

2. Manufacturing

Packaging has been done by following a slightly modified LTCC process flow, shown in Figure 2. Unsintered sheets of LTCC are laser cut, vias are filled with conductive paste and such prepared tapes are stacked forming a cavity in which the SiC sensor is placed prior to uniaxial lamination and sintering. Sintering takes place in a box furnace and follows the profile advised by the LTCC manufacturer. Laser shaping allowed precise formation of gas inlet to the gas-sensing part of the chip, with the rest being still covered. Direct electrical connections were made between the chip’s contact pads and silver-filled conductive vias, thus eliminating the need for flip-chip or wire bonding.

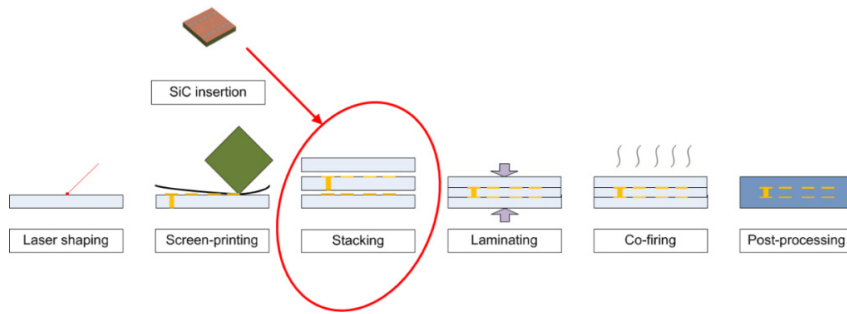


Figure 2. Displays the LTCC packaging process including the direct integration of SiC MOSFET sensor devices.

3. Results

The packaged sensor device was characterized structurally and electrically by SEM, EDX, XPS as well as I/V- and C/V-measurements followed by exposure to 100-1000 ppm CO at 200 °C.

The electrical measurements provided good evidence for the concept of direct “one-step” packaging through co-firing being feasible, showing a fully functional MOSFET device (Figure 3). Slight changes in threshold voltage and saturation current could be noticed, however that is expected from SiC transistor devices exposed to high temperature (Figure 3). The saturation current increased by about 50% while the change in threshold voltage was more substantial.

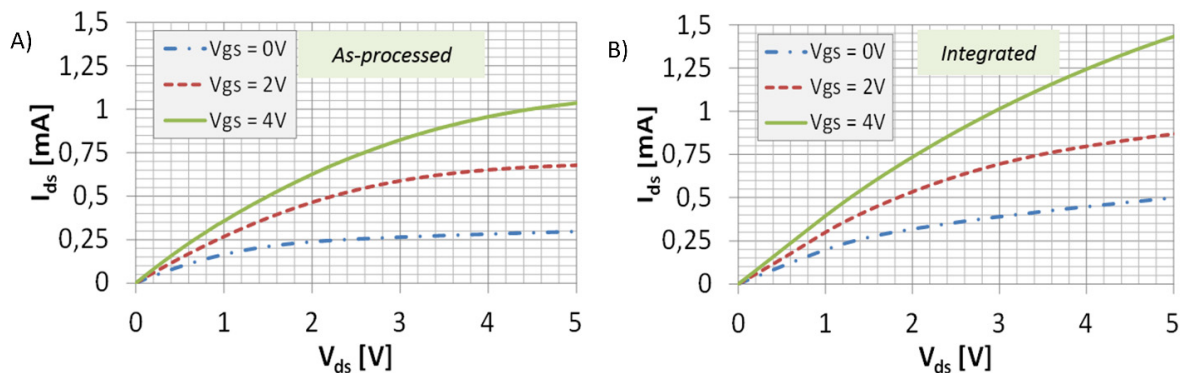


Figure 3. Displays the I_{ds}/V_{ds} characteristics for 0, 2, and 4V gate bias for both as-processed (a) as well as LTCC packaged (b) MOSFET sensor devices.

Despite certain damage to the top most passivation layer (Figure 4a) the structural integrity of the drain, source, gate area underneath the passivation layer was intact, the EDX/XPS not indicating any diffusion of LTCC material through the passivation layer into the metallization/ semiconductor materials. The damage to the top most layer might have resulted from the high-pressure of lamination or the sintering stresses caused by 0.2% planar shrinkage and the small mismatch of CTE between the materials (LTCC 6,1 ppm/°C; SiC 4.0 ppm/°C). However, lack of cracks in the main parts of the transistor further proves the feasibility of this packaging method.

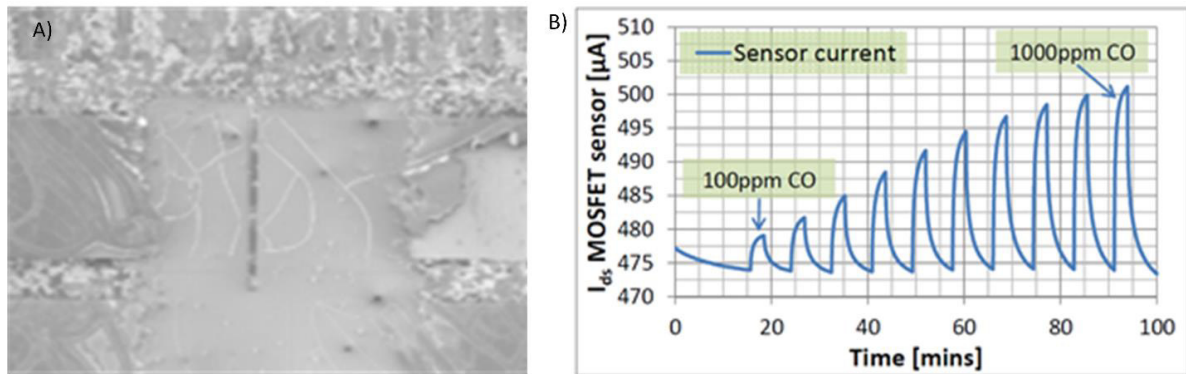


Figure 4. Displays in (a) an SEM picture of the source/ drain/ gate area top surface of the embedded SiC MOSFET after removal of the LTCC packaging and in (b) the response (change in drain current) of a packaged sensor to 3 min pulses of CO, ranging from 100 to 1000ppm CO (in steps of 100) in air at 200°C

Through the exposure of packaged devices to 100-1000 ppm CO at 200 °C it could also be concluded that the gas sensing characteristics were retained (Figure 4b).

4. Conclusions

A novel method of packaging for SiC gas sensors has been presented. Through electrical, structural and gas sensing measurements the performance of LTCC encapsulated gas sensor have been evaluated and proved the concept of “one-step” co-firing. Eliminating of die-attachment, wire bonding and encapsulation can decrease the price of packaging. Further studies should be carried out

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