Microelectronics Reliability xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/mr

Novel failure mode of chip corrosion at automotive HALL sensor devices under multiple stress conditions

M. Simon-Najasek [a,*], G. Lorenz [a], A. Lindner [b], F. Altmann [a]

[a] Fraunhofer Institute for Microstructure of Materials and Systems IMWS, Halle, Germany
[b] Micronas GmbH Freiburg, Germany

ARTICLE INFO

Article history:
Received 4 July 2016
Accepted 6 July 2016
Available online xxxx

Keywords:
Corrosion
Failure analysis
Reliability test
Mechanical stress
Sensor device

ABSTRACT

Semiconductor devices used in automotive applications undergo numerous stress situations depending on their particular application. Corrosion, as one main crucial failure mechanisms, can affect the lifetime of electronic components on system, device or even die level. In this paper, a novel corrosion mechanism on HALL sensor devices is investigated and clarified. This corrosion is only occurring under complex conditions like layout aspects, ionic impurities combined with humidity penetration and thermo-mechanical strain due to packaging and additional mechanical load from further over moulding. It is shown how advanced physical and chemical analysis can be combined with finite element simulation to ascertain a chemical degradation running on silicon, silicon dioxide and metallisation level to derive the complete chemical reaction mechanism for the observed corrosion defects. To verify the new failure mode, experiments to recreate this type of corrosion were carried out. Finally, conclusions are drawn on how failure modes can be prevented and how the robustness of the HALL devices under harsh environments can be increased.

1. Introduction

Quality requirements for microelectronic devices in automotive applications have steadily become more and more complicated. Especially for harsh environment conditions e.g. on-engine, on-or in-transmission and street near sensing devices, where complex mechanical, thermo-mechanical and humidity stress conditions are causing new and very complex failure modes. The occurrence of related defects could furthermore be affected by process or design related issues which are not relevant for standard applications under moderate conditions.

In this paper, a new failure mode related to chip corrosion at linear HALL sensors applied in over-moulded packages for customized car sensing applications was identified. Defective HALL sensor devices showed a failing output signal after 100 km up to 150,000 km lifetime, in different critical applications and at different automotive suppliers. First investigations revealed degradation of the active die structure, see Fig. 1, only at the shorter edges of the HALL sensor die, Fig. 2. Electrical malfunction was caused by locally corroded via structures in this area.

To clarify the origin and required conditions of this local die corrosion, multiple microstructural and chemical analyses were combined with finite element simulation and deduced stress testing.

2. Physical failure analysis at corroded die areas

As first step the packages of electrically failed HALL sensor devices were opened using nitric acid (HNO_3) to get access to the die surface. Then corroded structures at the die edges were identified by optical inspection. The defect area was further investigated by scanning electron microscopy (SEM) at local cross-sections, prepared by focused ion beam (FIB) milling. The complete corrosion path could be seen at this cross-section, starting with degraded silicon substrate, followed by large void formations within the inter-metal dielectric (IMD) layer and finally defective via interconnects, see Fig. 3.

The locally altered silicon substrate was found next to the crack protection trench where the Si_3N_4 passivation is deposited directly on the silicon. It was found that the silicon was locally attacked in a [1] crystallographic orientation within the affected trench structure, Fig. 4.

The sensor fails if the corrosion reaches via interconnects within the IMD layer close-by the die edge. The interconnect metallisation was degraded and electrically open. It can be seen that the aluminium metallisation within these via interconnects is completely corroded while the TiN barrier is cracked or oxidised.

Subsequently, high resolution structural and chemical analysis were performed using transmission electron microscopy (TEM), combined with energy dispersive X-ray spectroscopy (EDX) mapping to screen for contaminants and to characterize the reaction products.

TEM cross section overview in Fig. 5 shows the IC structures at the corroded die edge with the attacked silicon and subsequent IMD of a

* Corresponding author.
E-mail address: Michel.Simon-Najasek@imws.fraunhofer.de (M. Simon-Najasek).

http://dx.doi.org/10.1016/j.microrel.2016.07.008
0026-2714/

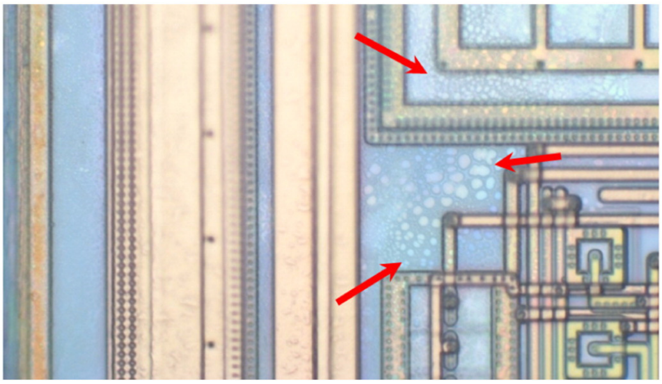

Fig. 1. Light optical image of degraded oxide layers showing voids within insulation in different sizes.

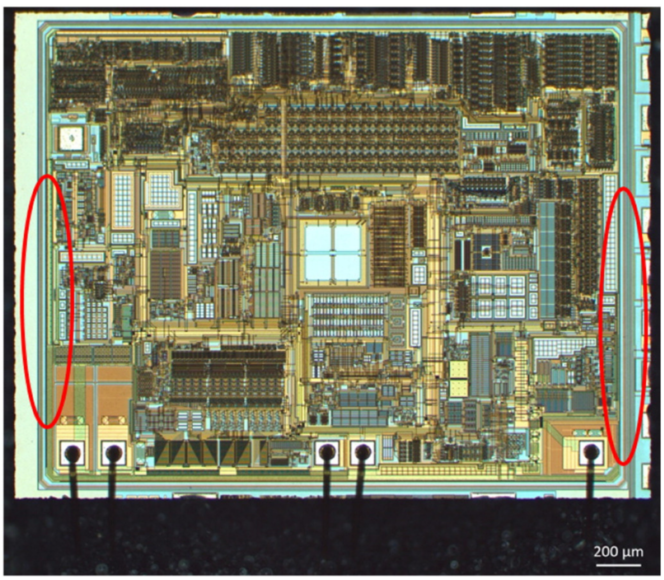

Fig. 2. HALL sensor die with marked main defect areas on the shorter die edges.

further sample. The silicon degradation starts within the trench and is present only at the outer few microns of the active silicon which is here directly covered by a chemically inert silicon nitride passivation. At the end of this structure it entered into the adjacent IMD which is also altered and accumulated with large voids.

STEM-EDX measurements at the red square in Fig. 5 revealed a reduced concentration of silicon, a significantly increased amount of oxygen and additionally some potassium contamination within the altered silicon substrate, Fig. 6. During TEM investigation small voids were growing within this degraded silicon. Besides TEM investigations, time-of-flight secondary ion mass spectroscopy (TOF-SIMS) was carried out to characterize the corroded die structure, to verify the EDX results and to search for further contaminants. By light optical investigations it was found at one die that the passivation layer was locally broken, so that the corrosion products could directly enter on to the die surface. Also, potassium could be identified here, Fig. 7. Further contaminants could not be found.

Finally, from microstructural analysis it was concluded that humidity and potassium entered the package and reached the IC structure from the shorter die edges or by local passivation cracks to initiate corrosion processes until the die electrically fails. Three different mechanisms could be found: (1) locally corroded silicon by a KOH like chemical reaction starting from the crack protection trench, (2) decomposition of the following IMD layer with void formation and volume expansion and finally (3) Al/TiN corrosion within the via interconnects. These three corrosion mechanisms are discussed in the following chapter in more detail.

3. Corrosion mechanism

3.1. Failure type 1

The physical investigation revealed a degradation of the silicon at the protection trench where the silicon nitride passivation is directly placed on the silicon. At the degraded silicon an increase of small voids were seen during TEM measurements (Fig. 5). It can be explained by water decomposition, driven by the electron beam irradiation. The water is divided into proton and hydroxide. The protons are gettering electrons from the electron beam forming hydrogen which escapes.

$$H_2O \leftrightarrow H^+ + OH^- \quad (1)$$

$$2H^+ + 2e^- \rightarrow H_2\uparrow \quad (2)$$

Due to the minor amount of water within these reaction products, the voids are rather small.

Furthermore a crystalline dependent silicon corrosion within the trench along the [1] crystallographic orientation (Fig. 4, red arrow) was observed in combination with potassium and humidity. Such an anisotropic attack is typical for KOH etch on silicon, e.g. as used for pressure sensors. The [111] orientation has a higher activation energy, it thus is more robust against the alkaline solution [1,2].

The reaction at silicon can be simplified explained as the following:

$$Si + 4OH^- \rightarrow Si(OH)_4 + 4e^- \quad (3)$$

$$4H_2O + 4e^- \rightarrow 4OH^- + 2H_2\uparrow \quad (4)$$

The reaction product is mono-silica (also referred to as: orthosilicic acid). Silica can have different hydroxy groups, representing the involved water, so that it can be written as: $SiO_2 \cdot n\ H_2O$ (poly silica).

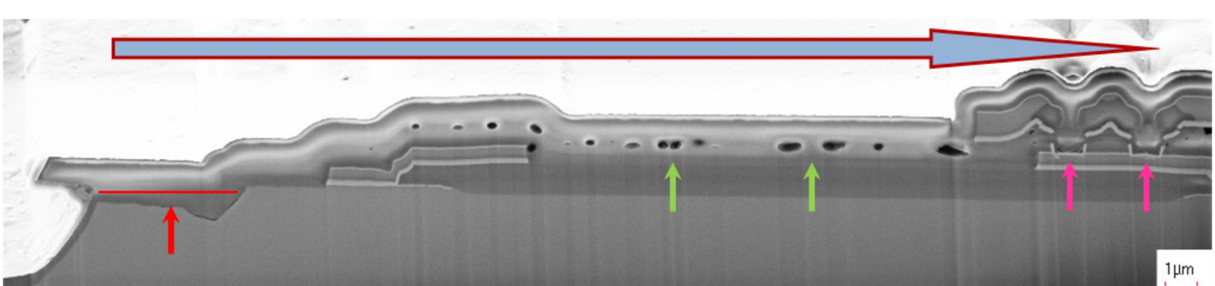

Fig. 3. FIB cross-section at the defect area near the die edge showing the corrosion of the silicon substrate directly at the trench (left), void formation in IMD layer (middle) and corroded via interconnects (right).

Please cite this article as: M. Simon-Najasek, et al., Novel failure mode of chip corrosion at automotive HALL sensor devices under multiple stress conditions, Microelectronics Reliability (2016), http://dx.doi.org/10.1016/j.microrel.2016.07.008