Microelectronics Reliability xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Microelectronics Reliability

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

Simulation of packaging under harsh environment conditions (temperature, pressure, corrosion and radiation)

Kirsten Weide-Zaage

RESRI Group, Institute of Microelectronic Systems (IMS), Leibniz Universität Hannover, 30167 Hannover

ARTICLE INFO

Article history:
Received 31 May 2017
Received in revised form 5 July 2017
Accepted 5 July 2017
Available online xxxx

Keywords:
Reliability
Simulation
Temperature
Pressure
Corrosion
Radiation

ABSTRACT

An important role of microelectronic packages is the protection of the chip against environmental influences like moisture, pollutants and other chemical active species. If the chip is exposed to these conditions, for instance corrosion is resulting. Furthermore, due to high temperature load and pressure or vibrations, the reliability of the package is influenced by thermo-mechanical stress. The unavoidable presence of particle radiation on ground and in the atmosphere leads to unwanted failures in the electronic devices, partly affected by the package material and solder. All these harsh conditions will happen more and more in the frame of automotive, medical and avionic applications. For space application all of these parameters are important as well.

Due to this, an essential aspect of the package design is the careful combination of materials to avoid mechanical stress and to improve the thermal-electrical and mechanical behavior as well as the corrosion resistance and radiation hardness of the package.

Simulation analysis can give, using the appropriate software, depending on the material properties, the package geometry as well as the boundaries, a fast and reliable solution to investigate the influence of mechanical stress as well as the thermal, electrical and mechanical behavior of the package.

1. Introduction

Microelectronic devices and components are rapidly increasing in all areas of life. In a lot of applications like air and space, automotive and drilling, it is well known that the devices and components are exposed to harsh environment conditions like radiation, high or very low temperature, high or low pressure, corrosive surroundings like moisture, acid, and vibrations. Also in medical application we find a harsh environmental situation.

High temperatures as well as high pressures occur mainly in downhole oil or gas drilling situations in deep sea under power application, in industrial power plants or electronics of aerospace engines. The reliability of microelectronic devices under such harsh conditions has to fulfill special demands.

>20% of failures in microelectronic devices are classified as corrosion related. Victims are here the plastic encapsulates and metallization. Electronic components corrode in the same ways as airplanes, automobiles, bridges, and pipelines. Aggressive manufacturing processes can also trigger corrosion. Small dimensions of microelectronic components and devices make them orders of magnitude more susceptible to corrosion. This means, that electronic device fails with a minimum loss of one picogram of the material. Microelectronic products are exposed to atmospheric moisture, contamination & temperature. Furthermore temperature/humidity/bias aging is used to evaluate the product reliability.

The quantity of products from the different technology nodes shows, that the portion of the products that are still manufactured today in 180 nm technology node is about 16%, the proportion produced in 130 nm technology node is about 38%, the portion in the 90 nm and the 65 nm node together is 29% [1]. A look on the particle impact concerning the SRAM cells shows that one particle hints only one cell in the 130 nm node but six cells in the 45 nm node.

2. Temperature, pressure and vibration

Microelectronic components under high temperature mean a working situation of such components in an area of temperatures above 200 °C. Electronics can be cooled in this application, but this is undesirable, due to cooling adds cost and in terms of aircraft weight increasing. Furthermore failure of the cooling system could lead to failure of the electronics that control critical systems. Wide band gap materials (III/V) or SiC are an alternative to Si but need specialized packages and solder materials. Epoxy or organic package materials as well as eutectic solders cannot anymore be used. An overview of different package and device materials as well as their endurance temperatures is given in [2]. In downhole drilling situations, electronics of aerospace engines beside high temperature exposure, on electronics for highly pressurized environment, the requirements is now targeting up to 250 °C and 30 kpsi,

E-mail addresses: weide-zaage@ims.uni-hannover.de, Kirsten.Weide-Zaage@ims.uni-hannover.de.

http://dx.doi.org/10.1016/j.microrel.2017.07.026
0026-2714/© 2017 Published by Elsevier Ltd.

known as x-HTHP (eXtreme High Temperature and High Pressure) condition [3]. Most devices are SOI (Silicon-on-Insulator) components with aluminum wedge wire or tungsten interconnects.

In Fig. 1 a graphical overview of the elements of IC-Packaging is given.

There are many different factors affecting the package integrity at high temperature. The die attach almost has low glass transition temperatures Tg furthermore attention has to be paid for the coefficient of thermal expansion (CTE) between the die, die-attach, and substrate. For the wire bonding the compatibility of the metals used for the wire and bond-pad metallization is beside intermetallic compound (IMC) growth, of major concern in terms on mechanical as well as corrosion effects. Instead of to the plastic encapsulates, hermetic ceramic packages are preferred for high-temperature application. High melting point (HMP) solder alloys have to be chosen, like Pb93.5Sn5Ag1.5 [4]. FR-4 PCB has to be changed to Polyimide, which has a Tg of about 250 °C.

Often special designed metal packages are used as preferred package for high heat dissipation, thermal shock or vibration. Glass–to–metal seal and ceramic–to–metal seal are the common choices for such hermetic packages. Another possibility is ceramic packages for ultra-high temperature application starting at 500 °C. In High Temperature Co–fired Ceramic (HTCC) technology, the entire assembly is co–fired or sintered at temperatures as high as 1600 °C. For such packages robust assembly techniques have to be used [5].

When selecting a power module, system designers make trade-offs between cost, design effort and performance. As the number of power rails and the current rating increases, the design of the power sub-system requires significantly more design effort. In [6] the development of a modular prototype integrating a Half-Bridge-Switch (HBS) and a double-side liquid cooler is investigated concerning the thermal performance. FEM (Finite-Element-Method) simulation with COMSOL was used to determine the temperature distribution.

In [7] improved numerical modelling for thermal optimization design of a D^2PAK validated by measurement can be found. First attempt to use simulation for package optimization were described in [8,9].

A parametrised model of a 20-Pin FR4-board mounted JEDEC MO-166 package (Fig. 2) containing a MOSFET and diodes was created. In the simulations radiation as well as convection was considered.

In Fig. 3 on the left side the temperature distribution in the package is shown. The MOSFET in the left part indicated by high temperature (red). Fig. 3 (right) shows the infrared image of the package the measurement and simulation distribution of the temperature show a very good agreement.

Vibration fatigue results from mechanical stress on a devices and components. The stress is a function of the acceleration (along with its derivatives) due to the vibration, and the vibration frequencies as they relate to the resonant frequency of the device or the PCB. Also very small vibrations can cause strong damage if the frequencies cause a component to resonate. Finite element methods can be here useful tools in failure prediction. In [10] a discussion about vibration non-sensitive COTS and the vibration protection of critical components under harsh condition can be found.

3. Corrosion

Corrosion is an interaction between material, environment and a reaction resulting in pitting or crevice corrosion for example. It can be divided into three types. Galvanic corrosion needs moisture and two conductive materials with different electrochemical properties. Electrolytic corrosion occurs in corrosive liquids (electrolyte), enhanced by electrical fields with a potential difference between anode and cathode. Electrolytic corrosion is high destructive and has a high acceleration factor. Chemical corrosion occurs without humidity under high temperature exposure. Fouling is a biological process resulting in metal corrosion. Corrosive environments can be for instance organic compounds, inorganic or organic acids and reactive gaseous like: H_2SO_4, HCl and HNO_3, O_3, H_2O_2, NH_3, H_2S, NaCl (marine harsh environment). Furthermore fingerprints or etchants, saliva or fluxes for tinning the leads can be also such promoter. A prevention against corrosion can be done actively or passively, like recorded in Table 1. Looking on marine or harsh marine conditions, metal corrosion is an electrochemical process that is inevitable unless the metal is well protected by methods like coating or sacrificial anodes. Coating involves organic passivation like plastic or varnish or other non-conducting coating on the metal surface to prevent the electrolytes from reaching the metal surface. Also a metallic passivation like gold- electroplate or oxidation can suppress corrosion. Using a sacrificial anode for big structures commonly involves attaching a metal more anodic than the metal to be protected, forcing the structural metal to be cathodic and thus to be spared from corrosion. In microelectronic components this might be difficult except the devices are in a housing which fulfills this demand. In general there is no complete stopping against corrosion but it is possible to hinder it with different kinds of corrosion prevention.

Moreover corrosion is depending on the grain orientation of the metal [11] like shown in Fig. 4. Tensile Stress and chemical susceptibility localized micro-or macro- cracks can result in cracking and potential differences in grain boundaries can result in intergranular corrosion which appears as uniform damage.

Software for corrosion simulation deal mostly with specialized mechanisms. One of the first corrosion calculating programs is described in [12]. The corrosion rate equations and models developed as well as a crack growth module were there converted into a FORTRAN program, enabling the analysis to give recommended times for inspection and

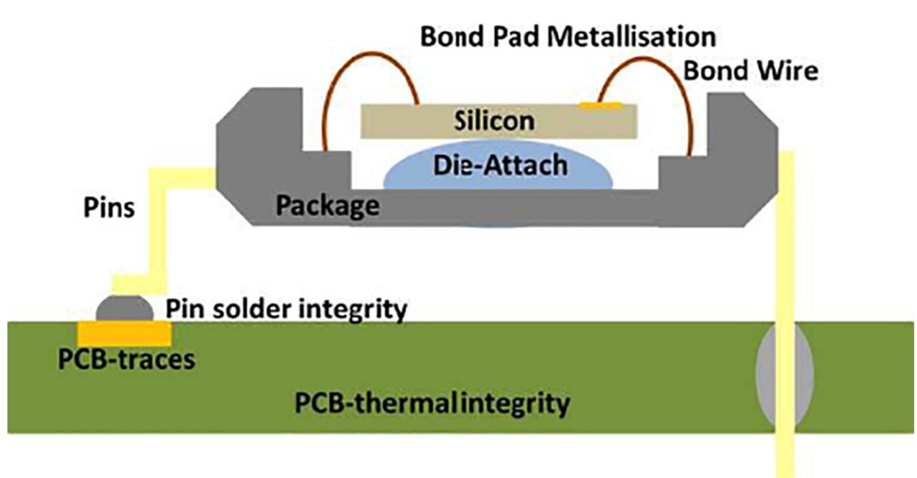

Fig. 1. Graphical overview of the elements of IC packaging and mounting.

Please cite this article as: K. Weide-Zaage, Simulation of packaging under harsh environment conditions (temperature, pressure, corrosion and radiation), Microelectronics Reliability (2017), http://dx.doi.org/10.1016/j.microrel.2017.07.026