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Reliability experiments of sintered silver based interconnections by accelerated isothermal bending tests

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ABSTRACT

Integration of more functionality and smaller chips into decreasing package volume leads to increasing heat generation. In addition, the use of new compound semiconductors like SiC and GaN require a high thermal conductivity of the interconnect materials. One of the promising solutions is a layer of sintered silver between semiconductor and substrate. The advantages compared to conventional solders are significant. A higher thermal and electrical conductivity in combination with a higher duty temperature due to a higher melting point should enhance the reliability of the package. However, even as the large scale commercial usage of the material has been started by the industry recently, many important details of the mechanical properties and the reliability behavior are still unknown. While the thermal properties could be characterized relatively easy and are quite repeatable and stable, the mechanical properties - important for the reliability - are extremely process-dependent and wide-spreading. The hunt for lowest feasible sintering process parameters - such as temperature, time and especially pressure - even amplify that behavior and led to an impasse in some cases. Also their failure mechanisms, to be identified in lifetime investigations, are yet unknown as well as their stability and predictability. In order to enable prolonged function of these interfaces, thermo-mechanical reliability has to be assured. Within this paper, we show the status of silver sintering and the problems regarding mechanical material characterization found in literature. Additionally, we present a guideline for the mechanical acceleration of reliability experiments by isothermal bending tests. Finally a proof of concept by failure analysis will be presented.

1. Introduction

The generation of meaningful lifetime-models is a serious and time-consuming challenge throughout the field of packaging. Wherever different materials are joined, the coefficient of thermal expansion (CTE) mismatch will usually lead to thermo-mechanical fatigue due to the temperature cycles [1–3]. As a result, the fatigue of interconnections is the limiting factor for reliability of electronic packages [4–6]. Usually lifetime investigations are performed as active or passive thermal cycles using the final systems with fixed amplitudes. Therefore the full system with all connections and capsulations will be cycled actively or passively till the defined failure criterion for the respective (most dominant) failure mode (e.g. interface delamination, via failure) is reached [7]. In most of the cases, only a passive temperature cycle with constant T-amplitude (-40°C up to 125°C) is used as standard procedure of industry. This is usually considered to be sufficient to validate the chosen technology and process parameters. The aimed main objective is rather the validation that the system will exceed a defined minimum threshold, than the developing of a full lifetime-model. Detailed investigations are often bypassed due to time and financial limitations. The future benefits of a lifetime-model, i.e. by gaining understanding of failure mechanisms and the possibility to predict them by modelling are often not considered [8–12]. Especially for interfaces based on newly developed and mostly insufficiently examined materials- more detailed experiments are necessary to understand the physics of failure. Porous materials like sintered silver have a large time- and highly process-depended behavior. Such results are required for the technology developing and optimization of fatigue behavior. Therefore more experiments with samples of different technology parameters as well as different amplitudes or load-regimes are necessary to examine the stability of failure mechanisms and the damage accumulation. New concepts to conduct such lifetime investigations faster are urgently needed [8]. The idea presented in this paper is to

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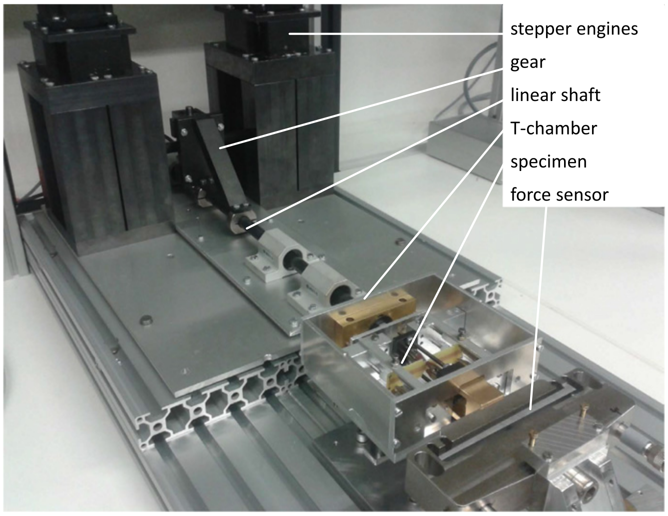

Fig. 1. Image of the built fatigue tester.

show a suitable method to substitute lengthy thermal cycling tests by rapid isothermal fatigue tests.

For that purpose, we built a strain controlled fatigue tester which can induce fatigue cracks into the samples rapidly by isothermal bending. The bending machine is shown in Fig. 1. Hereby, the bending amplitude is created out of the phase difference between two rotatory stepper engines. That amplitude moves the shaft as linear actor which bends the fixed sample inside the aluminum thermal chamber sinusoidal [9]. A high density displacement sensor is behind the shaft and measures the bending amplitude. Hereby it could be possible to bypass the large time-consumption of thermal-cycling tests as long as the failure mechanism of both load regimes are the same. This has to be validated. With this test-bench and the test samples the detailed investigations such as influence of amplitude changes are possible. The concept is outlined in Fig. 2. This paper is organized as follows: In section 2 we summarize the status of silver sintering in literature. In section 3 we describe and discuss appropriate mechanical material characterization and the challenges thereby. In section 4 we introduce into failure modes, mechanisms and a concept of mechanical acceleration. In section 5 we discuss the failure parameter and where to obtain it. In section 6 we present the results of the isothermal bending tests. Section 7 is dedicated to the failure analysis. In section 8 we show the lifetime models. Sections 9 and 10 belong to the next steps and conclusions.

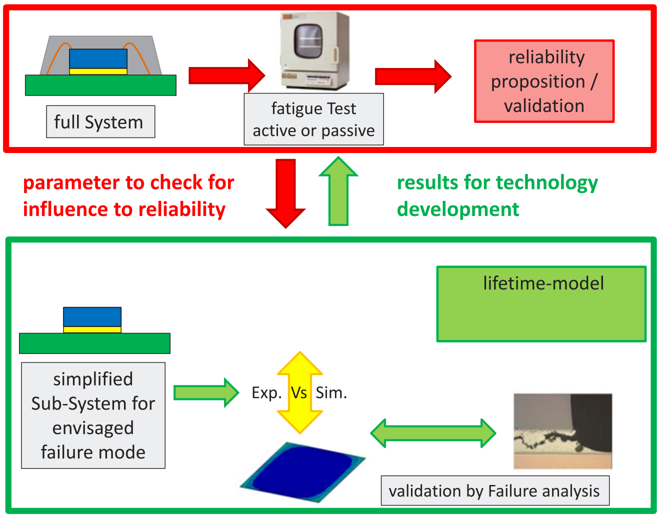

Fig. 2. Concept outline of reliability experiments for physics of failure investigation.

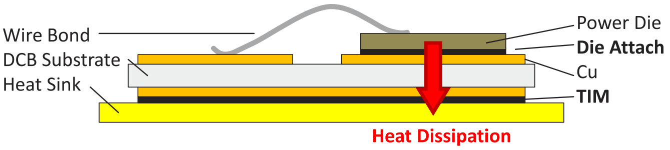

Fig. 3. Sketch of a common power module.

2. Sintered silver as thermal interface material and die attach

One of the promising solutions for a thermal interface material (TIM) as well as die attach is a layer of sintered silver between semiconductor and substrate. The advantages compared to conventional solders are significiant. A higher thermal and electrical conductivity in combination with a higher operating temperature due to a higher melting point is anticipated. This should also enhance the reliability of the package. However, a well understood sintering process to outgas all of the organic additives by a minimum temperature and pressure is needed for industrial application [13]. On package level the electromigration behavior is a primary issue. Efforts are made to reduce that problem by the improvement of passivation and encapsulation [14,15]. Fig. 3 shows an example sketch of common power package where the sintered silver layer can be used to provide electrical and especially thermal connections.

The electrical and thermal properties of sintered silver are denoted superior to solders materials according to literature [16–18]. First used by Siemens over 30 years ago, the first major efforts in developing of sintered silver die attach technologies for today's packaging solutions had been published around the year 2000 [19]. By that time, the so-called Low Temperature Joining Technique (LTJT) was still reported as state of the art [20,21]. Here, $AgNO_3$ is used to generate silver-particles which are eventually grounded to μ-flakes with a size of 100 μm–500 μm. Then the fatty acids, which are used to avoid premature agglomerations during the grinding process, will be washed out and replaced by terpineol to create a processible paste. With a drying time of $\sim$1 h at $>$ 150°C, a sinter temperature of $\sim >$ 200°C, pressures of 20–40 MPa and a sinter-time within the range of a few minutes, very reliable structures with a porosity level of 15% can be achieved [22]. While this described process was the profile of choice, efforts are made to reduce the needed pressure (or obviate the need for a sinter press at best) [21–23]. Eventually the investigations led to the development of nano-particles with a better sinter performance due to their larger overall surface. However, such pastes do need a lot of additives to avoid premature particle agglomeration and furthermore it will complicate the sinter-process to outgas all of that material under the given pressure restrictions [21,23,24]. Common porosities for nano-silver lie at $\sim$30% using the envisaged reduced pressure and temperature profiles [21–24]. Beyond the processing-problem, also the mechanical properties will suffer from the particle size reduction. The larger inner-surface to volume ratio and the relatively high porosity, emerging at low-temperature and pressure, will lead to higher creep effects and reduce the reliability due to a lower yield limit of the effective material [21,23,24]. As a consequence of the insufficient behavior of the pure nano-particle sintered silver paste, current investigations are focused to hybrid-pastes to find an acceptance by the industry. To enhance the reliability, the sintering process can be improved by taking the sintering atmosphere into account [25,26].

3. Mechanical material characterization of sintered silver and issues

A detailed understanding of the material-behavior is essential, if lifetime-modelling is envisaged. These data are needed to judge

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