ARTICLE IN PRESS
MR-12439; No of Pages 4

Microelectronics Reliability xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Microelectronics Reliability

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

Evaluation of effective stress times and stress levels from mission profiles for semiconductor reliability

A. Hirler [a,*], J. Biba [a], A. Alsioufy [a,b], T. Lehndorff [a,b], T. Sulima [a], H. Lochner [b], U. Abelein [c], W. Hansch [a]

[a] Universität der Bundeswehr München, Werner-Heisenberg-Weg 39, 85577 Neubiberg, Germany
[b] AUDI AG, Auto-Union-Straße 1, 85045 Ingolstadt, Germany
[c] Infineon Technologies AG, Am Campeon 1-12, 85579 Neubiberg, Germany

ARTICLE INFO

Article history:
Received 19 May 2017
Received in revised form 12 June 2017
Accepted 13 June 2017
Available online xxxx

Keywords:
Automotive electronics
Mission profile
Semiconductor reliability
Cumulative stress modeling
Effective stress

ABSTRACT

Lifetime and duty cycles of automotive electronics are increasing, inducing new challenges to reliability predictions and testing. For qualification purposes, the automotive industry generates various time-dependent mission profiles with various stressors and varying stress levels according to different use cases.
We present a theoretical model, describing the common approach, to reduce the stressors from time-dependent mission profiles to the two single parameters "effective stress level" and "effective stress time" for equivalent reliability testing. In a first step, the cumulative exposure (CE) model is shown to describe the future reliability behaviour after steplike stress level changes. Taking into account the individual characteristic lifetimes T_{63} of the corresponding Weibull distributions, in a second step, an effective T_{63} lifetime can be derived. For this calculation, periodic stress cycles are defined and transformed into an equivalent effective stress level. This procedure confirms the industry-wide used approach of dealing with effective stress levels for reliability testing.
For the experimental validation metal-oxide-semiconductor (MOS) capacitors are fabricated and stressed by voltage and temperature. The received reliability data fit the theoretical predictions within the statistical variations.

1. Introduction

The automotive industry is steering into a future of new, innovative challenges with driver assistance systems, autonomous driving, electric mobility and car connectivity on their way into the market. In order to realise such ambitious new features, the usage of leading-edge semiconductor technologies is essential. To further on secure the typical high reliability standards requested in the automotive industry, great efforts are made to standardise and advance existing qualification processes. One example are the stress test qualification plans of the Automotive Electronics Council (AEC). In addition to standardised test conditions, they also consider customer mission profile based qualification and robustness validation in case the standard conditions in the AEC-Q100 are not sufficient to cover the application's lifetime requirements [1].

Mission profiles are usually a conglomeration of all relevant stresses on the chosen product in form of time series, histograms or effective stressors (see Fig. 1). Due to the extended duty cycles e.g. for electric mobility applications that are predicted for the future, standard test times may not be sufficient anymore and other ways of qualification must be considered. Either a thorough robustness validation [2] is performed or the already hastened qualification test must be further accelerated. The latter is not always possible, because at higher stresses other usually insignificant failure mechanisms can become the dominant reason for failure or other components of the test device will fail due to enhanced stresses, for instance packaging at high temperatures. Besides that, the degree of detail of mission profiles is constantly increasing to distinguish e.g. different installation locations or supplier adjustments.

While the use of mission profiles becomes increasingly necessary, as already stated, literature on the physical justification for the creation of histograms and effective qualification stresses is barely available.

Therefore, a basic concept is presented on this issue with focus on the experimental validation of cumulative damage models as well as the transformation of alternating step-stress accelerated life tests (SSALT) into one parameter equivalents of effective stress level and effective stress time. The experimental validation is done by using

* Corresponding author.
E-mail address: alexander.hirler@unibw.de (A. Hirler).

http://dx.doi.org/10.1016/j.microrel.2017.06.022
0026-2714/

Please cite this article as: A. Hirler, et al., Evaluation of effective stress times and stress levels from mission profiles for semiconductor reliability, Microelectronics Reliability (2017), http://dx.doi.org/10.1016/j.microrel.2017.06.022

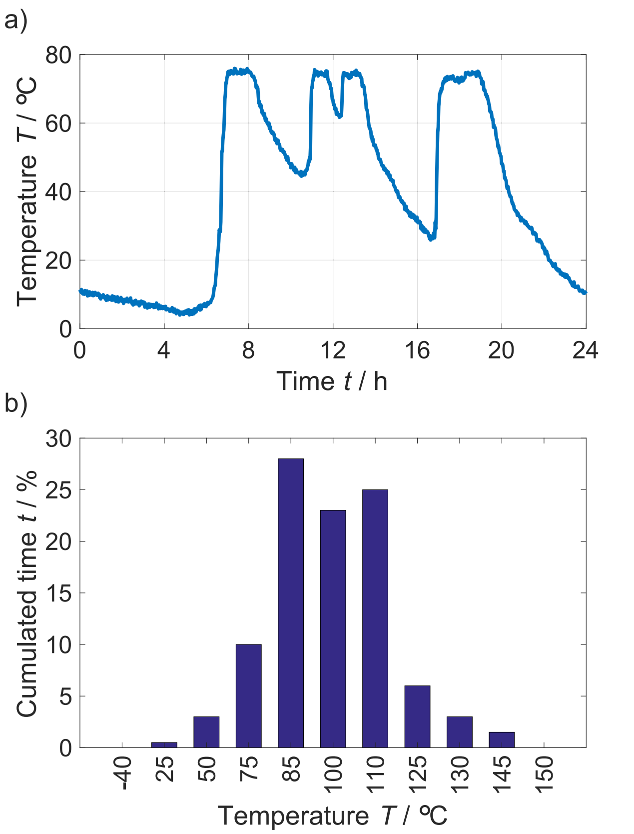

Fig. 1. Mission profiles a) an exemplary stress-time diagram; b) an exemplary stress histogram.

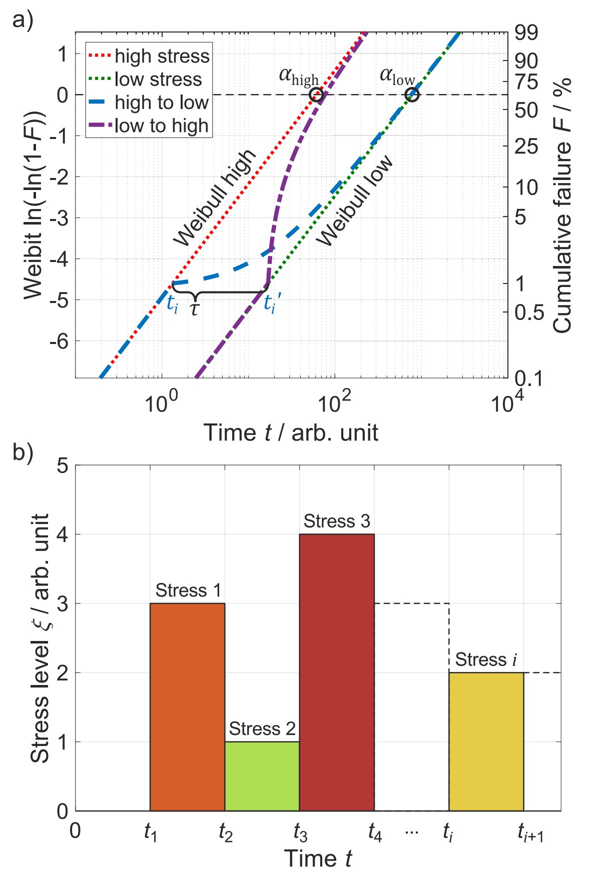

Fig. 2. a) Weibull CDFs of step-stress life tests according to the CE model with two different stress levels and their permutation are drawn with dashed lines, whereas the constant reference stresses are drawn with dotted lines. b) Arbitrary mission profile consisting of various step stresses.

metal-oxide-semiconductor (MOS) capacitors and their failure mechanism time-dependent dielectric breakdown (TDDB) [3] for testing purposes.

2. Cumulative damage model

In order to analyse accelerated life test data from step-stress tests, different cumulative damage models were proposed in literature [4,5,6]. It was shown that for specific conditions these different models coincide with each other [7]. As it is the case for the presented data, Weibull distributions with a shape parameter β of slightly >1 are not suitable to expose the differences of the mentioned models.

Nelson [4] suggested the cumulative exposure (CE) model. While he applied his model to Weibull distributions and an inverse power law stress-lifetime relationship, the CE model can be generalised [8] and applied to many other accelerated life models.

Nelson stated that the remaining life of a specimen depends only on the current cumulative fraction failed and the cumulative distribution function (CDF) of the current stress. The order in which the stress is accumulated is irrelevant and consequently the CE model is a linear one [4].

2.1. Theoretical model description

The CE model can be described by starting with two Weibull CDFs $F_1(t)$ and $F_2(t)$. The resulting CDF $F_{CE}(t)$ depends on the time t and the point of time t_i, when the stress level i is applied:

$$F_{CE}(t) = F_1(t), \qquad t_1 < t \leq t_2, \tag{1}$$

$$F_{CE}(t) = F_2(t - t_2 + t_2'), \qquad t > t_2. \tag{2}$$

t_2' indicates the equivalent start time of the second CDF $F_2(t)$. This is when the cumulative fractions of $F_1(t_2)$ and $F_2(t_2')$ have the same value (see Fig. 2a). With the introduction of an additional location parameter τ_i of the Weibull distribution,

$$\tau_i = t_i - t_i', \tag{3}$$

the current CDF of step i can be simplistically described as a three-parametric Weibull distribution. The CDF is given by

$$F_i(t) = 1 - \exp\left[-\left(\frac{t - \tau_i}{\alpha_i}\right)^{\beta}\right], \tag{4}$$

where α_i is the Weibull scale parameter, which corresponds to the T_{63} time, and β denotes the Weibull shape parameter.

When considering the arbitrary mission profile in Fig. 2b with stress change times t_i, where t_1' is 0, the CDFs of the CE model $F_{CE}(t)$ can recursively be expressed as the following:

$$F_{CE}(t) = F_1(t - \tau_1), \qquad t_1 < t \leq t_2, \tag{5}$$

$$F_{CE}(t) = F_2(t - \tau_1 - \tau_2), \qquad t_2 < t \leq t_3, \tag{6}$$

$$F_{CE}(t) = F_3(t - \tau_1 - \tau_2 - \tau_3), \qquad t_3 < t \leq t_4, \tag{7}$$

$$F_{CE}(t) = F_i\left(t - \sum_{k=1}^{i} \tau_k\right), \qquad t_i < t \leq t_{i+1}. \tag{8}$$

Please cite this article as: A. Hirler, et al., Evaluation of effective stress times and stress levels from mission profiles for semiconductor reliability, Microelectronics Reliability (2017), http://dx.doi.org/10.1016/j.microrel.2017.06.022