Reliability Assessment Of High Temperature Automated Handling Equipment Retrofit For CDM Mitigation

L.H. KOH (1), GOH Yohan (1), S.H. LIM (1)

(1) Everfeed Technology Pte Ltd, 2 Tuas Link 1, Jurong Industrial Estate, 638590 Singapore
tel.: +65-6863-1488, fax: +65-6863-0488, e-mail: info@everfeed.com.sg

Abstract – Functional semi-conductor automated handling equipment (AHE) manufactured decades ago with little or inadequate Electrostatic Discharge (ESD) protection consideration, have great potentials for CDM mitigation through retrofit to meet new ESD specifications. Retrofitted AHE hardware component failure is a stochastic process, where the system reliability assessment can be performed using statistical techniques.

I. Introduction

Mass volume testing of semi-conductor devices using automated handling equipment (AHE) has prevailed for more than two decades. This has brought tremendous cost benefits; increase productivity and fast turn-around time for semi-conductor manufacturers. The underlying Charge Device Model (CDM) risks leading to catastrophic failure or latency issues with testing of Electrostatic Discharge Sensitive (ESDS) Devices in AHE, remain a well-known phenomenal widely reported by industry. Technology scaling and the ever-increasing demand on device operating speed pose a severe challenge to maintain the sensitivity of ESDS devices on-chip protection [1-4]. There remain many existing and functional AHE in semi-conductor manufacturers' test floor, built many years ago where there were little or no considerations on charge mitigation on testing of ESDS devices. This paper narrates fifty units of existing high temperature (Hi-Temp) AHE test handlers retrofit for high pin count ESDS Devices. Usually, the old and functional Hi-Temp AHE is unable to meet new customers' stringent AHE ESD specifications. The new AHE ESD requirements can be accomplished by understanding the needs, incorporate customized design, meticulous installation and implementation with new novel concept in Hi-Temp air ionization and minimize risks of CDM whilst testing. Robust reliability of air ionization system is an imperative factor for research. Reliability is defined as a probability that an item will perform a required function when used for its intended purpose, under the stated conditions, for a given period of time. Availability is defined as the characteristic of an item expressed by the probability that it will be operational at a future instant in time. The availability is measured at an instant and the reliability during a period of time [5-7]. Reliability evaluation of a particular system is usually associated with probability distribution. The statement is realistic as not all components will fail after the same operating time, but will fail at different times in the future. The time-to-failure characteristics can be depicted via probability distribution, i.e. the probability of a component failing within a certain specific time.

Section I provides the background of upgrading functional AHE for ESDS device CDM mitigation; and the need for retrofitted system reliability assessment. Section II narrates the technical details of Hi-Temp AHE retrofit. In Section III, probabilistic concept is studied to evaluate retrofitted system reliability with concluding remarks.

II. AHE Retrofit

The original design of AHE by equipment manufacturer, shown in Figure **1** catered for an open-loop air ionization at Hi-Temp testing chamber Zone-2 without adequate ESD specifications. It incorporated a variable DC High Voltage Controller to balance two units of Hi-Temp DC Ionizers in open-loop mode. The open-loop voltage control, components' drift and aging in power electronics, temperature variation in Hi-Temp Chamber, etc., led to high offset voltage in short duration. In addition, the original variable DC High Voltage Controller has no interface for remote output alarm to indicate ionizer malfunction, nor warning for AHE operator interface. Zone-3 has no air ionization in the original

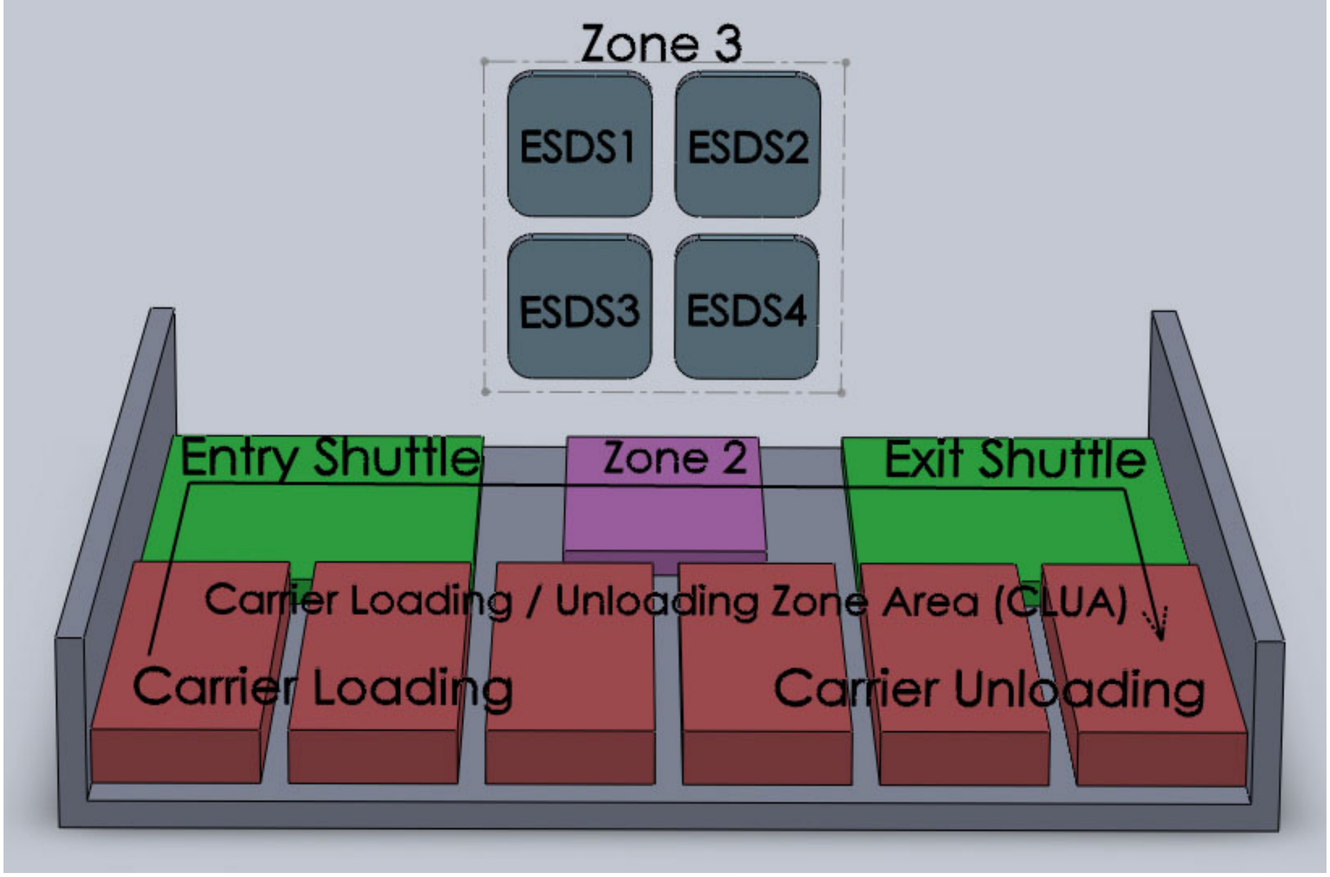

Figure 1 AHE Overview

machine design and relied on left over ionization from Zone-2 for neutralization. Tribo-charging of ESDS Devices for each pick and place action, and insulator around test areas at Zone-2 to-from Zone-3 increases the CDM risks in Hi-Temp chamber. New corporate ESD specifications indicated 5-seconds decay time from +/-1000V~+/-100V within +/-100V offset at Zone-2 and Zone-3 at Hi-Temp whenever possible, with some form of alarm indication for operators if air ionization malfunction and/or warning. Clean dried air (CDA) purging in test chamber will create a homogenous temperature within all zones.

A. Air Ionization Retrofit

1. High Temperature Zone-2 & Zone-3

From Figure **1** the location of Zone-2 and Zone-3 are illustrated. Figure 2 shows a retrofitted AHE block diagram, where an isolated metal strip (10mm x 50mm) was designed for each Hi-Temp DC ionizer mounted at a pre-determined distance. The ion controller was setup with an inner loop using ion current control to have minimal variation with component aging and process temperature change. An outer-loop control with feedback via isolated sensor feedback maintained the offset desired, which can be adjusted below the required ESD offset requirement.

Zone-2 has two series isolated sensor installed to sense two open-loop Hi-Temp DC ionizer as closed-loop feedback. Servo motor fan blowing through air vent at fixed speed on both DC ionizers will determine the decay time and offset at Zone-2. Zone-3 has no dedicated air ionization and relied primarily on left over ion from Zone-2 for neutralization. Hence, a new Hi-Temp DC ionizer with isolated sensor fixture and pre-determined CDA purging was introduced in Zone-3, which effectively meet the required ESD specifications at Hi-Temp chamber testing. Both Zone-2 and Zone-3 have their independent ion controller with sensor feedback [2, 4]. Each ion controller was pre-configured with a failed safe relay output to indicate air ionization failure or malfunction and/or warning, to the system.

2. Carrier Loading / Unloading Zone

The original Carrier Loading / Unloading Zone area (CLUA) for Figure **1** was installed with an open loop 1-fan DC ionizer blower with no alarm output interface. It was retrofitted with a steady-state 1-fan

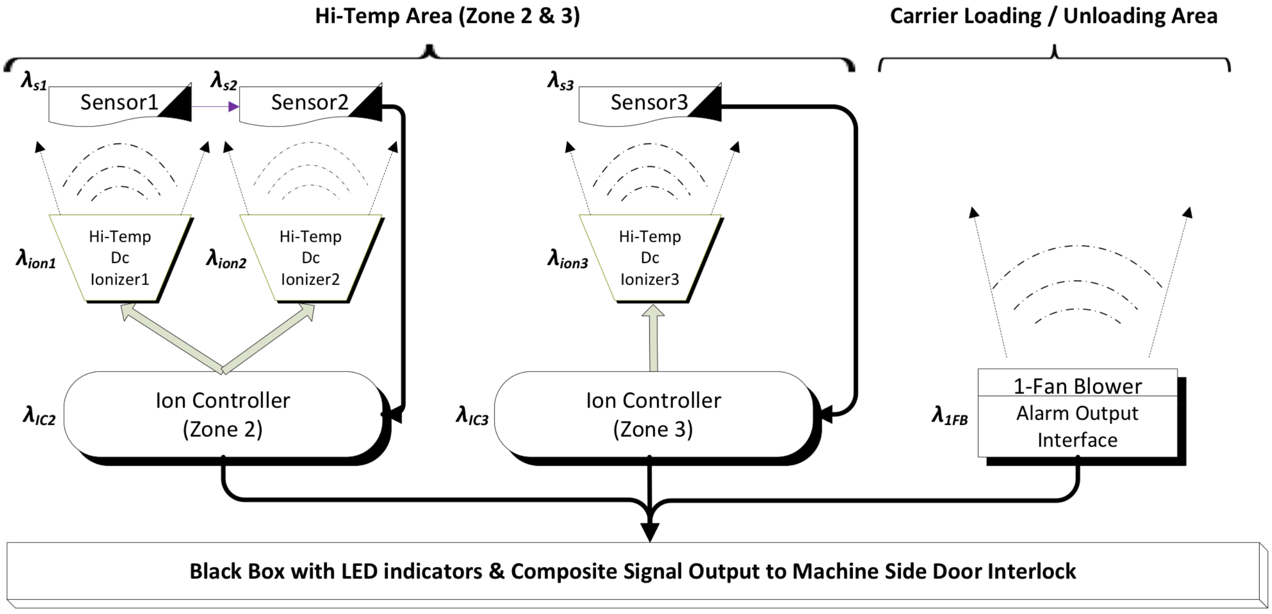

Figure 2 Retrofitted Hi-Temp AHE Control Block & Failure Rates

+/-3V DC ionizer blower with alarm output interface. To aid operator distinguish between chamber air ionization malfunction and side-door opened, a black box with RED and GREEN LED indication shall be displayed. The CLUA 1-fan blower alarm output has a similar relay logic wired as composite signal for air ionization malfunction to side-door opened interlock, like Zone-2 and Zone-3 logic as shown in Figure 2. As the application software of Hi-Temp AHE test handler was not accessible, the failed safe relay output was wired in series to the side door interlock, which was pre-programmed to stop the AHE operation once air ionization triggered on composite alarm / warning signal.

B. Performance Data

Table 1 shows the final test performance after soaking at Hi-Temp for more than 8-hour operation with a 6”x6” plate. The charge plate monitor complies with ANSI/ESD STM3.1. The results clearly indicate that the newly designed, installed and implemented air ionization met the new ESD specifications with consistent performance.

III. Statistical Modeling

Probability distribution has two categories; Discrete or Continuous. Discrete distributions are Poison and Binomial distributions. Continuous distributions include Gaussian (or Normal), gamma, Weibull, Rayleigh and exponential distributions.

Table 1: AHE Air Ionization Performance Results

DESCRIPTIONS	+1000V ~ +100V (SEC)	-1000V ~ -100V (SEC)	BALANCE (VOLTS)
1-FAN BLOWER AT TRAY STORAGE	1.0	1.6	-3
ZONE-2 AIR IONIZATION	1.4	1.7	-36
ZONE-3 AIR IONIZATION	1.9	2.6	45
REQUIREMENTS	**5.0**	**5.0**	**+/-100V**

A. Probability Distribution Model

(1) and (2) show cumulative failure distribution ***Q(t)***, and survivor function or reliability ***R(t)***, as a function of probability density function (PDF), ***f(t)***. PDF is also the failure density function distribution.

$$Q(t) = \int_0^t f(t)dt \tag{1}$$

$$R(t) = 1 - \int_0^t f(t)dt = \int_t^\infty f(t)dt \tag{2}$$

For time dependent failure rate $\boldsymbol{\lambda(t)}$, reliability ***R(t)*** is shown in (3) without assuming any specific form of functions and is equally applicable to all probability distributions used in reliability evaluation.

$$R(t) = \exp\left(-\int_0^t \lambda(t)dt\right) \tag{3}$$

Similarly, series system reliability $\boldsymbol{R_s(t)}$ and parallel system reliability $\boldsymbol{R_p(t)}$ with n-component can be derived as shown in (4) and (5), respectively.

$$R_s(t) = \prod_{i=1}^{n}\left\{\exp\left(-\int_0^t \lambda_i(t)dt\right)\right\} \tag{4}$$

$$R_p(t) = 1 - \prod_{i=1}^{n}\left(1 - \exp\left(-\int_0^t \lambda_i(t)dt\right)\right) \tag{5}$$

$\boldsymbol{\lambda(t)}$ may be independent of time or a constant { $\boldsymbol{\lambda}$ } in some unique situation. ***R(t)***, $\boldsymbol{R_s(t)}$ and $\boldsymbol{R_p(t)}$ can be proven as in (6), (7) and (8), respectively. (7) and (8) are tailored for n-component system, where $\boldsymbol{\lambda_i(t)}$ is known and integrated, resulting in $\boldsymbol{\lambda_i}$. Assuming an exponential distribution the equivalent failure rate for n-component system, $\boldsymbol{\lambda_e}$, is shown in (9). Using (1), PDF is 1st derivative of ***Q(t)***, or negative derivative of ***R(t)*** as shown in (10).

$$R(t) = \exp(-\lambda t) \tag{6}$$

$$R_s(t) = \exp\left(-\sum_{i=1}^{n}\lambda_i t\right) \tag{7}$$

$$R_p(t) = 1 - \prod_{i=1}^{n}\{1 - \exp(-\lambda_i t)\} \tag{8}$$

$$\lambda_e = \sum_{i=1}^{n}\lambda_i \tag{9}$$

$$f(t) = \frac{dQ(t)}{dt} = -\frac{dR(t)}{dt} \tag{10}$$

B. Formulation

(6) to (9) formed the basis for formulation. As per Figure 2, Zone-2 Ion Controller 2 failure rate, Hi-Temp Dc Ionizer-1 failure rate, Hi-Temp Dc Ionizer-2 failure rate, Sensor-1 failure rate and Sensor-2 failure rate are $\boldsymbol{\lambda_{IC2}}$, $\boldsymbol{\lambda_{ion1}}$, $\boldsymbol{\lambda_{ion2}}$, $\boldsymbol{\lambda_{s1}}$ and $\boldsymbol{\lambda_{s2}}$, respectively. Zone-2 reliability $\boldsymbol{R_{Z2}}$ is described in (11).

$$R_{Z2} = exp(-\lambda_{IC2}t)\,.\,[1 - \{1 - exp(-\lambda_{ion1}\,t)\}\{1 - exp(-\lambda_{ion2}t)\}].\,exp\,(-[\lambda_{s1} + \lambda_{s2}]t) \tag{11}$$

Zone-3 Ion Controller 3 failure rate, Hi-Temp Dc Ionizer-3 failure rate and Sensor-3 failure rate are $\boldsymbol{\lambda_{IC3}}$, $\boldsymbol{\lambda_{ion3}}$ and $\boldsymbol{\lambda_{s3}}$, respectively. Zone-3 reliability $\boldsymbol{R_{Z3}}$ is determined by (12).

$$R_{Z3} = exp\,(-[\lambda_{IC3} + \lambda_{ion3} + \lambda_{s3}]t) \tag{12}$$

CLUA 1-fan blower failure rate is $\boldsymbol{\lambda_{1FB}}$ and reliability is $\boldsymbol{R_{1fan}}$ depicted in (13).

$$R_{1fan} = exp\,(-\lambda_{1FB}t) \tag{13}$$

Hence, system level reliability $\boldsymbol{R_{sys}}$ is the convolution of $\boldsymbol{R_{Z2}}$**,** $\boldsymbol{R_{Z3}}$ and $\boldsymbol{R_{1fan}}$ as described in (14).

$$R_{sys} = exp(-\lambda_{IC2}t)\,.\,[1 - \{1 - exp(-\lambda_{ion1}\,t)\}\{1 - exp(-\lambda_{ion2}t)\}].\,exp\,(-[\lambda_{s1} + \lambda_{s2}]t).\,exp\,(-[\lambda_{IC3} + \lambda_{ion3} + \lambda_{s3}]t).\,exp\,(-\lambda_{1FB}t) \tag{14}$$

C. Sensitivity Study

Expanding on (11) to (14) with pre-assigned failure rate, Figure 3 showed the reliability characteristics of system and each area of interests. 1-fan blower has the highest reliability, followed by Zone-2 and Zone-3. As these three components are in series, the system reliability is considerably reduced. Taking ordinary differential equation with respect to time on (1), the system PDF, i.e. (10), is shown in Figure **4** which exhibited exponential distribution function over 10 years.

IV. Conclusion

Aged semi-conductor Hi-Temp AHE retrofitted with customized air ionization design, installation and implementation complete with alarm output can meet new ESD specifications. It has better performance consistency than old AHE and helps mitigate CDM in Hi-Temp testing dominated by pick & place activities. Reliability and probability density function (PDF) assessment of Hi-Temp AHE retrofitted components and system has been characterized through statistical technique. A technique to assess system reliability for 10 years or more can be implemented.

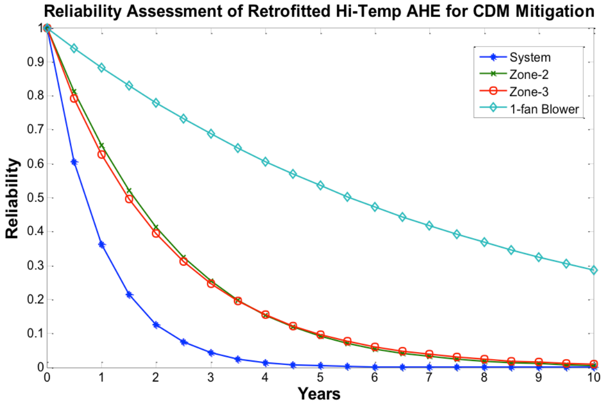

Figure 3 Reliability of Hi-Temp AHE Air Ionization System

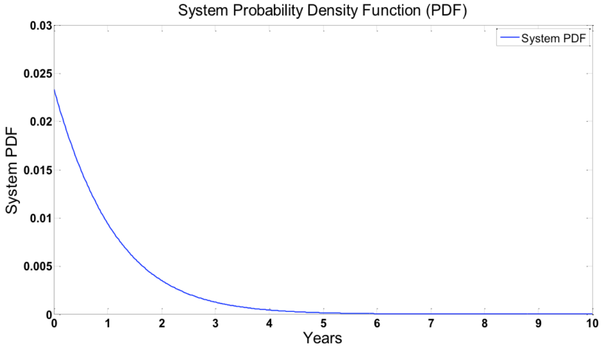

Figure 4 System Probability Density Function

Acknowledgement

The authors would like to acknowledge Mr. MA Tao contribution in the sketches of this paper.

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