# Robust electromigration reliability through engineering optimization

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**Abstract**

With complex process integration approach and severe fabrication limitations caused by introduction of new materials and diminishing process margins, there are mounting concerns with the increased failure rate at the early life cycle (e.g. <1 year operation) of product application known as infant mortality failures. A paradigm change in reliability qualification methodology aim at understanding the impact of variation on reliability is required to ensure reliability robustness. Using Electromigration (EM) as an example, this paper described a methodology where the impact of process variation on reliability is studied. A model that predicts the impact of process variation on EM sigma is also proposed which enables variation and its impact on reliability to be quantified. Using this methodology, the critical process parameters impacting reliability could be identified and controlled to ensure reliability robustness.

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## 1. Introduction

To sustain Moore's Law, the continuous scaling of integrated circuitry has resulted in very stringent requirements in the manufacturability and variation control capability of the fabrication tools. In advance technology, manufacturers have been working below a robust manufacturing level resulting in severe process and reliability marginality issue especially during mass production phase. Thus, a paradigm change in reliability qualification methodology aim to establish a good linkage process variation and product ramp up is required to ensure reliability robustness. An innovative Design-For-Reliability (DFR) methodology was previously proposed [1], using engineering optimization.

## 2. Methodology & Test Structure

In order to study process variation and its impact on reliability in the early stage of technology development, test structures with build-in variation are tested using fast Wafer Level Reliability (fWLR) methods. The DFR test structures are designed with the objective of simulating process variation and its impact on the reliability margin, as described in the previous report [1].

## 3. Experimental Results

Results collected from the DFR test structures are analyzed with reference to the nominal test structure for Electromigration (EM) reliability degradation mechanism.

### 3.1. Build-in Variation on Via

The first set of design aims to simulate variation in the Via lithography and etch process. With a Via misalignments varying by up to 30nm and Via critical dimension (CD) varying by up to ±25%, the impact of lithography overlay variation on the

subsequent etch profile and the corresponding impacts to EM performance, namely Time-To-Failure (TTF) are studied and modeled as shown in Figure 1 and Figure 2 respectively. For direction notation, X-direction is perpendicular to the metal line; while Y-direction is along the metal line.
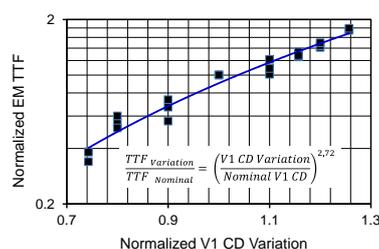


$$\frac{TTF_{Variation}}{TTF_{Nominal}} = \left(\frac{V1\ CD\ Variation}{Nominal\ V1\ CD}\right)^{2.72}$$

Figure 1. Normalized EM downstream performance (TTF) for structure with Via CD variation compared to the nominal structure with POR CD.



$$\frac{TTF_{Variation}}{TTF_{Nominal}} = exp\left(-0.39 \times \frac{V1\ MisalignmentY}{Nominal\ M1\ CD}\right)$$

$$\frac{TTF_{Variation}}{TTF_{Nominal}} = exp\left(-1.51 \times \frac{V1\ MisalignmentY}{Nominal\ M1\ CD}\right)$$
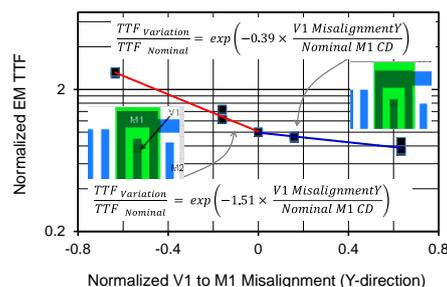
Figure 2 Normalized EM downstream performance for structure with Via misalignment in the Y-direction

The Via CD variation is modulating the current crowding effect and thus the EM downstream performance. Similar behavior was observed in the misalignment in X-direction. Physical analysis of the Via misalignment as shown in Figure 3 provide the physical evidence of the current density modulation due to Via variation, as shown in Figure 1.

For Via misalignment in the Y-direction, the variation modulated the line end extension of the metal interconnects. Work done by Christine S. Hau-Riege et al [2] suggest that the larger the reservoir at

the cathode, the better the EM performance. The increase in EM lifetime in negative Y direction can be explained by the reservoir effect, which affects the void formation and growth. Variation in positive direction merely modulated the current crowding.
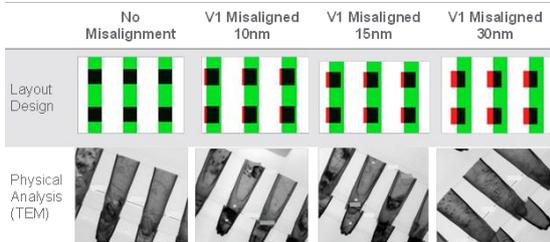


Figure 3. Physical analysis on Via misalignment (X-direction)

### 3.2. Build-in Variation on Metal alignment

Using a similar method used in the study of Via variation, the impact of variation in metal CD and trench depth is investigated. The result is similar to the finding on Via CD variation.

## 4. Process Variation EM Model

Using the method that correlate the impact of Via and metal variation to the normalized EM downstream performance. The EM downstream lifetime distribution sigma due to process variation can be derived as illustrated in equation (1).

For V1 misalignment in the −ve Y-direction:

$$\frac{TTF_{Variation}}{TTF_{Nonimal}} = VCD^{2.72} \bullet MCD^{1.65} \bullet MT^{1.56} \bullet VMA_X^{0.98} \bullet \exp(-1.51 \times VMA_Y)$$

(1)

Where    VCD, MCD, MT are normalized V1CD, M1 CD, M1 trench variations respectively.

$VMA_Y$ = V1 misalignment$_Y$ ÷ Nominal M1 CD
$VMA_X$ = (Nominal M1 CD − V1misalignment$_X$) ÷ Nominal M1 CD

Figure 4 shows the normalized EM downstream TTF predicted from inline process parameters while Figure 5 is the packaged level EM downstream TTF collected from the same die. Lot A is well controlled while Lot B is deliberately varied for this study. By subtracting the process variation sigma from the packaged level EM sigma, the true intrinsic EM sigma can be predicted. This method also enables the impact of various inline parameters variation on EM sigma to be quantified as illustrated in Figure 6.
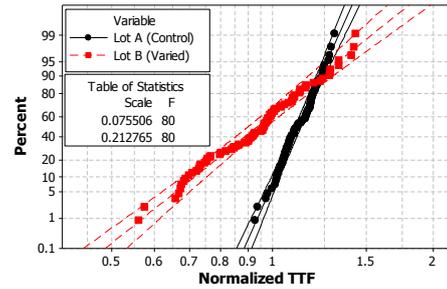


Figure 4. Normalized downstream EM TTF distribution predicted using the inline process parameters.
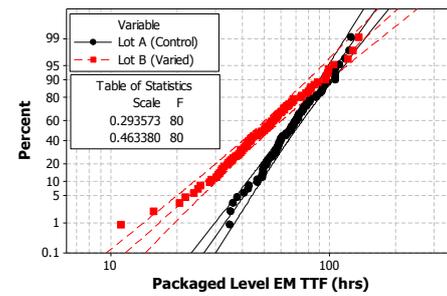


Figure 5. Packaged level EM testing performed on the site that the inline process parameters are collected.
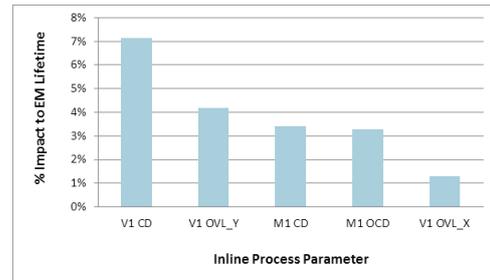


Figure 6. Impact of process variation on downstream EM

## 5. Conclusion

In this paper, we presented a methodology where the impact of process variation on reliability mechanism such as EM can be quantified. For application that required stringent reliability requirement (i.e. automotive etc.), this method enable the true intrinsic EM performance where process variation is minimal to be evaluated.

## References
[1] W.L. Ng *et al*, "Design For Reliability Through Engineering Optimization", IRPS, (2013)
[2] Christine S. Hau-Riege *et al*, "The Effect of Current Direction on The Electromigration in Short-Lines With Reservoirs", IRPS, (2008)