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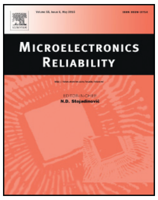

LER and spacing variability on BEOL TDDB using E-field mapping: Impact of field acceleration

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ABSTRACT

Understanding the impact of process variability on TDDB is crucial for assuring robust reliability for current and future technology nodes. This work introduces a lifetime prediction model that considers local field enhancement to assess the combined impact of die-to-die spacing variability and line edge roughness. The model is applied to 16 nm half-pitch BEOL interconnects assuming either the power law or the root-E as field acceleration model and the impact on lifetime reduction is discussed. In comparison with the ideal case of a straight line with a nominal spacing of 16 nm, a 1-sigma spacing variation of 0.6 nm and 1-sigma LER of 1 nm leads to ~3 orders of magnitude lifetime reduction when assuming power-law whereas this value is ~1 order of magnitude when assuming root-E.

1. Introduction

Low-k materials are used in advanced back-end of line (BEOL) interconnects to meet the required circuit performance of RC delay and power consumption. With scaling dimensions and increasing low-k porosity, time dependent dielectric breakdown (TDBB) is becoming a major concern [1]. Process variability including line edge roughness (LER), line-to-line (L2L) spacing variation and via misalignment significantly impacts TDDB reliability due to reduced thickness and local E-field enhancements [2–4]. Besides process variability, the assumption of the lifetime model used to project the lifetime from high fields to use conditions is also crucial to make reliable predictions [5,6]. The E model and the root-E model are widely used by industry since they give the most conservative lifetime predictions at operating fields while the impact damage model, the power law and the 1/E model give more optimistic predictions.

The impact of LER on BEOL TDDB has been discussed in the literature [4–8]. In [7,8], protrusion size and field enhancement factor were determined and the root-E model was modified to assess the impact of LER. In [5,6], the spacing distribution was modelled with a normal distribution assuming $E = V/s$, a constant field across the low-k and did not account for the local field enhancements. However, as clearly seen in Fig. 1, the E-field profile across the dielectric shows a parabolic shape behaviour with higher fields close to the copper and a flatter part in the middle of the low-k when roughness exists (for more details, see Methodology). For realistic TDDB predictions to assess the impact of process variability, this non-uniform E-field behaviour should be taken into account. Moreover, modelling roughness using a normally distributed spacing variation across the line does not result in realistic LER profiles. It is reported that roughness profiles are auto-correlated along the copper line and their amplitudes should be determined with a power spectrum obtained from Gaussian or exponential autocorrelation function (ACF) [4,9,10].

The aim of this study is to propose a lifetime prediction model based on E-field mapping after process emulations to predict the impact of LER and L2L variability on BEOL TDDB. Realistic LER profiles are generated from the power spectrum of a Gaussian ACF. Both the power law and the root-E are integrated into our proposed model as a field acceleration model and its impact on predictions is also discussed. The relation between the Weibull scale parameter η and field E is assumed as $\eta \sim E^m$ for power law and $\eta \sim \exp(\gamma.\sqrt{E})$ for root-E.

2. Methodology

The details of the methodology are given in [11]. In summary, a 3D model is generated from a 2D layout of 32 nm pitch straight lines using Sentaurus Process Explorer tool from Synopsys [12]. Random

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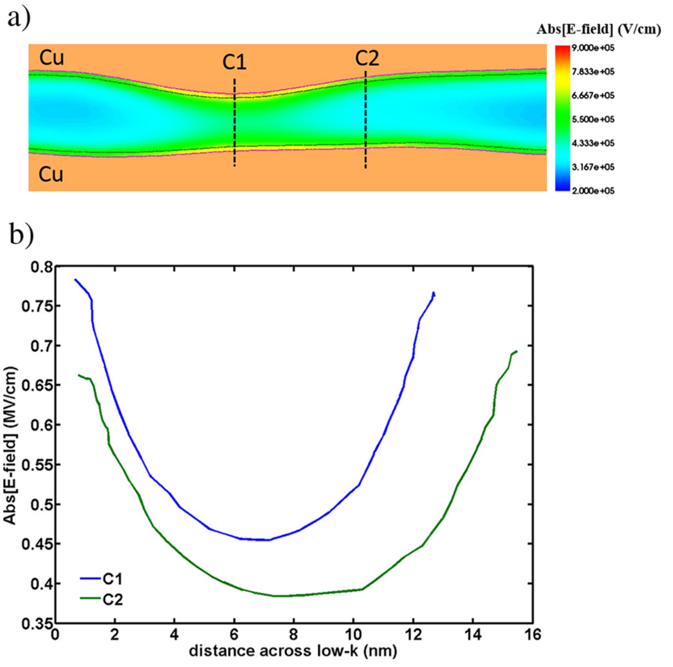

Fig. 1. (a) A typical E-field map with LER (b) Non-uniform E-field profile across low-k with LER.

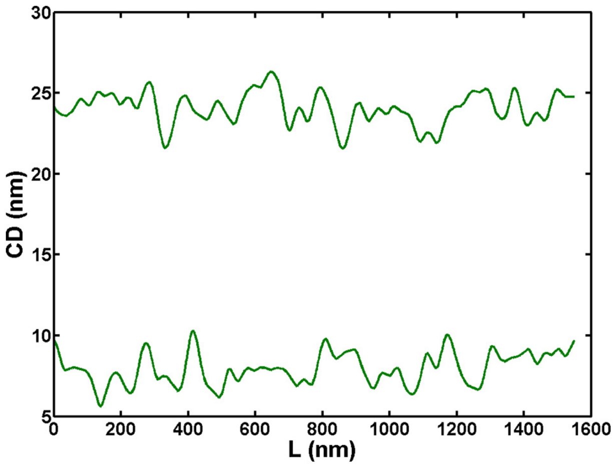

Fig. 2. Typical LER profile generated from a Gaussian autocorrelation function.

LER profiles are generated by the built-in function that applies a Fourier synthesis technique based on the power spectrum of a Gaussian ACF. In LER generation algorithm, the material is subdivided into N discrete segments, whose amplitude is determined with the power spectrum of a Gaussian ACF, after adding random phases.

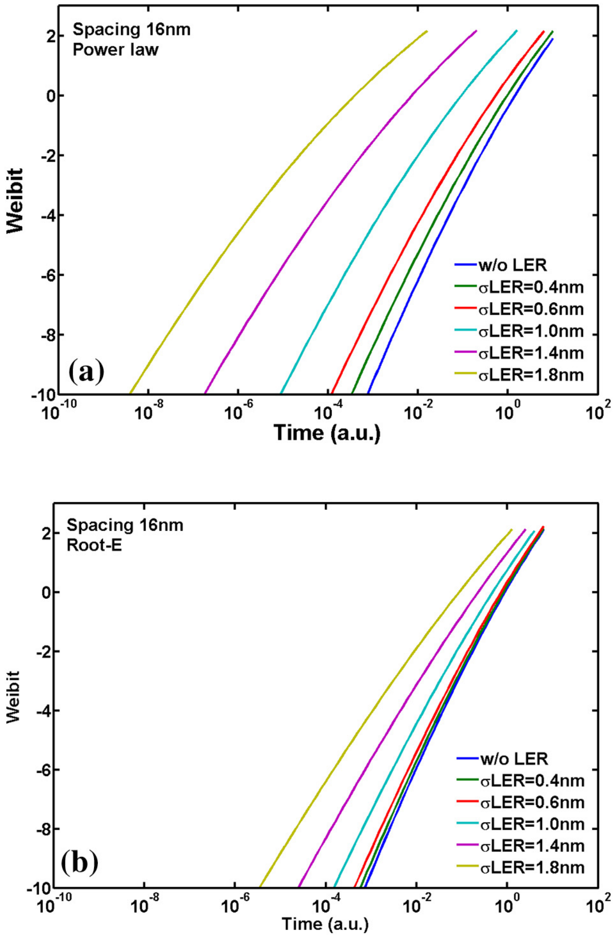

Fig. 4. LER-induced TDDB distributions for the spacing of 16 nm based on (a) the power law and the root-E (b).

$$S_G(k) = \sqrt{\pi\lambda\sigma^2 \exp\left[-\left(\frac{\lambda^2k^2}{4}\right)\right]} \tag{1}$$

S_G is the power spectrum of a Gaussian ACF, where λ and σ are the correlation length and RMS amplitude of LER profile, respectively. k is the wave-vector, $k = i(2\pi/Nd_x)$. d_x is the spacing between two adjacent segments and should be much smaller than λ to guarantee a reasonable resolution of discretization. In this study, $d_x = 0.5$, a value much smaller than λ, which is typically ranging between 20 and 50 nm [13] and $\lambda = 30$ nm. Fig. 2 demonstrates a randomly generated LER profile from a Gaussian ACF with a nominal thickness of 16 nm and a LER

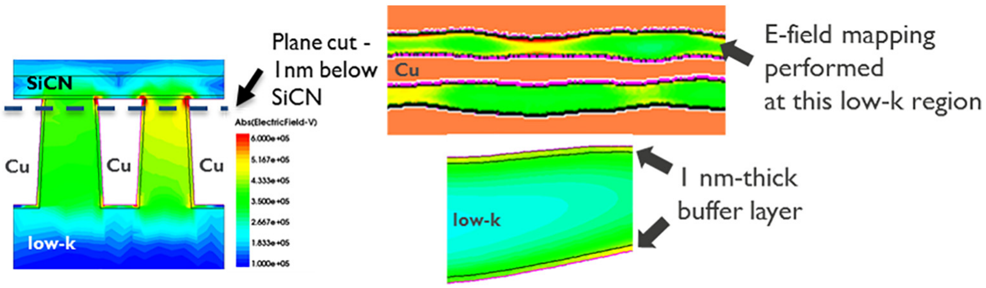

Fig. 3. Schematic model cross-section and methodology for E-field mapping.

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