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Characterization of Line-edge Roughness in Cu/low-k Interconnect Pattern

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1. Introduction

Degradation of time-dependent dielectric breakdown (TDDB) immunity is a serious problem in Cu/low-k interconnect [for example, 1, 2]. It is caused by Cu-ion diffusion into inter-metal dielectric (IMD) under the strong electric field strength. Therefore, the electric field enhancement at the corner of metal pattern was often discussed. Although the degradation of TDDB immunity by line-edge roughness (LER) was also pointed out [3, 4], it was considered to be small because LER was sufficiently small compared to pattern size. However, the pitch of interconnect pattern has been scaled down and will be smaller than 100 nm within a few years. Therefore, impact of LER on TDDB immunity should be evaluated quantitatively and measurement method for interconnect LER should be established.

In the case of gate edge-roughness, 3sigma of edge position or local-linewidth distribution was a valid metric. However, it is not yet clear whether this popular and conventional LER metric, 3sigma of edge position (denoted $3R_q$ hereafter), enables us to predict electric field enhancement. In this study, we characterized LER of a low-k pattern sample, modeled the average feature of the low-k LER, and simulated electric-field enhancement to obtain relationship between LER-feature parameters and electric- field enhancement.

2. Measurement of LER

Figures 1(a) and (b) show the extracted edges of an ArF resist and low-k patterns. The low-k pattern was fabricated by dry etching of the ArF resist pattern. The edge of a low-k line pattern has several wedges protruding into the low-k material while the LER of ArF resist pattern is almost symmetric. This kind of wedge can also be seen in the SEM images in the previous papers [3, 4].

First, we thus assumed the model feature of low-k LER as the wedges shown in Fig. 2. The actual low-k LER is described by superposing the wedge-shaped LER and the symmetric LER (that is, ArF type). However, we modeled only the wedge-shaped portion for electric-field simulation because the wedge (especially its tip) mainly affects TDDB immunity. The tip of the wedge was assumed to be an arc of circle C, which came into contact with the slope of the line of the wedge at point P. It was assumed that the wedge appears periodically on the line edge with the period of 2L. Independent feature parameters are L, q, w, and q (shown in Fig. 2). The average x-coordinate of the edge points and radius of C were defined as a and r, respectively.

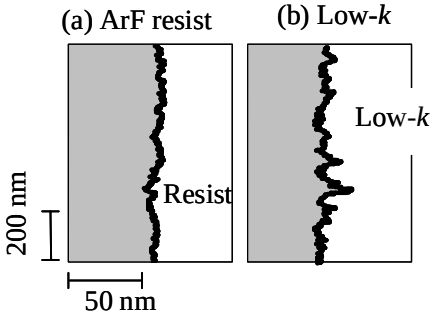

Fig. 1 Typical LER in ArF resist and low-k pattern.

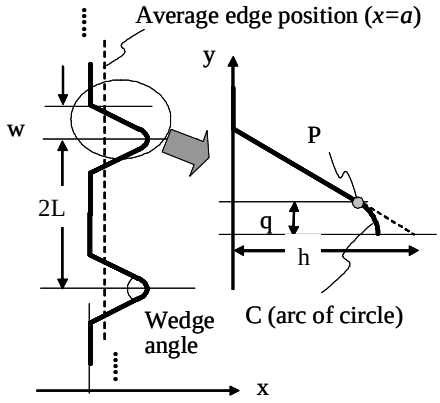

Fig. 2 Model feature of low-k LER

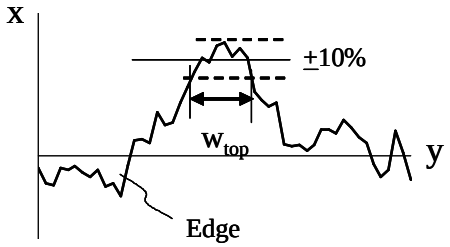

Fig. 3 Definition of w_{top} of wedge

Next, typical values of these four independent parameters were determined based on the measurement results. Eighteen clear wedges (shown in Fig. 3) were observed on 2800-nm-long line; therefore, L was set to 160 nm. Resolution limit in y-direction was 7 nm and the width of the wedge-tip (w_{top} in Fig. 3) was smaller than 7 nm in most

cases. Then q (=w_{top}/2) was set to 1, 2, and 3 nm. Value of w was set to 30 nm, the average of correlation length. Finally, h was calculated from distribution of edge position, and set to 14 nm.

3. Simulation of Electric Field

Simulation conditions (LER models) are listed in Table I. The other edge of a line is a smooth line (i.e., has no LER). Average width of the low-k line was set to 50 nm, corresponding to the 100-nm-pitch interconnect pattern. Distribution of the electric-field strength in the low-k region was simulated using an electromagnetic field simulator (PHOTO-VOLT, PHOTON CO., Ltd.). The result for typical case is shown in Fig. 4. All the results are summarized in Fig. 5. These values are the ratio of the field strength at the tip (E_{max}) to the field strength obtained when there is no wedge (E_0). The ratio is found to be 1.7 to 3.2, which is considered to be sufficiently large to cause TDDB immunity degradation.

Table I Simulation conditions

No.	w (nm)	L (nm)	h (nm)	q (nm)
Typical	30	80	14	1,2,3
Small	30	80	9	1,2,3
Narrow	21	56	14	1,2,3
Small & Narrow	21	56	9	1,2,3

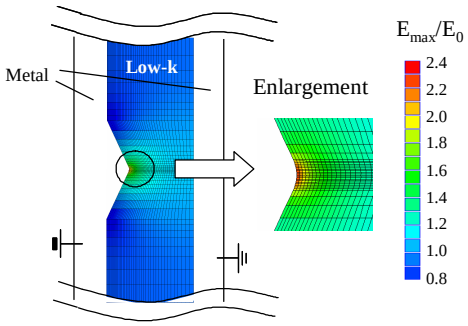

Fig. 4 Electric field obtained with typical condition.

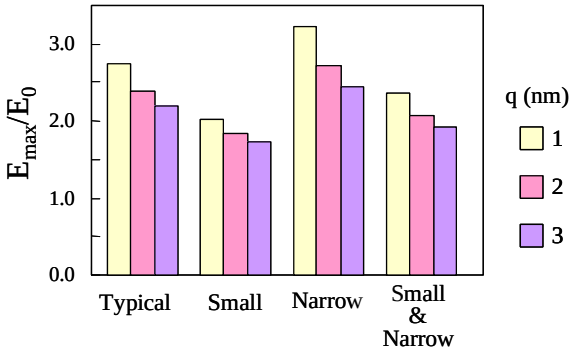

Fig. 5 Electric field enhancement (E_{max}/E_0).

To identify the feature that dominates electric field enhancement, correlations between the various feature parameters and E_{max}/E_0 were calculated. It was found that electric field strongly depends on curvature of tip (1/r), wedge angle and minimum linewidth as well as $3R_q$ [Figs. 6(a) to (d)]. That is, the curvature of the tip and wedge angle can be a useful metrics for evaluating interconnect LER from the viewpoint of TDDB property.

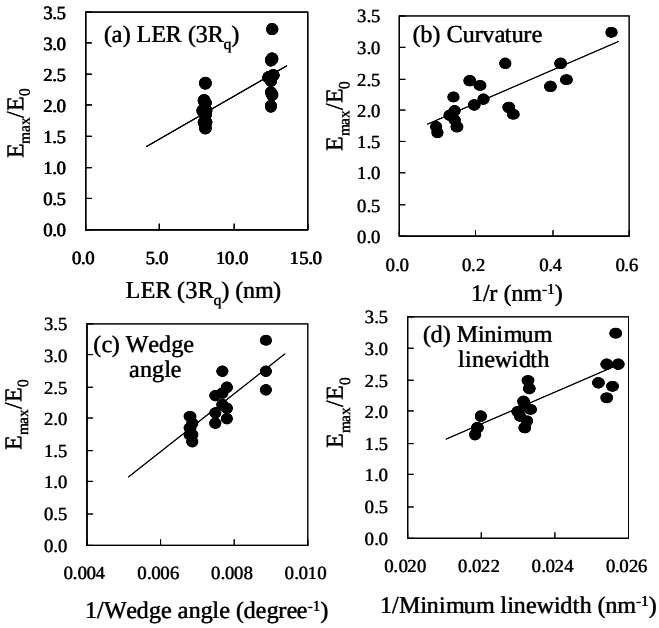

Fig. 6 Dependence of maximum electric-field on (a) 3Rq, (b) curvature, (c) wedge angel, and (d) minimum linewidth.

3. Summary

To estimate the impact of line-edge roughness (LER) in Cu/low-k interconnect pattern on their reliability, we observed low-k line patterns and simulated electric-field enhancement based on the observation results. Simulation showed that the maximum electric-field strength, which is at the tip, was 1.7 to 3.2 times greater than when there was no LER, assuming a 50-nm-wide low-k line. Although the maximum electric-field strength depends on the conventional LER metric, $3R_q$, it depends more strongly on the curvature of the tip and wedge angle.

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