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Characterization of post-copper CMP surface with scanning probe microscopy: Part II: Surface potential measurements with scanning Kelvin probe force microscopy

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Abstract

We demonstrate in this paper for the first time the use of Scanning Kelvin Probe Force Microscopy (KFM) to characterize post-CMP copper structures with varying line width and spacing. This work is in the continuity of previously published results concerning surface leakage measurements with conductive Atomic Force Microscopy. The feasibility of KFM will be shown by studying patterned samples and post-CMP copper samples. Results show clearly the capability of this technique in the detection of metallic contamination. It has also been observed that a post-CMP cleaning solution impacts the copper work function. A special study has been done by varying the pH of a cleaning solution. Moreover, electrostatic simulations have been performed to analyse the results obtained for patterned wafers.

Keywords: Chemical mechanical polishing (CMP); Post-CMP cleaning; Atomic force microscopy

1. Introduction

Controlling metallic residuals after copper CMP is getting more emphasis in advanced interconnects [1]. Cleaning efficiency and the removal of metallic contaminations have appreciable impact on productivity and reliability. The control of metallic residuals is essential with the implementation of new integration schemes such as self aligned electro-less passivation [2–4]. Recent work has been published concerning the characterization of post-copper CMP surface leakage with conductive atomic force microscopy [5]. A different scanning probe microscopy (SPM) method is explored in this paper for the characterization of post-copper CMP surfaces.

Scanning Kelvin Probe Force Microscopy (SKPFM or KFM) is a well known technique which enables to build a surface potential map of the sample [6]. KFM is a non contact operation mode in which the electrostatic interaction between tip and sample is used in order to determine the local work function of the material. Until now KFM has been typically used in large field off applications, such as mapping of biased p–n junctions [7], measuring of local dopant concentration [8] and for characterizing local electronic properties of self-assembled semiconductor nanostructures [9] to name only a few examples. However, to the best of our knowledge, no report has been published so far on the use of KFM in conjunction with post-CMP cleaned surfaces.

2. Experimental setup

2.1. Surface potential measurement with KFM

AFM measurements were performed in air with a Veeco MultiMode scanning probe microscope using a scanning stage AS-130 (''J'') with Nanoscope IIIa electronics. KFM measurement technique is based on a two-pass LiftMode™ measurement. LiftMode™ allows the imaging of relatively

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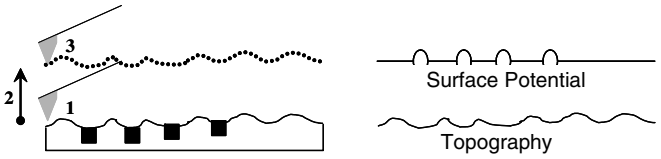

Fig. 1. Lift Mode principle (Veeco®): (1) cantilever measures surface topography on first (main) scan; (2) cantilever ascends to lift scan height and (3) cantilever follows stored surface topography at the lift height above sample while responding to electric influences on second (interleave).

weak but long-range electrostatic interactions while minimizing the influence of topography. Measurements are taken in two passes (each consisting of one trace and one retrace) across each scan line. First, topographical data is obtained in TappingMode™ on one trace and retrace. The tip is then raised to the final scan height and electrostatic measurements are performed by maintaining a constant separation between the surface topography (Fig. 1).

The silicon tips used were coated with Co/Cr and had a stiffness of $k \approx 2.8$ N m^{-1} and a resonant frequency of $f_0 \approx$ 75 kHz.

2.2. Samples

Sematech MIT854 mask has been chosen as it is widely used for CMP topographic studies and characterization of post CMP electrical performance [10]. Plasma enhanced chemical vapor deposited TEOS dielectric was used. Twenty-three structures are available on a die. Six structures have been selected with varying pitch (line width_line spacing = 0.18_0.18, 0.25_0.25, 0.5_0.5, 1_1, 2_2 and 1_9 μm) for surface potential measurements. Patterned samples have also been polluted with a solution containing 1 ppm (in mass) of Cu(II). With this solution, we expect to have on TEOS 10^{12} at/cm^2 of Cu which simulates an inefficient post-CMP cleaning.

KFM has also been performed on blanket post-CMP copper samples before and after a cleaning step. During 1 min, the sample was immerged in a cleaning solution at several pH and then rinsed using DI water during 15 s.

2.3. Polishing

CMP polishing was performed on a Mirra 200 mm applied materials® tool. CMP was carries out using a two step process. First, copper was removed by stopping on a barrier layer using selective slurry. The end point was detected optically. Then, the barrier was removed using non selective slurry.

3. Results and discussions

3.1. Post-CMP copper samples

Surface potential has been measured on post CMP copper before and after a cleaning step using solutions containing benzotriazole (BTA) or 1,2,4-triazole (TA) described in Table 1.

Fig. 2 gives the surface potential shift due to the effect of a cleaning solution.

As it can be seen, the potential shift is different for each solution. It is also interesting to observe the change with TA concentration. From chemistry B to chemistry D, the TA concentration increases whereas the potential shift decreases.

A study has been done in order to look at the influence of the pH. A solution containing BTA (0.002% in mass) has been tested at different pH. The Table 2 gives the results obtained in terms of absolute sample work function before and after cleaning.

First, it is important to notice that the work function of post-CMP copper is not the same for all the samples. This difference is not due to the measurements, because the standard deviation is quite low and has been evaluated being around 10 m, but due to the sample. Furthermore, Fig. 3 shows the impact of the pH on the potential shift. The

Table 1
Composition of the cleaning solutions

Solution	A	B	C	D
Corrosion inhibitor	BTA	None	TA	TA
Concentration (mass)	0.002 %	None	1 %	3 %
pH	Acidic	Alkaline	Alkaline	Basic

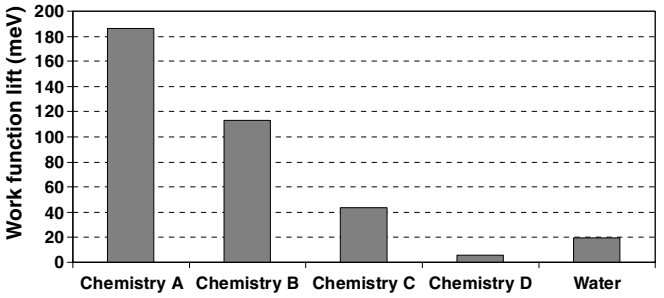

Fig. 2. Copper surface potential after cleaning step. Different level are observed depending on the cleaning solution.

Table 2
Work functions of post-CMP copper samples before and after a cleaning step

pH	Cu post-CMP work function (eV)	After cleaning (eV)
2.4	5.180	4.899
3.64	5.186	4.940
4.67	5.193	4.98
6.83	5.183	4.990
8.08	5.175	5.010
9.22	5.208	5.044

Experiments have been reproduced four times for each sample.