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Effect of mechanical factor in uniformity for electrochemical mechanical planarization

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ABSTRACT

Since copper (Cu) electrochemical mechanical planarization (ECMP) process is both a mechanical and electrochemical process, a polymeric pad must have mechanical integrity and chemical resistance to survive the rigors of polishing. Mechanically, a polishing pad should have acceptable levels of hardness and modulus, and good abrasion resistance to endure the Cu ECMP process. Chemically, a polishing pad should be able to survive the aggressive electrolyte chemistries, which include either highly alkaline, or high acidic electrolyte. Therefore, the characteristics of the polishing pad have been measured and evaluated. Although the material removal rate (MRR) is proportional to the current density of the Cu ECMP process, the planarization and uniformity in the wafer level are poor. To improve planarization of the wafer level, the effect of the abrasive is evaluated, with respect to the planarization and uniformity of the wafer and the abrasive properties of the electrolyte. In this study, the concentration of the abrasive (silica; SiO_2) in the electrolyte with H_3PO_4 6 wt%, H_2O_2 0.5 wt%, and BTA 0.5 wt%, glycine 0.5 wt% and citric ammonium 5 wt% should be above 10 vol%.

1. Introduction

Planarization processes such as lapping, spin-on-glass (SOG), reflow, tech back, electron cyclotron resonance (ECR), chemical mechanical planarization (CMP) and electrochemical mechanical planarization (ECMP) etc., are used to planarize the topography created by the previous semiconductor processing step. Hence, the depth of focus (DOF) of existing photolithography tools can be extended in sub-micron technology. However, the planarization length is different in each planarization process. Among the various planarization processes, the CMP process requires the longest planarization length [1], as shown in Fig. 1. When the CMP process was introduced, its first role was to planarize inter-layer dielectric (ILD) films to enable multiple levels beyond two or three metal interconnects [2]. As with any other step in semiconductor processing, the CMP step comes with a significant number of integration issue and their associated performance tradeoffs [2,3].

The ECMP process is a recent development in planarization technology of semiconductor fabrication. In the ECMP process, metal film on the Si wafer is polarized anodically by an input charge as the polishing pad mechanically wears the metal surface. The contact of polishing pad with the surface creates a low down pressure, so the metal film does not delaminate from the underlying low-k film [4,5], and as a result, defects such as dishing, erosion, and scratch that are common in the conventional CMP process are minimized. The applied charge controls the material removal rate (MRR), which is electrochemically converted to metal ions and passivation film on pure metal surface. The low-lying areas of the film are protected by the passivation film while the protruding features are polished by the polishing pad. The ECMP process has an advantage; the polishing process can be modified according to the total charge.

Significant variation in planarization length exists a cross the wafer, and the spatial non-uniformity is more clearly apparent in copper (Cu) ECMP process. The wafer scale shows trends according to the process conditions: for example, a drop in the planarization length is apparent. In this study, a method for improving the uniformity of wafer scale was investigated for various process conditions.

2. Experimental

2.1. Viscoelasticity of polishing pad

The role of polishing pad is to wear a passivation film by electrochemical reaction, as shown in Fig. 2. Therefore, various types of polishing pad are used in the CMP process because the type

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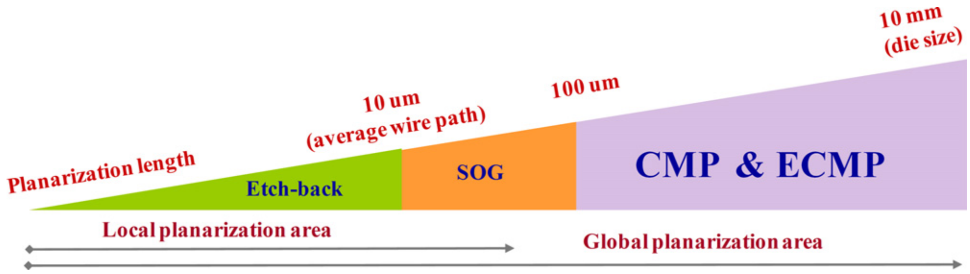

Fig. 1. Planarization length of various planarization processes.

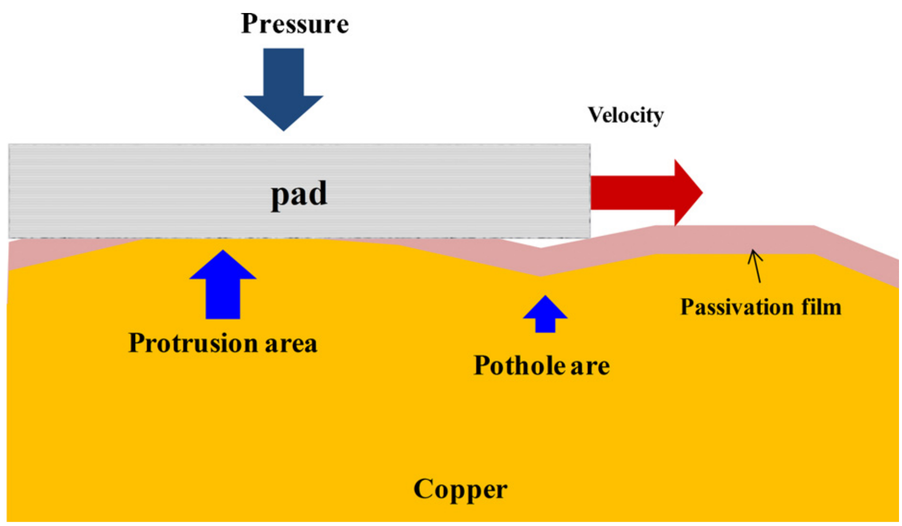

Fig. 2. Role of polishing pad in Cu ECMP process.

is very important. Conventional wisdom ascribes the bulk of the material removal to asperity interaction with the Cu wafer surface, so it is essential that the surface profiles of the polishing pad be well characterized [6–8]. The classic model of the polishing pad shows a surface that is covered with polymer protrusions of different lengths, heights, and widths. These then become the primary elements that transmit force to the wafer surface from the pressure on the carrier head and the response pressure of the polishing pad [6,7]. Therefore, the characteristics about polishing pad should be investigated.

Experiments were carried out to verify the effect of the mechanical properties of the polishing pad. Viscoelastic deformation of

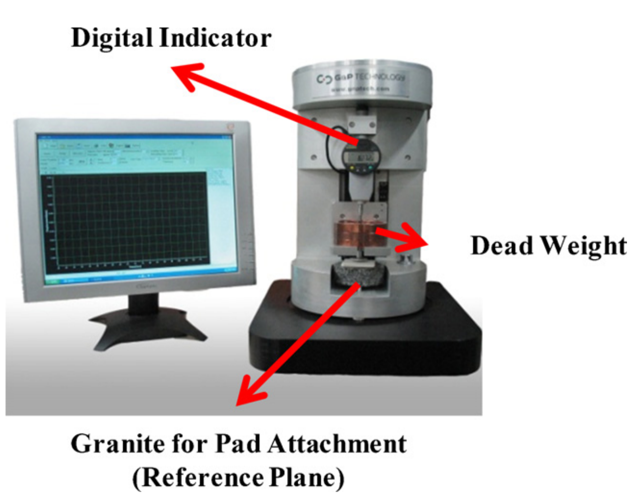

Fig. 3. Viscoelastic behavior measurement system.

the polishing pad was measured and the strain of the polishing pad was analyzed. To measure the viscoelastic behavior of the polishing pad, a GNP PV system (G&P tech.) was used, as shown in Fig. 3. A GNP PV system can measure compressibility, elastic recovery, permanent deformation, viscoelastic property and other time related physical properties of polymeric materials. This viscoelasticity measurement system has resolution of 1 μm. Table 1 shows the experimental conditions. Viscoelastic behavior of the polishing pad was measured by using a piece of polymer impregnated felts pad (Suba 600, Nitta-Haas) and polyurethane pad (IC 1400 k-groove, Nitta-Haas). A pressure of 100 g/cm^2 was applied to the polishing pad sample for 30 s (loading time), and released for 30 s (unloading time). To eliminate the abnormal compressive deformation by the loading force, a 4 cm diameter sample of polishing pad is obtained, because the plate area of viscoelastic measurement system is 2 cm diameter. To verify the mechanical properties of the polishing pad, it was soaked in deionized wafer (DIW) and electrolyte with H_3PO_4 6 wt%, H_2O_2 0.5 wt%, and BTA 0.5 wt%, glycine

Table 1
Experimental conditions for viscoelastic behavior of polishing pad.

Parameters	Conditions
Pressure	100 g/cm^2
Polishing pad	Polyurethane pad (IC 1400 k-groove), polymer impregnated felts pad (Suba 600)
Loading/unloading time	30/30 s
Cycle	30 cycles
Solution	(1) Non-solution (dried state) (2) DIW (3) Electrolyte (6 vol% of H_3PO_4 solution, 0.5 wt% of H_2O_2 solution, 0.5 wt% of BTA, 2 wt% of citric ammonium, and 0.5 wt% of glycine)