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A study on the chemical mechanical polishing of oxide film using a zirconia (ZrO_2)-mixed abrasive slurry (MAS)

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Abstract

We have studied the chemical mechanical polishing (CMP) characteristics of mixed abrasive slurry (MAS) retreated by adding of zirconium oxide (ZrO_2) abrasives within 1:10 diluted silica slurry. These mixed abrasives in the MAS are evaluated with respect to their particle size distribution, surface morphology, and CMP performance such as removal rate and non-uniformity. As an experimental result, the comparable slurry characteristics when compared to the original silica slurry were obtained from the viewpoint of high removal rate and low non-uniformity for excellent CMP performance. Therefore, our proposed ZrO_2-MAS can be useful to save on the high cost of slurry consumption since we used a 1:10 diluted silica slurry.

Keywords: Chemical mechanical polishing (CMP); Mixed abrasive slurry (MAS); Zirconia (ZrO_2); Diluted silica slurry (DSS)

1. Introduction

As semiconductor devices are shrunk to the deep submicron region for ultra large scaled integrated circuit (ULSI) applications, a chemical mechanical polishing (CMP) process has been widely used for the global planarization of the multi-level interconnection structure [1–4]. The CMP performances can be optimized by process parameters such as equipment and consumables (pad, backing film, and slurry). One of the critical consumables in the CMP process is a slurry typically containing both abrasives and chemicals acting together to planarize films. The conventional slurry consists of abrasive particles of the solid state suspended in a liquid state chemical solution [5]. An abrasive in the slurry transfers mechanical energy to the surface being polished and helps in its material removal. Through chemical and physical actions, the abrasive-liquid interactions play an important role in determining the optimum abrasives' type and size, their shape, and concentration [6]. The slurry designed for optimal performance should produce reasonable removal rates, acceptable polishing selectivity with respect to the underlying layer, low surface defects after polishing, and good slurry stability [7].

In a single abrasive slurry (SAS), the solid source consists of only one type of abrasive particle. Until now, in addition to many studies of silica (SiO_2) slurry, the polishing of the spin-on glass interlayer by ceria (CeO_2) slurry has been reported [8,9]. The polishing by zirconia (ZrO_2) slurry has been presented [10]. Also, manganese oxide (MnO_2) slurry has been developed for polishing of an oxide layer [11–13].

On the other hand, the mixed abrasive slurry (MAS) consists of a mixture of two types of abrasive particles chosen from Al_2O_3 [14,15], SiO_2, CeO_2, ZrO_2, TiO_2 [16,17], MnO_2 [18], etc. We observe that some of the problems associated with the use of SAS can be easily controlled

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by using MAS with proper composition and choice of constituents of the solid phase [14,15]. Babu and his working group have reported the characteristics of Al_2O_3-MAS in order to improve the polishing selectivity for a multi-level interconnection with the Cu/Ta/oxide structure [15]. In our earlier studies, we polished barium titanate (BTO) thin film using a CMP process with either $BaTiO_3$-MAS or TiO_2-MAS in order to obtain good planarity of the electrode/ferroelectric film interface for ferroelectric random access memory (FRAM) chip application [16,17]. The removal rate of the BTO thin film by using the $BaTiO_3$-MAS was higher than that by using the TiO_2-MAS in the same concentrations. These results will be promising for application to global planarization for FRAM in the near future. Also, the CMP performance of Al_2O_3-MAS, based upon diluted silica slurry (DSS), has been studied for planarization of oxide film [19,20]. Recently, we have reported the effect of these mixed two particles (silica abrasive and manganese oxide abrasive) on the CMP characteristics of the oxide layer through a CMP process using MnO_2-MAS based upon a diluted silica slurry [18].

In the present work, slurries containing zirconia and silica particles dispersed in de-ionized water (DIW) at pH 11–12 have been studied for the oxide CMP process. We evaluated the modified abrasives in MAS with respect to their particle size distribution, surface morphology, and CMP performance such as removal rate and non-uniformity.

2. Theoretical and experimental details

2.1. MAS

The potential energy (V) between the particles as the sum of the repulsive (V_R) and the attractive potentials (V_A) was firstly introduced by Verwey and Overbeek [21–23]. For the case of $|V_R| < |V_A|$, the particles tend to agglomerate. As a result, the micro-scratches due to the large particles, which originate from the agglomeration of slurry, cause a circuit failure and affect the yield of the devices [24,25]. A schematic diagram of the polishing mechanism by both abrasives in MAS, consisting of two types of abrasive particles such as alumina and silica, has been reported by Babu and his laboratory members [14,15]. When two types of particles are dispersed together, additional particle–particle interactions occur. One of examples is to disperse mechanically larger particles in the slurry containing relatively smaller particles. This dispersion has enough abrasion capability for material removal without surface defects. That is to say, there is improved CMP performance of MAS due to the interplay between the abrasive action of the larger particles and the chemical-tooth nature of the smaller particles surrounding the larger particles.

2.2. CMP test

The CMP setup and procedures have been described elsewhere [1,3,4,16–20,24,25]. In brief, in order to prepare the MAS, KOH-based fumed silica slurry of pH 11 with solid content of 13% was diluted in de-ionized water (DIW) with a 1:10 ratio. KOH was added as a buffering agent to keep the pH levels constant. The zirconia (ZrO_2) abrasives' particles were, then, added in the DSS in order to compare the effect of agglomeration and dispersion on polishing efficiency. The concentration of ZrO_2 abrasive was varied from 1 wt% to 5 wt%. The particle size distribution of the slurries was measured by using a Zeta potentiometer from Malvern Co. A Tetra-ethyl ortho-silicate (TEOS) oxide layer of 1800 nm was deposited on a 4-inch blanket wafer. The CMP polishing of all test wafers was performed with a G&P POLI-380 CMP polisher (see Fig. 1). The polishing pad was an IC-1400 from Rohm and Haas Company. A diamond pad conditioner was utilized to abrade the pad before conducting each polishing test. The parameter range of the optimized CMP process is summarized in our previously published papers [18,20]. Typical CMP process conditions were: The carrier head speed, table platen speed, slurry flow rate, head pressure, and polishing time were 60 rpm, 40 rpm, 90 ml/min, 300 g/cm^2 and 60 s, respectively.

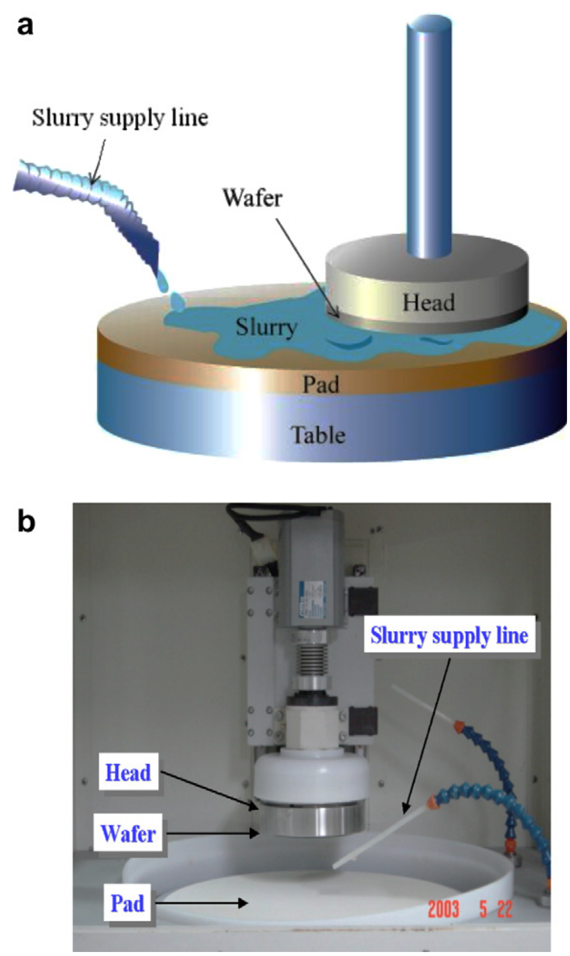

Fig. 1. (a) A schematic diagram of the CMP process and (b) a photograph of a G&P POLI-380 polisher.