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Improvement of TEOS-chemical mechanical polishing performance by control of slurry temperature

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Abstract

Effects of slurry temperature on the chemical mechanical polishing (CMP) performance of tetra-ethyl *ortho*-silicate (TEOS) film with silica and ceria slurries were investigated. The change of slurry properties as a function of different slurry temperatures was also studied to obtain higher removal rates and smoother surface morphology. The changes observed with increasing temperature are as follows: the pH showed a slight tendency to decrease, the conductivity of the slurry showed a tendency to increase, the particle size in the slurry decreased, and the zeta potential of the slurry decreased with temperature. The removal rates linearly increased and maintained at the temperature of about 40 °C. The hydroxyl (OH^-) groups increased in the slurry as the slurry temperature increased and then they diffused into the TEOS film. The surface of the TEOS film became hydro-carbonated by the diffused hydroxyl groups. The hydro-carbonated surface of TEOS film could be removed more easily. Better surface morphology of TEOS films could be obtained at 40 °C of silica slurry and at 90 °C of ceria slurry. It is found that the CMP performance of TEOS film could be significantly improved or controlled by change of slurry temperature with the same slurry.

Keywords: Chemical mechanical polishing; Tetra-ethyl *ortho*-silicate; Slurry temperature; Removal rate; Planarity

1. Introduction

Chemical mechanical polishing (CMP) has been widely recognized as the most promising technology for the planarization of multi-layer structures in semiconductor manufacturing [1–4]. It is generally known that several process parameters including equipment and consumables (pad, backing film and slurry) can optimize and improve the CMP performance [5–8]. Among the consumables for CMP process, especially, the slurry and its properties play a very important role in the removal rates and planarity for the global planarization ability of the CMP process [9]. There are several slurry properties that affect the material removal procedure such as slurry chemicals, potential of hydrogen (pH), size and hardness of abrasive particles, slurry viscosity, and stability of the abrasive suspension in the slurry, etc. [10]. Polishing temperature is one of the most important factors that affect the material removal process. There are two methods to study the effect of temperature on CMP performance: (1) by controlling the temperature of both the pad and slurry at the desired value, or (2) by adjusting only the temperature of the slurry and maintaining the temperature of the polishing pad constant [11]. To investigate the effects of slurry temperature on CMP performance, we selected the latter method with the identical process temperature by the same head speed, table speed, and down force. It is well known that the material removal properties shown a strong temperature dependence in CMP slurries [10]. Although there have been some

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investigations on the influence of temperature on the properties of the slurry, those works show a lack of consistency [11–13]. In this paper, we have investigated the correlations between slurry properties and CMP performance of tetraethyl *ortho*-silicate (TEOS) as a function of different temperatures of the slurry. Thermal effects on the individual slurry properties such as pH, particle size, conductivity and zeta potential were studied. Moreover, the relationship between the removal rate and planarity with slurry properties caused by changes of temperature were investigated. The change of chemical attacks by increase of slurry temperature was investigated by X-ray photoelectron spectroscopy (XPS). Therefore, the understanding of these temperature effects provides a foundation to optimize the TEOS CMP process for ULSI multi-level interconnection technology.

2. Experiments

All the samples in this paper were prepared on 4-inch n-type (1 1 1) oriented silicon wafers with resistivity of 3–6 Ω cm. For cleaning and removal of native oxide, the substrate was rinsed with the solution of H_2SO_4:H_2O_2 (1:4), H_2O:HF (DHF; 10:1), and de-ionized water (DIW), consecutively. TEOS film of 1900 nm was deposited on the silicon by plasma enhanced chemical vapor deposition (PECVD). The CMP polishing of all test wafers was performed with a G&P POLI-380 CMP polisher [14]. Rodel IC-1300 and Suba IV were glued by a bonding agent of PSA II to make a double pad [14]. The parameter ranges of design of experiments (DOE) technique for the optimized CMP process is summarized as follows: table speed, head speed, slurry flow rate, and down force were 40 rpm, 60 rpm, 90 ml/min, and 300 gf/cm^2, respectively [15]. CMP processing time was 60 s. The conditioning pressure was fixed at 2 kg/cm^2 to exclude the effects of pad-conditioning. The polishing pad was used without change because of its good stability. A commercial silica-based oxide slurry (silica slurry) and ceria-based oxide slurry (ceria slurry) were used as CMP slurries. To prevent aging effects, the slurries were dispersed by using a Sonic Tech ultrasonic wave homogenizer before polishing. Polishing was carried out with the slurries cooled or heated from 10 to 90 °C at intervals of 10 °C by chiller and hot plate. All temperatures in this experiment were measured by IR (infrared rays) sensor. Post-CMP cleaning proceeded using a sequence of 3 min in SC-1 chemicals (NH_4OH:H_2O_2:H_2O = 1:2:7), 2 min in diluted HF (DHF) of 1:10, and 4 min in ultrasonic cleaning. Particle size, conductivity, and zeta potential of the each slurry were measured using Zetasizer (Malvern Instruments Ltd., Nano ZS) by the self-operating temperature control. Film thickness at 9 points from the center to the edge was measured clockwise on each wafer using a spectroscopic ellipsometer (J.A woollam, M-2000 V). In order to understand the effects of temperature on chemical reactions between slurry and TEOS film, the variations in chemical composition of the surface was analyzed by XPS (VG-Scientific ESCALAB 250) measurement. The sample was immersed in slurries with a fixed temperature for 60 min. Then it was transferred to the analysis chamber for the XPS after air-drying. For XPS analysis, Al Kα (1486.6 eV) was used as an X-ray energy source. A scan interval was 1 eV (wide scan spectrum) and 0.05 eV (narrow scan spectrum), respectively. All binding energy (BE) values were referred to C 1s (284.5 eV). The surface morphology after the CMP process was measured with AFM (PSIA XE-200).

3. Results and discussion

Fig. 1 shows the removal rates of TEOS film according to the temperature variations of silica and ceria slurries, respectively. The removal rates of TEOS films polished with silica slurry were 203.8 and 183.0 nm/min at the temperatures of 10 and 20 °C, respectively. Then, the removal rates maintained approximately constant values between 332.4 and 395.4 nm/min in the ranges of slurry temperature from 30 to 90 °C. The removal rate of the TEOS film polished with ceria slurry was proportional to the increase in temperature to 40 °C, and then remained constant. The removal rate of 448.5 nm/min at a temperature of 10 °C rapidly increased to 785.6 nm/min at 40 °C. The removal rate of the TEOS film polished with both the silica and ceria slurries kept up to values between 1.5 and 2 times. The removal rate of TEOS films polished with ceria slurry was higher than that with silica slurry at all temperature conditions. On the other hand, within-wafer non-uniformity (WIWNU%) of polished TEOS film was below 10% under the all temperature conditions. In the case of ceria slurry between 20 and 40 °C, the uniformity was insufficient for the deep submicron semiconductor manufacturing. The best uniformity of TEOS films polished with ceria slurry was obtained at the 50 and 90 °C conditions.

In order to investigate the origin of changes of removal rates, the slurry properties as a function of temperature

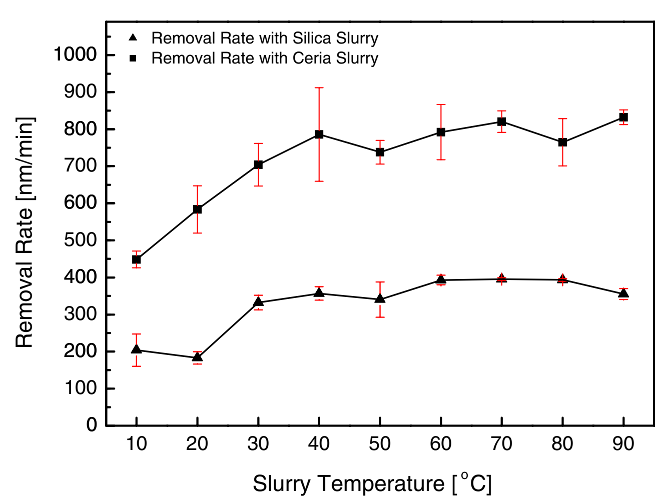

Fig. 1. Comparison of TEOS removal rates with an increase of temperature in silica and ceria slurries.