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Exploration on chemical mechanical planarization of ZnO functional thin films for novel devices

Kailiang Zhang [a,*], Taofeng Zhang [a] Fang Wang [a,*], Yujie Yuan [a], Yuzhuo Li [b]

[a] School of Electronics Information Engineering, Tianjin Key Laboratory of Film Electronic & Communication Devices, Tianjin University of Technology, Tianjin 300384, PR China
[b] Center for Advanced Materials Processing, Clarkson University, Potsdam, NY 13699, USA

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ABSTRACT

Zinc oxide (ZnO) is an attractive material for its application in the electronics, optics, acoustics, and sensor field. With the shrinking of minimum feature size of the devices and the increasing of devices function layers, surface planarization of each layer is demanded in the devices manufacturing. However, ZnO thin films deposited directly have high surface roughness which could cause device performance degradation. Therefore, ZnO thin films must be planarized in order to obtain high density and high integration devices. In this paper, chemical mechanical polishing (CMP) was used for ZnO thin films planarization, these films were deposited on 4 inch Si blanket wafer by RF magnetron sputtering. The influence of the process parameters on CMP removal rate including pressure, platen speed was discussed, and the results demonstrated that removal rate still exist when there is no pressure and velocity, hence Preston equation was slightly modified. The effect of slurry pH on CMP removal rate was also investigated in detail after considering different corrosion rate of ZnO films in different solution. After optimizing CMP process parameter, the removal rate of ZnO films was up to 165.1 nm/min, and the surface root mean square roughness was reduced from 16 to 1.9 Å.

1. Introduction

In recent years, ZnO thin films has attracted widely attention for a variety of optoelectronics and microelectronics applications [1–8], it can be widely used in transparent thin films transistors (TFTs), resistive random access memory (RRAM) devices [9], surface acoustic wave device and other fields. To accommodate the improvements such as decreased feature size, increased device speed and more intricate designs, each layer in the devices must be flatted. However, ZnO thin films which deposited directly have a rather high surface roughness and pinholes, which could degrade devices performance. For example, the optical propagation loss in ZnO thin films is significantly affected by films surface morphology due to scattering at rough surface [10–11], the SAW filters in a structure of ZnO/IDT/glass, ZnO thin films surface roughness has a mass loading effect which causes SAW velocity dispersion [12]. Hence the surface of ZnO thin films in the devices must be flatted. CMP is the only technique that can offer excellent local and global planarity on the surface of the material in IC industry [13].

Sushant Gupta et al. [14] provided a comprehensive study on the process parameters of CMP to ZnO thin films; they investigated the influence of parameters such as slurry pH, down pressure, platen speed, abrasive size and concentration to polishing effect of films. The removal rate and the surface root mean square roughness could reach 67 nm/min and 6 Å respectively, though the removal rate was low. There are some other methods to flat ZnO thin films such as gas cluster ion beam [15] and electron cyclotron resonance (ECR) system [16]. Both of them, the mechanism of material removal is more due to the physical sputtering than due to chemical reaction and abrasive, i.e. bombardment the surface material. This will lead to new defects appeared. In this paper, the influence of CMP process parameters such as slurry pH, pressure and platen speed to polishing effect of ZnO thin films were studied. The removal rate is up to 165.1 nm/min and the removal rate is not zero for both $P \rightarrow 0$ and $V \rightarrow 0$. Preston equation was slightly modified to as followed: $RR = KPV + R_0$, R_0 is a constant removal due to purely chemical reaction. The effect of slurry pH and mechanism of polishing were also studied in detail from the viewpoint of chemical and found the removal rate with acid slurry is higher the removal rate obtained by alkali slurry.

2. Experimental

All experiments studied in this paper were carried out on a 6EC-nspire CMP polisher (Strasbaugh, Inc.). The process parameters were shown in Table 1. The polishing pad which was full of

* Corresponding authors.
E-mail addresses: kailiang_zhang@163.com (K. Zhang), Fwang75@yahoo.com.cn (F. Wang).

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Table 1
Parameter ranges of CMP for ZnO films.

Polishing parameter	Value
Pressure (psi)	2 ~ 5
Platen rotation (rpm)	20 ~ 80
Head rotation (rpm)	20 ~ 80
Slurry flow rate (ml/min)	200
Slurry pH	4 ~ 10
Ring force (psi)	0

crossing groove was a type IC-1000 from Dow Chemical Company. Colloid SiO_2 slurry was used and the slurry pH was adjusted range from 4 to 10 by diluted nitric acid and solution of KOH. The post-CMP sample wafers were cleaned by megasonic cleaning using related clearing liquid, and then dried by spin rinse drying (SRD). The thickness of ZnO thin films of pre-CMP and post-CMP was measured by Dektak 150 system (Veeco Instruments Inc.) with the resolution of 0.1 Å. The surface topography and root mean square roughness of wafers were characterized by Atomic force microscope (5600LS of Agilent Technologies, Inc.).

ZnO thin film was deposited on 4 inch Si (100) substrate by RF magnetron sputtering. Fig. 1 represents the surface topography (10 μm × 10 μm) of AFM and the peak-to-valley value for the deposited wafers. The root mean square roughness is 16 Å and the peak-to-valley distance is 9.1 nm. Fig. 2 shows the X-ray diffraction spectrum for the as-grown ZnO thin film before polishing. From the XRD spectrum we know that ZnO films describe dominant (002) orientation.

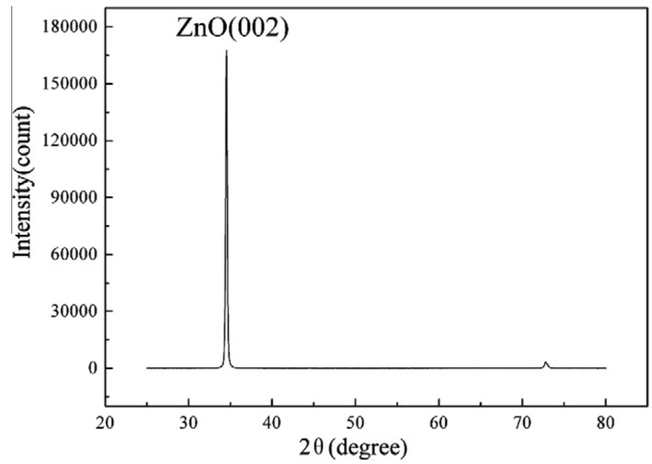
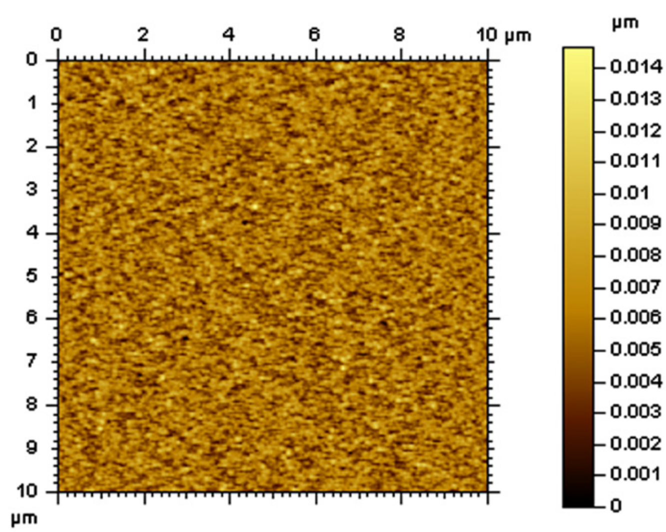


Fig. 2. XRD spectrum of ZnO thin films before polishing.

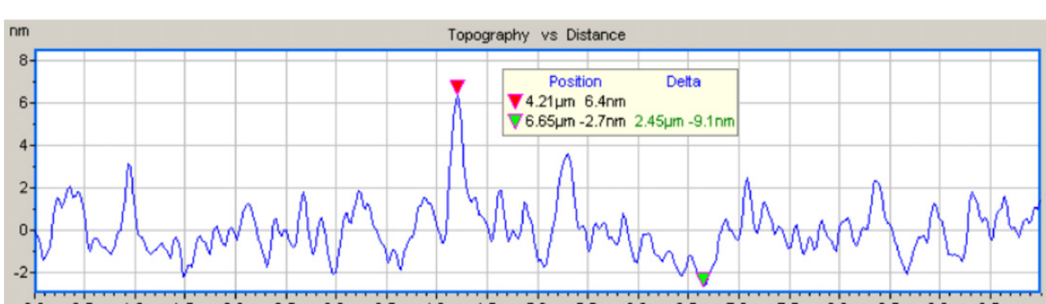
3. Results and discussion

3.1. Effect of down force on ZnO thin film CMP

Fig. 3 shows the relationship of removal rate (RR) with respect to down force. The test conditions were prepared as follows: the down force changes from 2 to 5 psi; the slurry pH is 6; both platen and head speed is 60 rpm; the slurry flow rate is 200 ml/min. From the Fig. 3, we can conclude that as the down force increases, the



(a) Surface topography (10μm×10μm) of the deposited wafer



(b) the peak-to-valley value of the deposited wafer

Fig. 1. AFM topography and the peak-to-valley value of ZnO thin films before polishing.