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Surface planarization of ZnO thin film for optoelectronic applications

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ABSTRACT

In this paper, surface morphology and optical properties are investigated to find the optimum microstructure of zinc oxide (ZnO) thin films deposited by radio frequency (RF) magnetron sputtering. To achieve a high transmittance and a low resistivity, we examined various film deposition conditions. The transmittance and surface morphology of ZnO thin films were measured by an ultraviolet (UV)–visible spectrometer and atomic force microscopy (AFM), respectively. In order to improve the surface quality of ZnO thin films, we performed chemical mechanical polishing (CMP) by change of process parameters, and compared the optical properties of polished ZnO thin films. As an experimental result, we were able to obtain good uniformity and improved transmittance efficiency by the CMP technique.

1. Introduction

Nano-structured materials sometimes have some peculiar properties that cannot be expected in bulk materials, and the elucidation of these properties has already led to breakthrough in various fields of science and technology [1–3]. Especially, zinc oxide (ZnO) nano-particles have recently received much attention due to a variety of applications like ultraviolet (UV) absorption, deodorization, and anti-bacterial treatment. ZnO is a direct band-gap semiconductor with $E_g = 3.37\,\text{eV}$ at room temperature (RT), and normally forms in the hexagonal crystal structure, the so-called wurtzite. Its luminescent property is principally related to the electronic and crystalline structure [4–6]. Recently, ZnO has attracted great attention due to its promising applications as UV light-emitting diodes and laser diodes, as well as its stability under UV light and relative high electric conductivity when compared to conventional sulfide phosphors. Also, ZnO is a high-efficiency phosphor in the green range for vacuum fluorescent displays, field emission displays, and light-emitting diodes [7,8]. It is well known that bright ZnO green phosphors are synthesized by firing ZnO powder in a reduction atmosphere. ZnO film has been prepared by DC sputtering, radio frequency (RF) magnetron sputtering, molecular beam epitaxial growth, chemical vapor deposition, spin coating, dip coating, and so on. The layer-by-layer self-assembly method as a technique to prepare thin films has many advantages: it allows detailed molecular-level control over film composition and thickness, and is independent of substrate size and topology [9–12].

Although there have been many reports on the formation or smoothing of hillocks of ZnO thin films, those works still report lack of consistency. Hillocks on ZnO thin film surfaces deteriorate light reflection, ultra-large scale integration (ULSI) pattern resolution, and device performance because they are dependent on surface morphology or roughness. A chemical mechanical polishing (CMP) process is a useful method for removing sub-microscale hillocks [13,14]. Therefore, understanding of micro-structure and surface morphology are required for advanced application of ZnO films. In this paper, we have investigated the properties of polishing and optical transmittance after the CMP process of ZnO thin film grown by RF magnetron sputtering with different parameters. Also, in order to examine whether silica slurry is suitable or not, we compared the CMP characteristics by silica slurry and de-ionized water (DIW).

2. Experiments

The experimental setup and procedures have been described elsewhere in detail [15–17]. In brief, ZnO thin film was deposited on Corning glass with a size of $2\,\text{cm} \times 2\,\text{cm}$ by RF magnetron sputtering. ZnO target size was 2 in, and had a purity of 5 N. In order to get rid of surface contamination, cleaning was carried out for the Corning glass substrate by the sequence of DIW, acetone, and ultrasonic. Ar gas with purity of 4 N and oxygen were used in this work. After mixing of Ar and oxygen, the flow rate of gas admitted into the chamber was adjusted using a mass flow

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Table 1
Conditions of RF magnetron sputtering

RF power	150 W
Distance to target	6 cm
Working pressure	6×10^{-2} Torr
Gas rate	50:50 ($Ar:O_2$)
Substrate temperature	30 °C

Table 2
CMP process conditions

Slurry flow rate	60 ml/min
Platen table speed	60 rpm
Carrier head speed	20, 40, 60, 80, 100 rpm
Polisher pressure	300 gf/cm^2
Pad width	16 in
Polishing time	60 s

controller (MFC). The distance between target and substrate was 6 cm, RF power was 150 W, base pressure was 2×10^{-6} Torr with rotary pump and diffusion pump, and finally Ar gas was admitted into the chamber. Work pressure was 6×10^{-2} Torr and deposition was carried out at RT. Table 1 lists the typical deposition conditions.

The CMP process parameters of POLI-450 polisher (G&P Technology) employed in this experiment are summarized in Table 2. The silica-based slurry of Rohm and Haas Company was used to polish the ZnO film surface prepared by RF magnetron sputtering. The head speed was increased from 20 to 100 rpm. We studied the polishing performance with increase of head speed. With the same conditions, we carried out the CMP process using a DIW instead of silica slurry, and measured their polishing characteristics. Post-CMP cleaning was performed by the sequence of SC-1, ultrasonic, and DIW. In order to investigate optical properties, the transmittance was measured by UV–visible spectrometer in the range of 300–900 nm. The thickness and surface morphology of the ZnO thin film were measured by a profilometer.

3. Results and discussion

Fig. 1 shows the removal rates of ZnO film with an increase of head speed. Here the CMP process was carried out with silica slurry and DIW. For the case of CMP process using a silica slurry, when the carrier head speeds were 20, 40, 60, 80, and 100 rpm, the removal rates were 45, 56, 78, 185, and 220 Å, respectively.

This result is consistent with Preston equation. Especially, the removal rate was very high at head speeds of 80 and 100 rpm; this was thought to be caused by enhanced frictional heat between the carrier head (ZnO film) and platen (polishing pad). With CMP process using a DIW, when the head speed was 20, 40, 60, 80, and 100 rpm, the removal rate was 12, 23, 41, 45, and 72 Å, respectively. At this point, although there was no large difference, the removal rates were slightly increased with an increase of head speed. This result implies that the polishing occurred by the mechanical effect of polishing pad only, without a slurry chemical effect.

Fig. 2 shows non-uniformities with an increase of head speed. For the case of CMP process using silica slurry, the non-uniformities were below 10% until 80 rpm. This means that the surface of ZnO thin film is smooth. However, for the case of over 80 rpm, the non-uniformity increased to 11.5 nm and the surface quality deteriorated. With CMP process using DIW, the non-uniformities were below 10% from 40 to 80 rpm and the surface of ZnO thin film was smooth. However, as the head speed increased to 100 rpm, the non-uniformity abruptly increased to 12.5 nm. Hence this result indicates that the CMP process should be carried out with relatively low head speed in order to obtain a good surface for ZnO thin film. The above-mentioned results can be discussed from the point of view of cost-benefit of CMP process as follows; if the CMP process using DIW is performed without any injection of expensive commercial slurry, the surface property of ZnO thin film can be fine and the cost for polishing can be cut down.

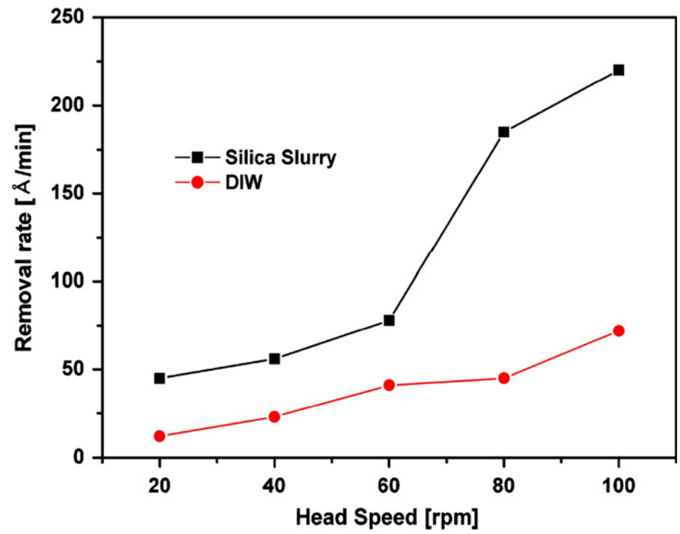

Fig. 1. Comparison of removal rate of silica slurry and DIW with an increase of head speed.

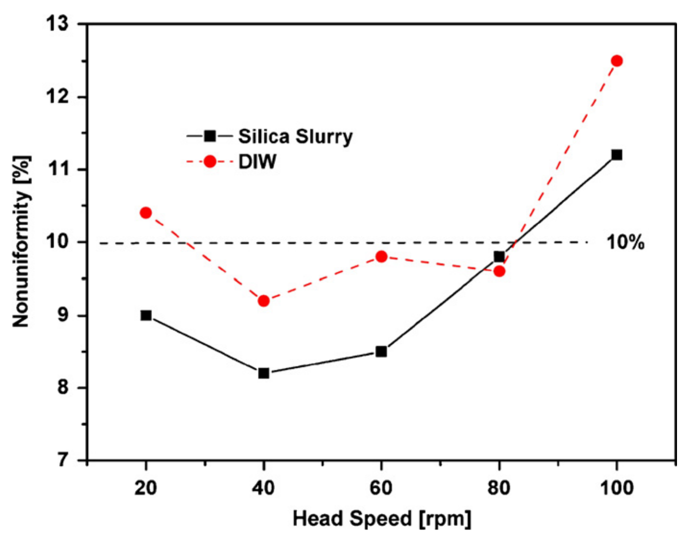

Fig. 2. Comparison of non-uniformity of silica slurry and DIW with an increase of head speed.

Fig. 3 shows the atomic force microscopy (AFM) analyses of ZnO thin film (a) before, and after CMP process with (b) DIW,and (c) silica-based slurry at the carrier head speed of 40 rpm. The surface in Fig. 3(b) was smoother in comparison with that in Fig. 3(a) by the CMP process using DIW. However, some scratches were observed. Mechanical polishing with DIW may achieve a