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HfO_2 gate insulator formed by atomic layer deposition for thin-film-transistors

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Abstract

We have investigated the effects of annealing temperature on the physical and electrical properties of the HfO_2 film deposited by an atomic layer deposition (ALD) method for high-*k* gate oxides in thin-film-transistors (TFTs). The ALD deposition of HfO_2 directly on the Si substrate at 300 °C results in the formation of thin $HfSi_xO_y$ interfacial layer between Si and HfO_2. The subsequent low temperature N_2-annealing of HfO_2 films (i.e., 300 °C) using a rapid thermal processor (RTP) improves the overall electrical characteristics of $HfSi_xO_y$–HfO_2 films. Based on the current work, we suggest that HfO_2 film deposited by the ALD method is suitable for high-*k* gate oxides in TFTs, which have to be fabricated at low temperature.

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Keywords: Thin-film-transistor; ALD; High-*k* oxide; HfO_2

1. Introduction

The development of reliable gate oxides, especially at low processing temperature, is an important issue for TFT research [1]. Specifically, gate oxides grown at low temperature have to exhibit good electrical and physical properties such as low leakage current, low interface trap density, and minimum value of hysteresis window [2,3]. One of the candidates for satisfying these requirements is multi-layered high-*k* film such as $HfSi_xO_y$–HfO_2. Since the multi-layered $HfSi_xO_y/HfO_2$ film consists of both amorphous $HfSi_xO_y$ and poly-crystallized HfO_2, the leakage current through the gate oxide can be minimized due to the mismatch of pinholes located at each layer [4]. It has been also reported that $HfSi_xO_y$ film remains amorphous, even after the relatively high temperature processing [4]. Since the formation of amorphous films on Si is desirable to minimize interface trap density, the Si/amorphous–$HfSi_xO_y$/poly-crystallized–HfO_2 structure may satisfy the requirements for both low interface trap density and low leakage current simultaneously. Furthermore, the desired value of effective dielectric constant can be easily controlled through the thickness change of $HfSi_xO_y$ and HfO_2; for example, the thickness ratio of $HfSi_xO_y$ and HfO_2 might be minimized to obtain a higher value of effective dielectric constant [5]. The $HfSi_xO_y$ and HfO_2 films can be formed by various techniques including ALD [6] and sputtering [7]. Recently, research efforts on the formation of high-*k* films have been focused on ALD since it has unique properties such as the exact controllability for both film thickness and composition [8]. Many research groups have demonstrated that the physical and electrical properties of high-*k* oxides deposited by ALD are suitable for alternative gate insulator in metal-oxide-semiconductor field effect transistors (MOSFETs). However, little information regarding the applicability of high-*k* oxides deposited by ALD to TFTs has been reported. In this work, we will report the effects of temperature annealing (300–700 °C) on the physical and electrical properties of HfO_2 films deposited by ALD for TFT applications. We will show that the deposition of HfO_2 films by ALD at 300 °C results in the multi-layered $HfSi_xO_y/HfO_2$ film, which consisted of both amorphous $HfSi_xO_y$ and poly-crystallized HfO_2. In addition, we will argue that the post deposition

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annealing (PDA) at 300 °C results in the best electrical characteristics, suggesting that the formation of reliable high-*k* HfO_2 films at low temperature for TFTs is feasible.

2. Experimental details

HfO_2 films were deposited by the ALD method on (100) p-type Si substrates at 300 °C. A traveling wave-type reactor was used. All wafers were cleaned using a standard RCA cleaning method, and were treated with a diluted HF solution for 15 s to remove the native oxide prior to the HfO_2 deposition. The ALD cycle for the deposition of HfO_2 films was set to obtain the final thickness of 55 nm. The base pressure was in the middle of 10 mTorr, and O_3 was used as oxidant. The precursor for the HfO_2 film was $HfCl_4$. The PDA of the HfO_2 films was performed using the rapid thermal processing (RTP) equipment at 300, 500 and 700 °C for 1 min in N_2 ambient. Pd was thermally evaporated on the samples using a shadow mask to form the metal-insulator-semiconductor (MIS) capacitors, and the gate area was $\sim 2 \times 10^{-4}$ cm^2. High-resolution transmission electron microscopy (HR-TEM), Auger electron spectroscopy (AES) and X-ray photoelectron spectroscopy (XPS) were used to determine the thickness of the films, and to investigate the structural changes due to the PDA temperature of the HfO_2 films deposited by the ALD method. Capacitance and current characteristics of the Pd–HfO_2–Si capacitor were measured using a boonton7200 capacitance meter at the frequency of 1 MHz and a HP4145B semiconductor parameter analyzer, respectively.

3. Results and discussion

Fig. 1 show the HR-TEM images of HfO_2 film with and without the PDA processing. Fig. 1(a) was obtained from the samples without subjecting to the PDA cycle, while the data shown in Fig. 1(b), (c) and (d) were obtained from the samples subjected to the PDA processing at 300, 500 and 700 °C, respectively. Note that the HfO_2 films shown in Fig. 1 were deposited by ALD at the substrate temperature of 300 °C. In Fig. 1, two distinctive layers (denoted by HfO_2 and $HfSi_xO_y$) were observed, although only HfO_2 film was deposited directly on the Si substrate by ALD. As we will discuss later in this article, the top and bottom layers in Fig. 1 were poly-crystallized HfO_2 and amorphous $HfSi_xO_y$ films, respectively. The mechanism for $HfSi_xO_y$ formation is not clear yet. Nevertheless, it is clearly shown in Fig. 1 that $HfSi_xO_y$ film remains as amorphous even after the PDA cycle at 700 °C. The

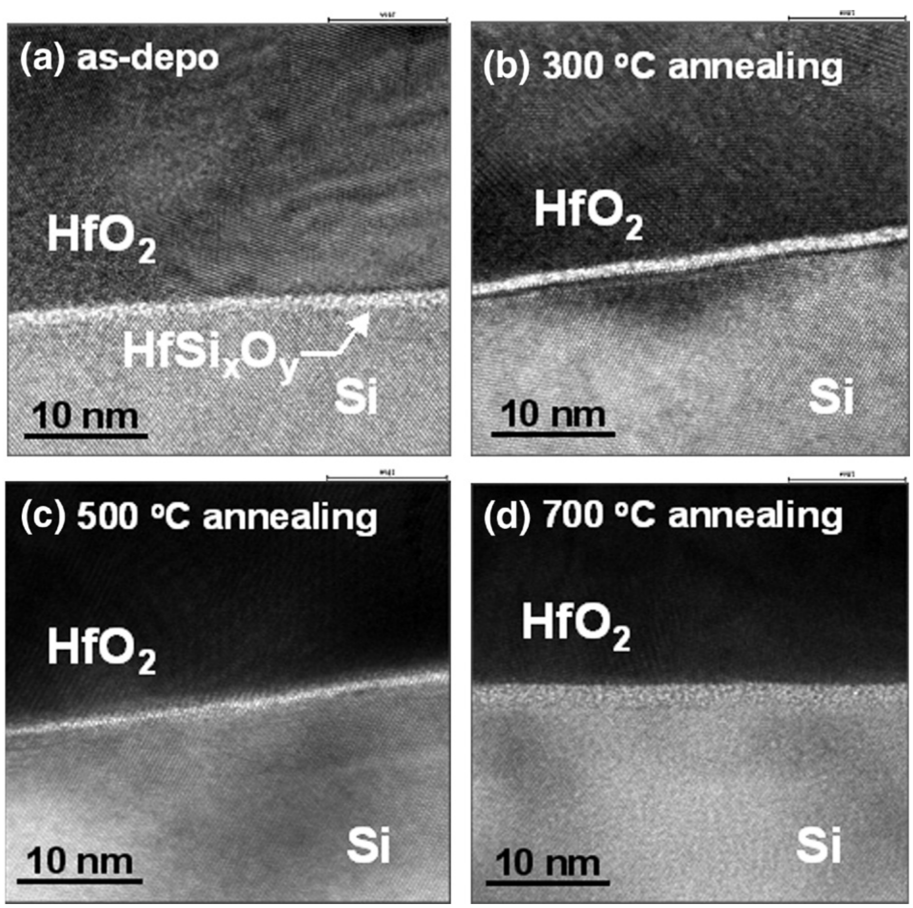

Fig. 1. High-resolution TEM images of HfO_2 film deposited by ALD at 300 °C: Fig. 1(a) represents the data obtained from as-deposited film (i.e., no annealing), and the data shown in Fig. 1(b), (c) and (d) were obtained from the samples annealed using RTP in N_2 ambient at 300, 500 and 700 °C, respectively. Annealing time was 1 min. The data shown in Fig. 1 indicate that amorphous $HfSi_xO_y$ film can be formed between HfO_2 film and Si during the HfO_2 deposition by ALD at 300 °C. $HfSi_xO_y$ film remains as amorphous even after completing the high temperature (e.g., 700 °C) annealing process.