Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Microelectronic Engineering 77 (2005) 399–404
MICROELECTRONIC ENGINEERING
www.elsevier.com/locate/mee

Oxygen pressure dependence of physical and electrical properties of $LaAlO_3$ gate dielectric

X.B. Lu [a,b,*], H.B. Lu [a], J.Y. Dai [b], Z.H. Chen [a], M. He [a], G.Z. Yang [a], H.L.W. Chan [b], C.L. Choy [b]

[a] *Institute of Physics, Chinese Academy of Sciences, Beijing, PR China*
[b] *Department of Applied Physics, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China*

Received 14 October 2004; accepted 24 January 2005
Available online 2 March 2005

Abstract

High k $LaAlO_3$ (LAO) films were deposited directly on silicon substrates in various oxygen pressures by laser molecular-beam epitaxy technique. The influence of oxygen pressures during film fabrication on the physical and electrical properties of LAO films was studied. High resolution transmission electron microscopy measurements indicate that the thermo stability of LAO films in contact with silicon substrates is greatly affected by oxygen pressures, and thicker interfacial layer would be expected for LAO films deposited in high oxygen pressure. Capacitance–voltage (C–V) and leakage current measurements indicate that the effective oxide thickness, leakage current, flatband voltage and hysteresis loop characteristics are affected by the oxygen pressure during film fabrication. Larger EOT, lower leakage current and smaller hysteresis loop is expected to be obtained for LAO films deposited in higher oxygen pressure or lower vacuum. When oxygen pressure is below or equal to 0.1 Pa, the absolute value of V_{FB} increases with the decrease of oxygen pressure. When oxygen pressure is above 0.1 Pa, the V_{FB} value begins to decrease slowly.

Keywords: High k dielectric; Flatband voltage; Oxygen pressure; Effective oxide thickness; Leakage current; Interfacial reaction

1. Introduction

With the continued scaling of MOS technology, the thin SiO_2 gate oxide must eventually be replaced by a high dielectric constant material [1]. Currently, there is much work being done in developing high-k dielectrics to replace silicon oxide as gate dielectric in the future MOSFETs [2–6]. Among the many potential high-k materials, $LaAlO_3$ has recently attracted much attention due to its many advantages such as medium dielectric constant, high bandgap, and amorphous structure

* Corresponding author. Tel.: +852 27665671; fax: +852 2333 7629.
E-mail address: apluxb@polyu.edu.hk (X.B. Lu).

0167-9317/$ - see front matter
doi:10.1016/j.mee.2005.01.023

up to high temperature [7–10]. It is known that oxide films deposited by pulsed laser deposition or laser molecular beam epitaxy technique (LMBE) often have oxygen vacancies, which plays important role in the electrical performance of the film [11,12]. To reduce the oxygen vacancies in the films, incorporation of oxygen with high pressure during film formation is the method often used [13]. One of the characteristics desirable for the high-*k* dielectric is that it has good thermal stability with silicon substrate [1]. However, for most of the high-*k* materials, possible interfacial reactions between gate oxide and silicon substrate will occur when they are fabricated in oxygen containing ambient [1,14,15]. Good electrical performance and thermal stability with silicon are necessary for high-*k* dielectrics used as alternative gate dielectrics. Thus, it is necessary to understand the growth mechanism that controls these factors and influences both the electrical properties and thermal stability with silicon of the LAO thin films. In this paper, the effect of oxygen pressure on the structure and electrical properties of laser-fabricated LAO high-*k* gate dielectric was studied.

2. Experimental details

LAO films were deposited by a LMBE system, equipped with in situ reflective high-energy electron diffraction (RHEED). Details of the system have been reported elsewhere [16]. Substrates were 2-inch *n*-Si (1 0 0) wafers with resistivity of $4 \sim 6\,\Omega\,\mathrm{cm}$. After wet-chemical cleaning, the Si substrate was dipped into a buffered HF (10%) solution for 60 s to remove the amorphous SiO_2 layer from the silicon surface, leaving a hydrogen-terminated surface. Then the Si substrate was immediately moved into the epitaxial chamber with a base pressure of $\sim 6 \times 10^{-5}$ Pa. Before the film deposition, the substrate was heated to the temperature when the 2×1 surface structure of Si was observed by RHEED, which reveals a clean surface. Then, the Si substrate temperature was switched to the setting substrate temperature. After the substrate temperature was constant, oxygen was introduced into the epitaxial chamber with the pressure ranging from 1×10^{-4} to 10 Pa.

To characterize the electrical properties of LAO films, Pt top electrodes with an area of $3.14 \times 10^{-4}\,\mathrm{cm}^2$ were deposited on the surface of the samples using a shadow mask. Then, an Ohm contact to the backside of the substrate was obtained by scraping the surface of the silicon substrate to remove the SiO_2 completely, immediately followed by the spreading of silver glue on the scraped silicon. Finally, the MOS capacitors were fabricated. The electrical properties of the MOS capacitors were evaluated with an Agilent4294A impedance/phase analyzer and a Keithely 236 source measuring unit. Cross sectional structures of the gate stack based on LAO films as gate dielectric were characterized by high-resolution transmission electron microscopy (HRTEM) (JEM-4000EX).

3. Results and discussions

For most of the high *k* oxide films, the thermodynamic stability of them in contact with silicon is a critical issue for the application of alternative gate dielectrics in silicon-based devices [1]. Furthermore, the thermodynamic stability of high *k* oxide films is tightly correlated to the content of oxygen during film growth [15]. The impact of oxygen pressure on the thermodynamic stability of LAO films was studied by HRTEM first. Fig. 1(a) and (b) show the HRTEM images of LAO films deposited at 700 °C in 0.1 and 1×10^{-4} Pa oxygen pressure, respectively. It can be seen clearly that there exists a very clear 3.2 nm interfacial layer between the silicon substrate and the LAO film deposited in 0.1 Pa oxygen. But nearly no evidence of interfacial layer can be seen between the silicon substrate and the LAO film deposited in 1×10^{-4} Pa oxygen pressure. This indicates that the interfacial reaction between LAO films and silicon is greatly affected by the oxygen pressure and higher oxygen pressure would be favorable for the formation of interfacial layer. Further study using X-ray photoelectron spectroscopy indicated that the interfacial layer between the Si substrates and the LAO films deposited in higher oxygen pressure is La–Si–O or Al–Si–O compound.