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Field-induced surface passivation of p-type silicon by using AlON films

S.N. Ghosh*,[1], I.O. Parm, S.K. Dhungel, K.S. Jang, S.W. Jeong, J. Yoo, S.H. Hwang, J. Yi

School of Information and Communication Engineering, Sungkyunkwan University, 300 Chunchun dong, Jangan-gu, Suwon-440746, Republic of Korea

Abstract

In the present work, we report on the evidence for a high negative charge density in aluminum oxinitride (AlON) coating on silicon. A comparative study was carried out on the composition and electrical properties of AlON and aluminum nitride (AlN). AlON films were deposited on p-type Si (1 0 0) substrate by RF magnetron sputtering using a mixture of argon and oxygen gases at substrate temperature of 300 °C. The electrical properties of the AlON, AlN films were studied through capacitance–voltage (*C*–*V*) characteristics of metal–insulator–semiconductor (MIS) using the films as insulating layers. The flatband voltage shift V_{FB} observed for AlON is around 4.5 V, which is high as compared to the AlN thin film. Heat treatment caused the V_{FB} reduction to 3 V, but still the negative charge density was observed to be very high. In the AlN film, no fixed negative charge was observed at all. The XRD spectrum of AlON shows the major peaks of AlON (2 2 0) and AlN (0 0 2), located at 2θ value of 32.96° and 37.8°, respectively. The atomic percentage of Al, N in AlN film was found to be 42.5% and 57.5%, respectively. Atomic percentages of Al, N and O in EDS of AlON film are 20.21%, 27.31% and 52.48%, respectively.

Keywords: Fixed negative charges; Flatband voltage; MIS; Aluminum nitride; Aluminum oxynitride

1. Introduction

Aluminum oxynitride (AlON) is a relatively new ceramic material with a cubic crystalline structure. This material is characterized by its high density of fixed negative charges, which can be used for field-induced surface passivation, creating a very effective back surface field layer at the silicon interface. Aluminum nitride (AlN) is a material of great technological advantage in microelectronics industry due to its wide bandgap, high decomposition temperature and low electrical but high thermal conductivity [1]. Currently there is a trend to use metal–insulator–semiconductor (MIS) structure in electronic device [2,3]. Aluminum oxide-(Al_2O_3)-based dielectric thin films [4,5] have been extensively studied as a promising alternate gate insulator to conventional silicon dioxide (SiO_2) and silicon (Si) oxinitride because of their high thermal stability against crystallization compared with other candidates such as ZrO_2 and HfO_2. Till now most of the reported works have been done on MIS using AlN [6,7], aluminum fluoride [8,9] have shown either no shift of the flatband voltage (V_{FB}) toward the positive value or a slight shift. It seems that only a few works have been reported concerning Al_2O_3 based negatively charged MIS structure. Employing a negatively charged insulator–semiconductor structure to the back surface of p-type silicon solar cell could replace the conventional back surface passivating dielectric layers like Si_3N_4 and SiO_2. Such conventional films have been mostly reported to have fixed positive charge. The inevitable trend toward thinner bulk silicon solar cells makes the issue of the field-induced passivation by fixed negative charge more and more significant. In this connection, scientific community has been hunting for proper dielectric film with appreciable fixed negative charge since long. It has been found that AlON films as deposited using the mixture of argon and oxygen plasma produces the AlON film with excellent electrical and optical properties. AlON has a high density of fixed negative charges, which can be used for field-induced passivation for some electronic devices including solar cells on p-type substrate. AlON

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*Corresponding author. Tel.: +91 22 2576 7890; fax: +91 22 2576 4890.
E-mail address: s.n.ghosh@gmail.com (S.N. Ghosh).

[1] Current addresses: Energy Systems Engineering, Indian Institute of Technology Bombay, Powai, Mumbai-400076, India and Nanoelectronics Center, Department of Electrical Engineering, IIT Bombay, Powai, Mumbai-400076, India.

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has dielectric constant as high as 13 and may be taken an ideal alternative to SiO_2 depending on its properties [5]. In this paper, experimental results of an MIS structure with a high density of fixed negative charges consisting of AlON is presented. The capacitance–voltage (*C–V*) measurements were done for as deposited AlON films and vacuum annealed AlON films at 600 °C. The results were compared with the AlN films prepared without oxidation.

2. Experimental details

RF or DC sputtering techniques [10] are generally used to deposit oriented films at low temperatures. Addition of magnetron capability to the sputtering system confines the secondary electrons emitted from the target. This trapping of the electrons reduces the electron bombardment of the sample surface, and also ensures better control of the substrate temperature.

In this study, an RF magnetron sputtering system with a magnet assembly was used to prepare AlN films. A target of AlN with 99.95% purity and a diameter of 4 in was used. The sample temperature was determined with a thermocouple inserted through the side and screwed from the bottom of the substrate holder. The substrate temperature was fixed at 300 °C. The p-type silicon substrate makes thermal contact to the substrate holder. The substrates were thoroughly cleaned just prior to deposition. The cleaning sequence for silicon was for the removal of organic impurities (trichloroethylene, acetone, methanol, sulfuric acid/hydrogen peroxide). The substrate heating sequence was started after pumping the chamber to a pressure of 2.5×10^{-3} mTorr. Once the substrate temperature was stabilized and the chamber pressure decreased to 2×10^{-6} mTorr, the sputtering gas (argon + oxygen) were introduced through flowmeters into the chamber. An ionization gauge was used to monitor the pressure. The gas at desired pressure and ratios were allowed to flow for 15 min to purge the chamber before sputtering. With the shutter covering the substrate, the target was sputter cleaned for 15 min in argon. The deposition of the film

Table 1
Typical AlON film deposition parameter using sputtering

Gas pressure	3 mTorr
Sputtering gas	Argon and oxygen
Target to substrate distance	60 mm
RF power	100 W
Substrate temperature	100 °C
Deposition rate	18 Å/min
Target	AlN-99.95%, 4 in. diameter

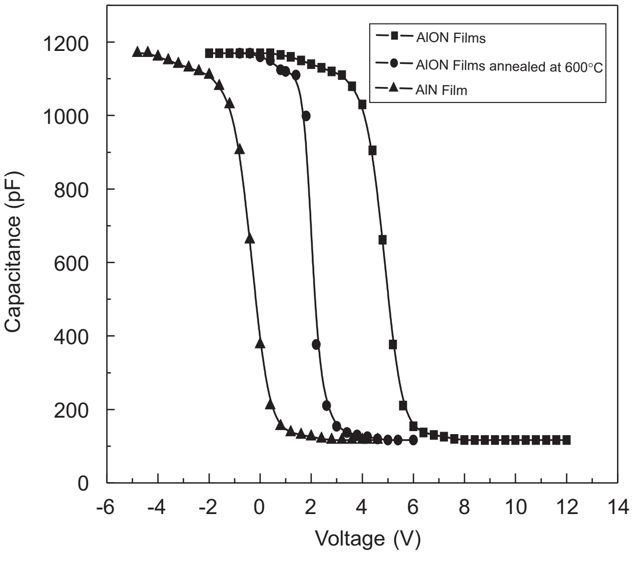

Fig. 1. *C–V* analysis of AlN and AlON films.

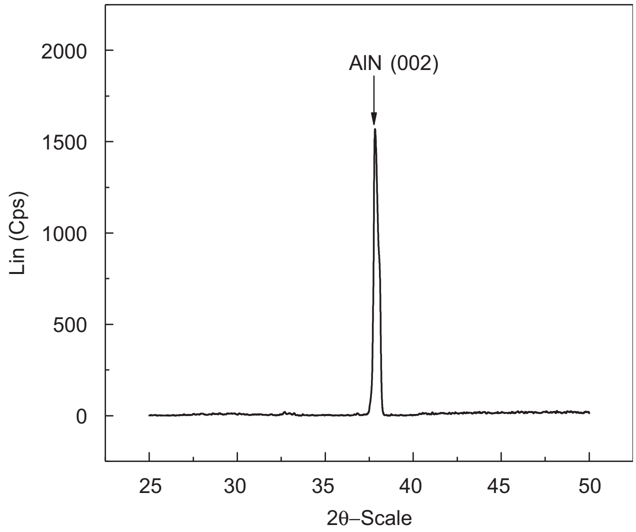

Fig. 2. XRD of as deposited AlN film.

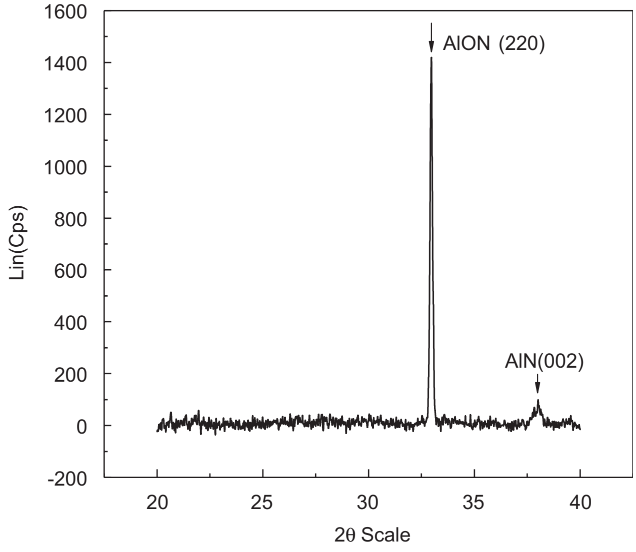

Fig. 3. XRD of AlON films deposited using the mixture of argon and oxygen plasma.