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High-dielectric constant AlON prepared by RF gas-timing sputtering for high capacitance density

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A R T I C L E I N F O

Keywords:
Aluminum oxynitride (AlON)
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Metal–dielectric–metal

A B S T R A C T

This paper presents the method to prepare and characterize high-dielectric constant aluminum oxynitride (AlON) formed by RF gas-timing sputtering. AlON layers of 725 nm have been prepared on metal–dielectric–metal structure with substrate temperature below 100 °C. Capacitance versus bias voltage has been measured. The dielectric constant of AlON has been calculated from the slope of the plot of capacitance versus capacitor area. The value of 11 has been obtained from this study. This depends on the composition of the AlON material, which is analyzed by Auger electron spectroscopy.

1. Introduction

Several techniques have been developed to prepare high-dielectric constant material compatible with CMOS technology. This is aiming at a high capacitance density, which will improve gate tunneling currents of downscaled CMOS. Most techniques are also focusing on low thermal budget. This will lead to develop cheap CMOS on plastic substrate. Aluminum oxynitride (AlON) is a transparent polycrystalline ceramic material of high strength and hardness. AlON film is widely applied as a protective coating against diffusion and corrosion [1,2], optical coating [3], optoelectronics [4] and other fields of technology. This is due to the possibility for a broad combination of the physical and chemical properties of the oxynitride films with variable concentrations of aluminum, oxygen and nitrogen. The film properties can be tailored between those of pure aluminum oxide (Al_2O_3) and aluminum nitride (AlN), depending on different applications. The synthesis of AlON films has been commonly reported using physical vapor deposition, such as ion-beam-assisted evaporation and sputtering [1,2,5,6]. The optical, mechanical and gas barrier properties of the AlON film have also been investigated [1,2]. Unfortunately, AlON is a refractory material; it requires high substrate temperatures (1300 K), which is difficult to obtain [7]. Then, the reactive gas-timing r.f. magnetron sputtering technique is utilized to implement AlON thin films with uniformity at low temperature. In this work, the AES study on AlON thin films grown by r.f. magnetron sputtering with the reactive gas-timing technique has been reported. The crystalline structure and surface morphology of the thin films have been investigated. The dielectric constant of AlON has also been calculated from capacitance.

2. Experimental

The AlON thin films have been grown on Si substrates by r.f. magnetron sputtering at room temperature (RT) using our technique called reactive gas timing. Aluminum (Al) with purity of 99.999% has been used as a target material. In the sputtering growth of AlON, argon (Ar) gas takes advantage of ion bombardment, while nitrogen (N_2)

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gas takes a function of reactive ions. The flow sequence of gases is shown in Fig. 1. The solid line denotes the sequence of Ar that bombarded the Al target for 10 s, and the dashed line denotes the sequence of N_2 that reacted with Al atoms for 90 s. The flow rate of Ar and N_2 has been fixed at 12 and 7 standard cubic centimeters per minute, respectively. The r.f. power has been fixed at 200 W with the base pressure in the chamber of 6×10^{-7} mbar. An AlON thickness of 725 nm has been deposited. The composition of the AlON films has been evaluated by Auger electron spectroscopy (AES). The crystallinity has been characterized by X-ray diffraction (XRD). Scanning electron microscopy (SEM) and atomic force microscopy (AFM) have also been used to investigate the morphologies of the deposited thin films. The capacitance–voltage (*C*–*V*) has been measured on different areas of metal–dielectric–metal structures at a frequency of 100 kHz.

3. Results and discussion

The composition of the AlON thin films has been studied by AES measurement. It indicates that the deposited AlON films at RT have an atomic percentage of Al KLL, N KLL and O KLL at 52%, 30% and 18%, respectively, as shown in Fig. 2. Fig. 3 shows how the atomic concentration of Al, N and O relates to the sputter time

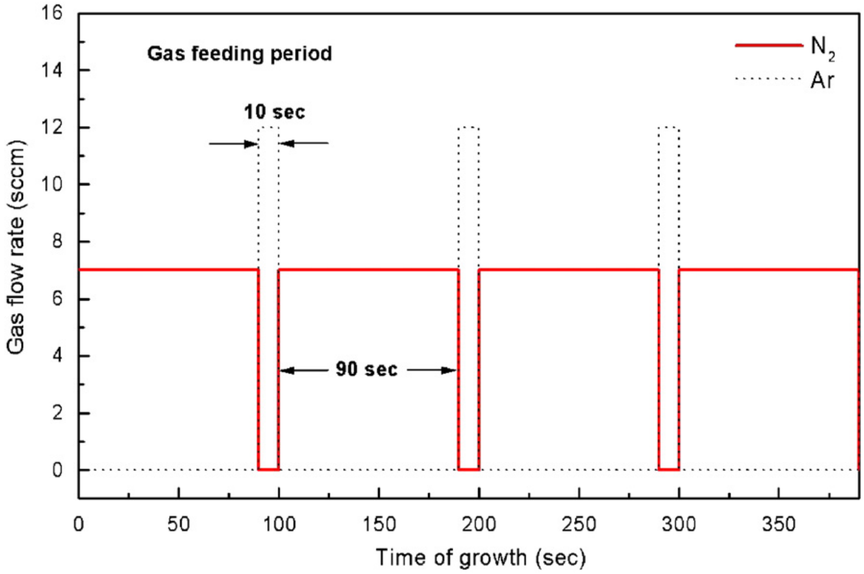

Fig. 1. Time sequence of gas flow rate of Ar and N_2.

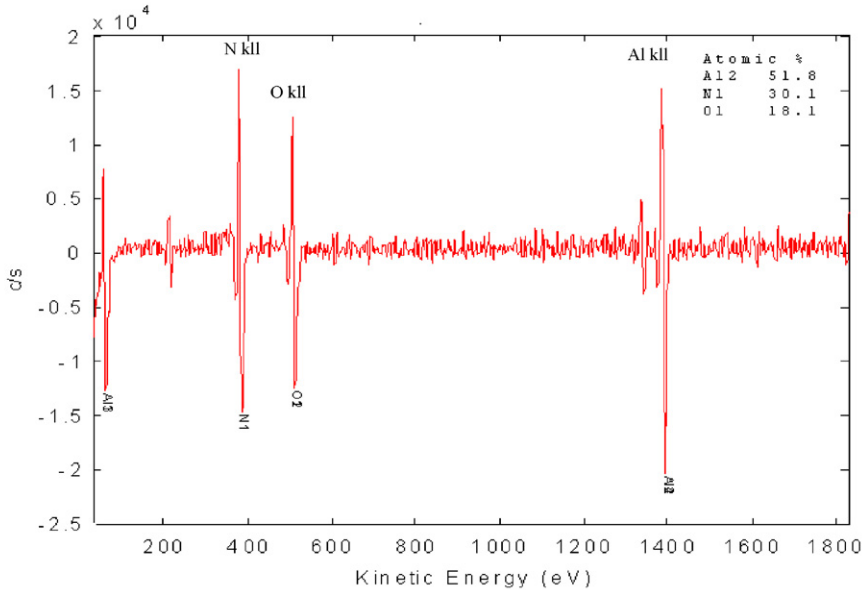

Fig. 2. Auger spectrum of AlON films on Si(1 0 0) substrate.

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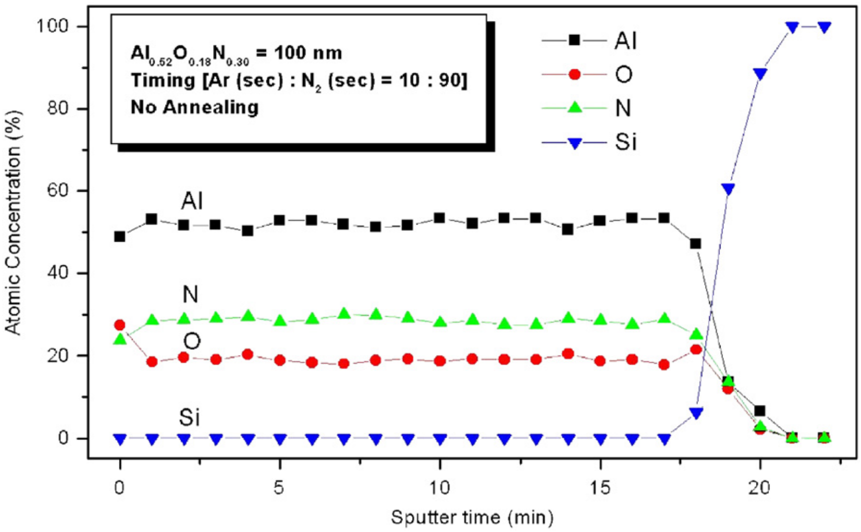

Fig. 3. Atomic concentration of Al, N and O related with sputter time from AES depth profiles.

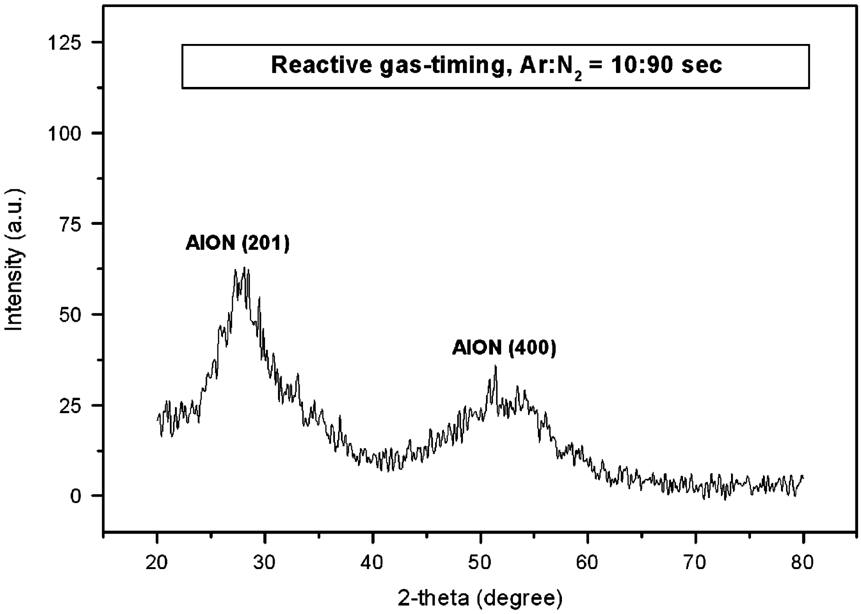

Fig. 4. The XRD spectrum from AlON thin films on Si substrate with timing of Ar:N_2 = 10:90 s.

from AES depth profiles. The O concentration is high at the surface. The oxygen observed in the thin films may be due to an unavoidable residual agent in the vacuum system at a base pressure of 10^{-7} mbar. This may imply oxygen contamination in the deposited films without feeding of O_2 gas into the vacuum chamber.

The crystallinity of AlON thin films has been characterized by XRD. Fig. 4 shows the XRD spectrum from a thin film deposited on an Si(1 0 0) substrate. It shows crystalline orientation of (2 0 1) plane as AlON hexagonal structures. This indicates that the reactive gas timing plays a key role in the crystallinity of thin films. The oxygen incorporation in the deposited thin films has been confirmed by AES analysis. However, the grain size as measured by FE-SEM (Fig. 5) and AFM (Fig. 6) remains well below 20 nm.

Fig. 7 shows the capacitance of difference area capacitors. Theoretically, the dielectric constant of AlON ($\varepsilon_{\mathrm{AlON}}$) can be calculated from

$$\varepsilon_{\mathrm{AlON}} = \frac{Ct}{A} \quad (1)$$

where A is the area of the capacitor (C), t is the film thickness and A is the area.

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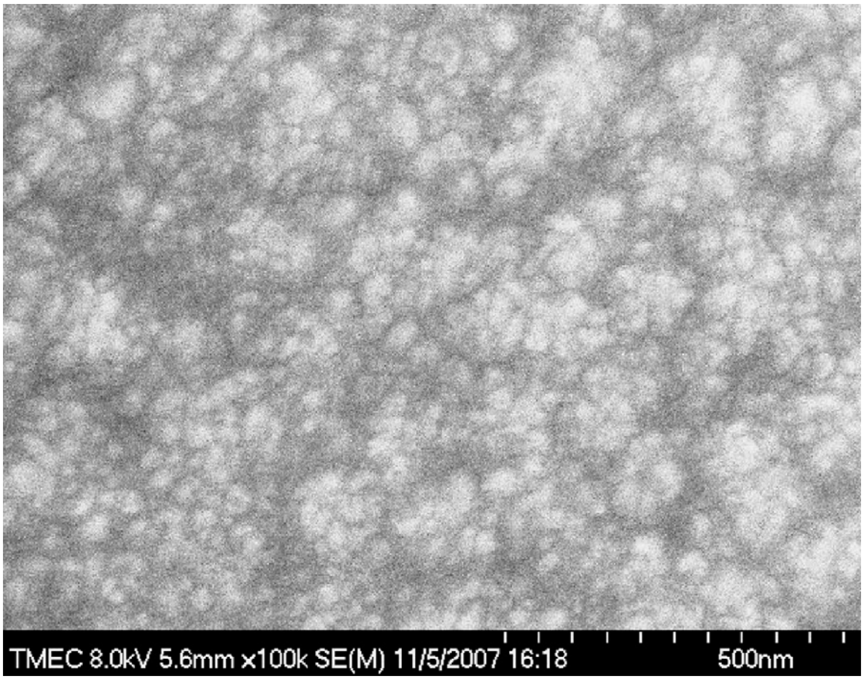

Fig. 5. The SEM image of an AlON thin film deposited on an Si substrate.

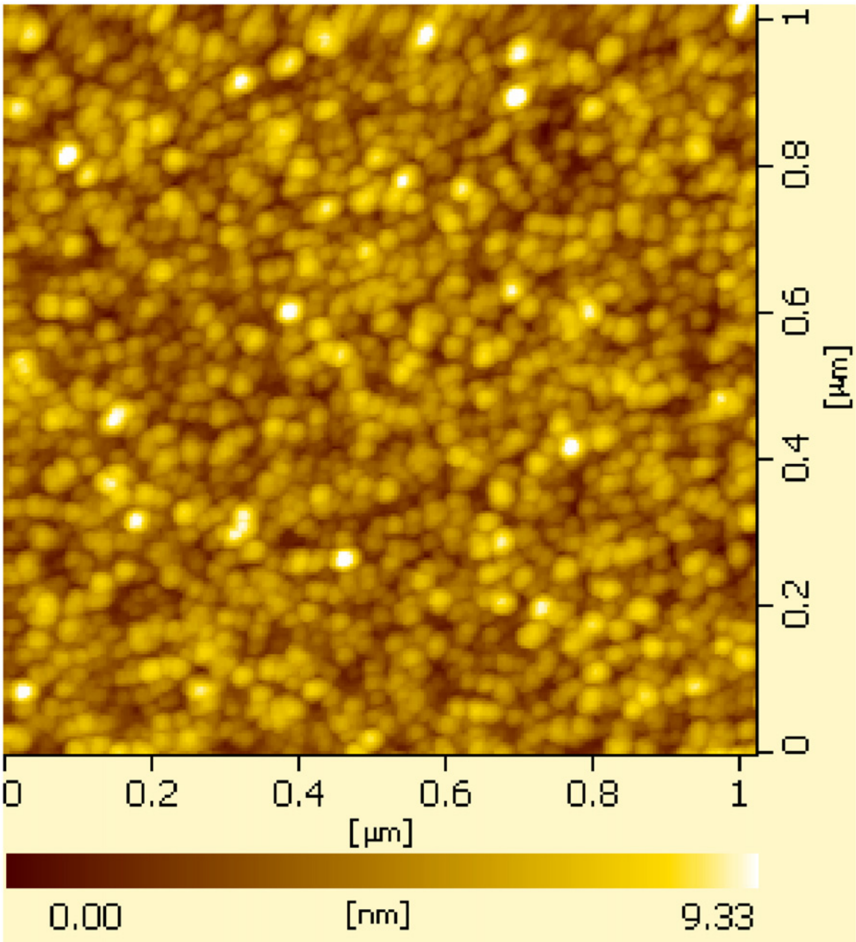

Fig. 6. The AFM image of an AlON thin film deposited on an Si substrate.

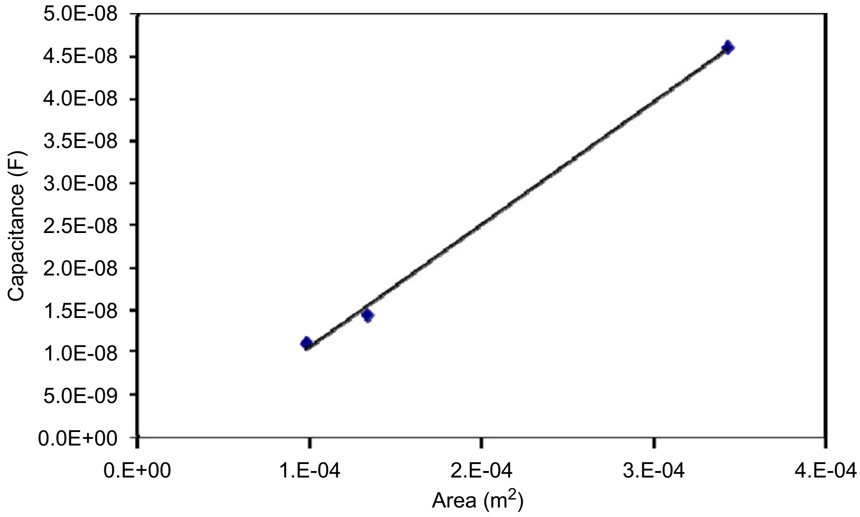

Fig. 7. Capacitance versus area of an AlON capacitor.

The dielectric constant of 11 has been calculated from the slope of the plot in Fig. 7. This is higher than the value of silicon dioxide and silicon nitride.

4. Conclusion

AlON thin films have been prepared on Si(1 0 0) substrates using a reactive gas-timing r.f. magnetron sputtering, without in situ substrate heating process. The thin films of AlON have been characterized using mainly AES depth profiling. AES indicates that the AlON contains 52%, 30% and 18%, of Al, N and O, respectively. The dielectric constant of AlON is 11, which is obtained from the slope of the plot between capacitance and area of capacitors.

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