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A STUDY OF THE ELECTRICAL PROPERTIES OF Al_2O_3 FILMS DEPOSITED ON GaAs SUBSTRATES BY SPRAY PYROLYSIS

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Electrical characteristics of high quality aluminum oxide thin films deposited by the spray pyrolysis technique on GaAs substrates are reported. The films were deposited using a spraying solution of aluminum acetylacetonate in N,N-dimethylformamide and an ultrasonic mist generator. The substrates were (100) GaAs wafers Si-doped (10^{18} cm^{-3}). The substrate temperature during deposition was in the range of 300–600°C. The electrical characteristics of these films were determined by capacitance and current versus voltage measurements by the incorporation of these films into metal-oxide-semiconductor structures. The interface state density resulted in the order of 10^{12} 1/eV-cm^2 and the films can stand electric fields higher than 5 MV/cm, without observing a destructive dielectric breakdown. The refractive index, measured by ellipsometry at 633 nm, resulted close to 1.64. The determination of the chemical composition of the films was achieved by energy dispersive X-ray spectroscopy; it resulted close to that of stoichiometric aluminum oxide (O/Al = 1.5) when films are deposited at substrate temperatures of 300–350°C.

1. Introduction

Compound semiconductor field effect transistors (FETs) occupy an important niche in the electronics industry. GaAs FET amplifiers, oscillators, mixers, switches, attenuators, modulators, and current limiters are widely used, and high-speed integrated circuits based on GaAs FETs have been developed. The basic advantages of GaAs devices include a higher electron velocity and mobility which lead to smaller transit time and faster response, and semi-insulating GaAs substrates that reduce parasitic capacitances and simplify the fabrication process.

The poor quality of oxide on GaAs and a correspondingly high interface state density (D_{it}) at the GaAs–isulator interface make it difficult to fabricate GaAs MOSFETs or MISFETs. Only very recently has the new approach of oxidizing a thin silicon layer grown by MBE on the GaAs surface offered hope for the development of a viable GaAs MOSFET technology. GaAs technology has a significant advantage over silicon in terms of speed, power dissipation, and radiation hardness.[1]

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The fabrication of thermodynamically stable insulator–GaAs interfaces with low interface state density (D_{it}), however, has remained one the key challenges in compound semiconductors during the last few decades.

Aluminum oxide (Al_2O_3) is considered to be one of the candidates for gate dielectrics, since it is a very stable compound with a high breakdown voltage; in particular, the interface Al_2O_3/InP has previously been studied.[2]

Aluminum oxide thin films present a high chemical stability and high radiation resistance.[3] These films also possess a high thermal conductivity, a high refractive index, and a high dielectric constant.[4] In addition, aluminum oxide thin films constitute an excellent barrier against alkali ions.[5]

In this work, excellent dielectric characteristics of aluminum oxide thin films deposited on gallium arsenide substrates by spray pyrolysis are reported. The optical characteristics of these films (refractive index and chemical composition) are similar to those reported previously for the system Al_2O_3/Si.[4]

In this case, it has been found that these films are able to stand electric fields higher than 5 MV/cm without destructive breakdown and with an interface state density of the order 10^{12} 1/eV-cm^2.

2. Experimental Details

The films of Al_2O_3 studied were deposited on GaAs substrates using the spray pyrolysis technique. High resistivity gallium arsenide wafers (GaAs) with a (100) orientation were used for the deposition of the films.

The cleaning procedure of the substrates consisted in a chemical etching in a H_2SO_4:H_2O_2:H_2O (3:1:1) solution at 60°C for 90 s, followed by a rinsing in flowing deionized water (18 MΩ/cm) for 15 min and finally flew dry with N_2. Also, we have deposited by spray pyrolisis a thin layer of gallium aluminum oxide previously to a pure aluminum oxide for passivating the surface; the time of deposit of this layer was between 2 and 30 s, with an optimal deposition time of 20 s.

The spray pyrolysis deposition system has been described in detail previously.[6,7] It consists of an ultrasonic generator used for mist generation from a spray solution. The mist is transported through a glass tube to the substrate surface which is being heated to achieve the pyrolysis reaction.

The substrate was placed on a tin bath used as a heating system. The carrier gas used was air at a flow rate of approximately 8 l/min. Aluminum acetylacetonate dissolved in N,N-dimethylformamide was used as a spraying solution. The concentration of this solution was 3 g of aluminum acetylacetonate dissolved in 100 ml of dimethylformamide. All these samples were deposited by adding a stream of water mist in parallel to the spraying solution. The films were deposited at temperatures in the range of 300–600°C.

For the electrical measurements metal-oxide-semiconductor (MOS) structures were fabricated by thermally evaporating aluminum contacts with an area of 1.1×10^{-2} cm^2 on top of the aluminum oxide film deposited on GaAs substrates.

The thickness and refractive index were measured with a manual ellipsometer from Gaertner, model L117, at 633 nm. Commercial automated equipment from Keithley was used for the capacitance and current versus voltage measurements.

The chemical analysis of our samples was performed by energy dispersive X-ray spectroscopy (EDS) using a Jeol 6300 scanning electron microscope (SEM), operated at 30 kV.

3. Experimental Results

Aluminum oxide deposited on GaAs substrates shows a deposition rate, a refractive index and the atomic ratio versus temperature (the deposition rate was lower to 30/s, the refractive index was near to 1.64 and the atomic ratio was near to 1.5, respectively) similar to the case where aluminum oxide is deposited on silicon substrates.[4]

Figure 1 shows the capacitance versus voltage characteristics for a film deposited at a substrate temperature of 400°C on (100) GaAs, with an Al metallic contact deposited by thermal evaporation. From these curves a dielectric constant value higher than 10 is calculated.

Figure 2 shows the surface state density obtained from the curves displayed in Fig. 1. It is observed that the density of states at midgap is of the order of 10^{12} 1/eV-cm^2. This value is, however, one order of magnitude higher than that obtained when Al_2O_3 is deposited on InP substrates, using the PECVD technique.[2]

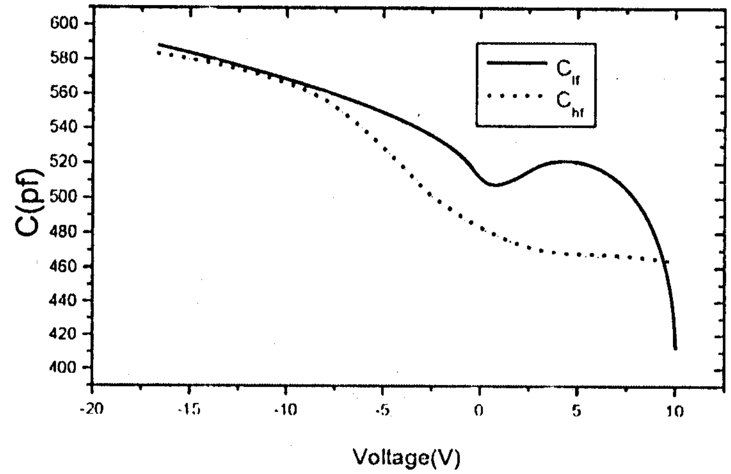

Fig. 1. Capacitance versus voltage characteristics for a film deposited at 400°C. The dotted line corresponds to the high frequency measurement and the solid line corresponds to the low frequency measurement.

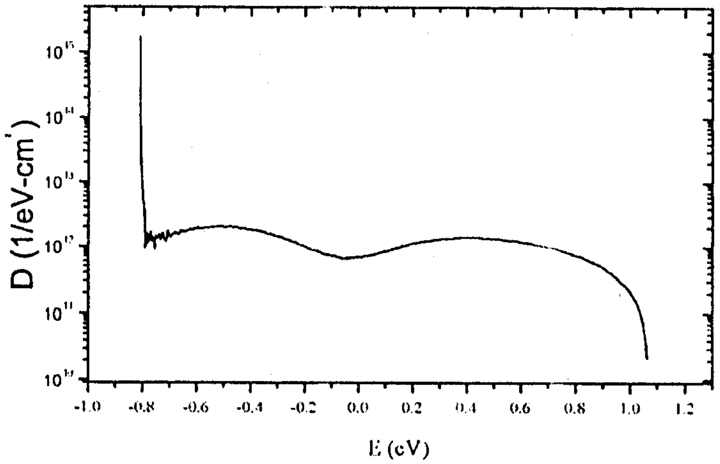

Fig. 2. Surface state density as a function of the GaAs band gap for a film of aluminum oxide deposited at 400°C.

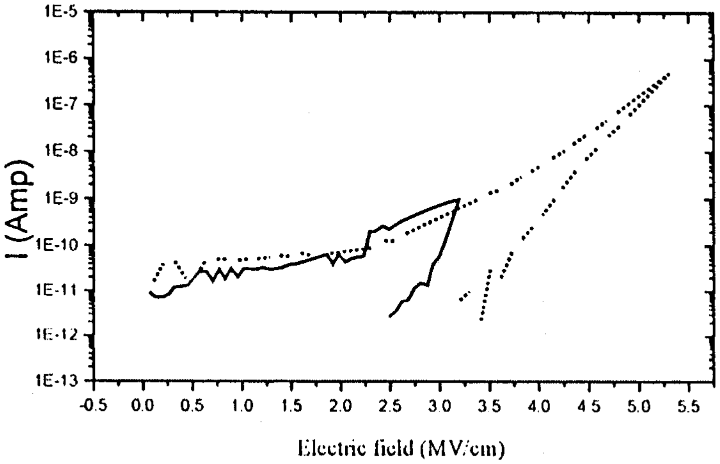

Fig. 3. Current density as a function of the applied electric field on a MOS capacitor fabricated from an aluminum oxide film deposited on GaAs substrate at 600°C.

The insulating properties of these films are illustrated by the electrical current density as a function of the electric field applied to the MOS capacitor, Fig. 3, for a film deposited at 600°C.

The current density observed at electric fields below 2 MV/cm is of the order of 10^{-10} amp/cm^2 and it is due to a displacement current associated the voltage ramp applied to the MOS structure.

At electric fields higher than 2MV/cm a real current injection across the aluminum oxide is observed and increases up to 10^{-6} amp/cm^2 at approximately 5 MV/cm. It should be pointed out that at this field no destructive breakdown of the film is observed.

4. Discussion

The optical characteristics of the aluminum oxide films on GaAs are similar to those deposited on silicon substrates. However, the dielectric constant calculated at accumulation voltages for the system Al_2O_3/Si was close to 7,[4] while that for the structures deposited on GaAs this value is of the order of 10.

The electrical characteristics show that the films can stand electric fields higher than 5 MV/cm without observing a destructive dielectric breakdown. An excellent passivation effect of the GaAs substrates is also obtained when the Al_2O_3 film is deposited on top of them, as suggested by the surface state density obtained (in the order of 10^{12} 1/eV-cm^2). This density of interface states can be compared with the result reported when Al_2O_3 is deposited on InP[2] and with the work of K. Kaminura *et al.*, which reported values for the surface state density for the system $Al_2O_3/GaAs$ higher to 10^{11} 1/eV-cm^2.[8] In the present work, the surface state density obtained with a simple, inexpensive technique is in the order of 10^{12} 1/eV-cm^2.

5. Conclusions

Good quality aluminum oxide films have been obtained by the spray pyrolysis technique using aluminum acetylacetonate dissolved in N,N-dimethylformamide on GaAs substrates. At accumulation, a dielectric constant average higher to 10 was obtained for the aluminum oxide on GaAs substrates, which is two times higher than the system SiO_2/Si.

The interface state density for the MOS structures fabricated with the films resulted in the order of 10^{12} 1/eV-cm^2. Also, the films are able to stand electric fields higher than 5 MV/cm, without observing a dielectric breakdown; besides, it is important to remark that this interface had good dielectric characteristics for substrate temperatures of 400–600°C.

Finally, we mention that our deposition system is economic and is not necessarily high vacuum.

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