Low interface states and high dielectric constant Y_2O_3 films on Si substrates

G. Alarcón-Flores and M. Aguilar-Frutis
CICATA-IPN, Legaria 694 Colonia Irrigación, C.P. 11500, Mexico, Distrito Federal, Mexico

C. Falcony[a)]
Departamento de Física, CINVESTAV, Apdo. Postal 14-470, Delegación Gustavo A. Madero, C.P. 07000, Mexico, Distrito Federal, Mexico

M. García-Hipolito
IIM-UNAM, Apdo. Postal 70-360, Delegacion Coyoacán, C.P. 04150, Mexico, Distrito Fedral, Mexico

J. J. Araiza-Ibarra
Unidad Académica de Física, UAZ, Zacatecas 98060, Mexico

H. J. Herrera-Suárez
CICATA-IPN, Legaria 694 Colonia Irrigación, C.P. 11500, Mexico, Distrito Federal, Mexico

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Y_2O_3 films were deposited on *c*-Si substrates at temperatures in the 400–550 °C range, with no further thermal treatment given to these samples, using the spray pyrolysis technique. The spraying solution was yttrium acetilacetonate disolved *N*,*N*-dimethylformamide. In addition, a solution of H_2O-NH_4OH was sprayed in parallel during the deposition process to improve the optical, structural, and electrical properties of the deposited films. The growth of a SiO_2 layer between the yttrium oxide and the Si substrate during this deposition process resulted in interface state density values as low as 10^{10} eV^{-1} cm^{-2}. An effective refractive index value of 1.86, and deposition rates close to 1 Å/s were obtained. The Y_2O_3 films were polycrystalline with a crystalline cubic phase highly textured with the (400) direction normal to the Si surface. An effective dielectric constant up to 13, as well as a dielectric strength of the order of 0.2 MV/cm was obtained for ~1000 Å thick as-deposited films incorporated in a metal-oxide-semiconductor structure. © *2006 American Vacuum Society.* [DOI: 10.1116/1.2214710]

I. INTRODUCTION

High-κ dielectric thin films are being studied for a variety of applications. Several materials have been studied for this purpose. In particular, metal oxides such as ZrO_2, HfO_2, Al_2O_3, as well as rare-earth oxides such as Y_2O_3, La_2O_3, Pr_2O_3, and Gd_2O_3 have been proposed to replace SiO_2 because their high dielectric constant $(10<\kappa<30)$, thermal stability, a relatively high conduction band offset, and a high dielectric breakdown.[1] Yttrium oxide (Y_2O_3) has a dielectric constant between 14 and 18,[2] a high crystalline stability[3] and mechanical strength,[4] and a high refractive index $(n\cong 2)$.[5] Epitaxial growth of rare-earth oxides has been reported to be achieved using molecular beam epitaxy (MBE).[6] Several other deposition methods have been used to obtain Y_2O_3 thin films, such as pulsed laser deposition,[7] rf-magnetron sputtering,[8] spray pyrolysis,[9] and sol gel.[10] In the present work we report the deposition and characterization of Y_2O_3 thin films obtained by ultrasonic spray pyrolysis. These films were deposited from a spraying solution of yttrium acetilacetonate [$Y(acac)_3$] in *N*,*N*-dimethylformamide (*N*,*N*-DMF). The mist of a second spraying solution, consisting of a mixture of H_2O-NH_4OH, supplied simultaneously, and in parallel to the yttrium spraying solution, improved dramatically the optical, structural, and dielectric properties of the Y_2O_3 films. Specifically, the formation of a high quality interfacial layer of SiO_2 improved the interface characteristics with the silicon substrate.

II. EXPERIMENTAL PROCEDURE

The ultrasonic spray pyrolysis technique was used to deposit the Y_2O_3 films on *c*-Si wafers with (100) orientation and low resistivity or (111) and high resistivity, for electrical and optical measurements, respectively. The silicon wafers were previously cleaned with a well established procedure.[11] Spray pyrolysis is considered a simple and low cost deposition method for film deposition. This technique has been used to obtain high quality metallic oxides.[12–15] It consists of an ultrasonic generator used for mist production from a spraying solution containing the proper reactive materials. The mist is transported through a glass tube to the substrate surface which is being heated to achieve a pyrolytic chemical reaction. This deposition process is performed in an atmospheric pressure air ambient. In this work, a 0.03 M yttrium spraying solution was prepared by dissolving $Y(acac)_3$ in *N*,*N*-DMF, from Alfa AESAR and J.T. Baker, respectively. In addition, the mist of a second spraying solution, consisting of a mixture of $1H_2O-1NH_4OH$ (J.T. Baker), was also carried, during the deposition process, to the surface of the silicon wafers, used as substrates. The mists of both spraying

[a)]Electronic mail: cfalcony@fis.cinvestav.mx