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Structural studies of zinc oxide films grown by RF magnetron sputtering

I. Sayago[a], M. Aleixandre[a], A. Martínez[a], M.J. Fernández[a], J.P. Santos[a], J. Gutiérrez[a], I. Gràcia[b,1], M.C. Horrillo[a,*,2]

[a] Instituto de Fisica Aplicada, Laboratorio de Sensores IFA-CSIC, Serrano 144, 28006 Madrid, Spain
[b] Centro Nacional de Microelectrónica, IMB-CSIC, Campus UAB, 08193 Bellaterra, Spain

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Abstract

The main purpose of this study consists of researching the piezoelectric characteristics of ZnO films grown by RF magnetron sputtering in reactive plasma. In this way the influence of deposition parameters, such as RF power and plasma oxygen content, on the structural and morphological properties of the films are analyzed.

ZnO films are grown on SiO_2/Si(1 0 0) substrate using a zinc oxide target. Different RF powers (from 50 to 200 W) and reactive plasmas (from 5 to 15% of oxygen content) have been tested and optimized to produce good quality films suitable for fabricating surface acoustic wave (SAW) devices.

Crystalline structures and morphological characteristics of the films are investigated by X-ray diffraction (XRD) and atomic force microscopy (AFM), respectively.

SAW devices are fabricated with "IDT(Al)/ZnO/SiO_2—Si" configuration. The frequency response of these devices is measured for their characterization.

Keywords: SAW; ZnO; Piezoelectric material; Sputtering

1. Introduction

Piezoelectric materials commonly used in SAW devices are single crystalline substrates (quartz, lithium tantalite and lithium niobite) [1,2], but they are not compatible with the integrated circuit (IC) technology.

SAW devices based on piezoelectric thin films and realized on silicon substrates present several advantages over the conventional devices: low power consumption, reduction of cost and circuit miniaturization and integration [3,4].

Among recently developed piezoelectric material thin films, ZnO is considered as a very promising material for developing SAW sensors on silicon due to its high piezoelectric coupling factor.

Zinc oxide films are piezoelectric when the crystallites have the *c*-axis perpendicular to the substrate. As a piezoelectric material it has been used in surface acoustic wave (SAW) filters/resonators, bulk acoustic wave filters/resonators, microsensors, microactuators and acousto-optic devices [5,6].

In general, polycrystalline ZnO films can be obtained using a variety of deposition methods (sol–gel process, spray pyrolysis, molecular beam deposition, chemical vapour deposition and sputtering) being sputtering the most commonly used [7,8]. Sputtering technique allows to obtain uniform films with good orientation on different substrates at a moderate deposition temperature and it is also compatible with the IC technology [9,10].

In this paper, we investigate the effect of RF power and plasma oxygen content on the properties of ZnO films grown by reactive magnetron sputtering and their possible application in SAW devices.

The crystallinity and crystal orientation of the films are analyzed by X-ray diffraction (XRD). The surface

* Corresponding author. Tel.: +34 915 618 806; fax: +34 914 117 651.
E-mail address: carmenhorrillo@ifa.cetef.csic.es (M.C. Horrillo).
1 Tel.: +34 93 5947700; fax: +34 93 58014965.
2 Tel.: +34 9156188062; fax: +34 915631794.

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Table 1
Sputtering parameters and deposition rate

$T_{substrate}$ (°C)	h (mm)	Power (W)	% O_2 (in plasma)	$v_{deposition}$ (nm/min)
250	50	50	7.5	17
			10	15
			15	15
250	50	100	15	40
250	50	150	15	55
250	50	200	15	64

morphology of the films is characterized by atomic force microscopy (AFM).

Appropriate deposition conditions must be achieved to obtain a good quality of ZnO films for fabricating SAW devices: ZnO films have to be piezoelectric (orientation growth along the [0 0 2] direction) and low surface roughness to allow a good wave transmission and avoid increasing the propagation losses.

Finally, SAW devices with "IDT(Al)/ZnO/substrate" configuration are fabricated. Their frequency response is measured by a network analyzer.

2. Experimental

ZnO films are deposited on SiO_2–Si(1 0 0) by RF magnetron sputtering method using a zinc oxide target (99.99% purity) in a reactive plasma (oxygen and argon mixed). The sputtering parameters are shown in Table 1.

The (1 0 0) silicon wafers used in this work are first cleaned by standard techniques and then thermally oxidized to obtain a 1 μm thick SiO_2 layer. Next, the wafers are ultrasonically cleaned in acetone and ethanol during 10 min, rinsed in deionized water, and subsequently dried with flowing nitrogen before being introduced in the sputtering system.

Before starting the deposition process, the target is presputtered for 10 min to remove any contaminant from its surface and reach stable conditions. The distance between target and substrate is 50 mm. The ratio of argon (99.999% purity) to oxygen (99.999% purity) is controlled by the electronic mass flow controllers. During film growth, the deposition temperature is maintained at 250 °C. The substrate temperature is monitored using a thermocouple placed near the substrate. The thickness of films is about 2–3 μm and it is measured with a Nanospec (AFT 200) interferometer.

XRD (Siemens D500) and AFM (Digital Instruments-Nano Scope III) measurements have allowed to determine the crystallinity and the surface morphology, respectively.

SAW devices with "IDT/ZnO/substrate (SiO_2–Si)" configuration are fabricated. IDTs are realized in Al by sputtering. The thickness is 200 nm and they are patterned using a micromachining process. The frequency response is measured with a network analyzer (HP 8510B).

3. Results and discussions

In order to investigate the effect of RF power on the properties of ZnO, a series of samples were grown at different RF powers (50, 100, 150 and 200 W) in an Ar plasma with 15% O_2. Fig. 1 shows the XRD of theses samples deposited at several RF powers in reactive plasma. The peak at about 34° corresponds to the diffraction from the (0 0 2) plane of the ZnO.

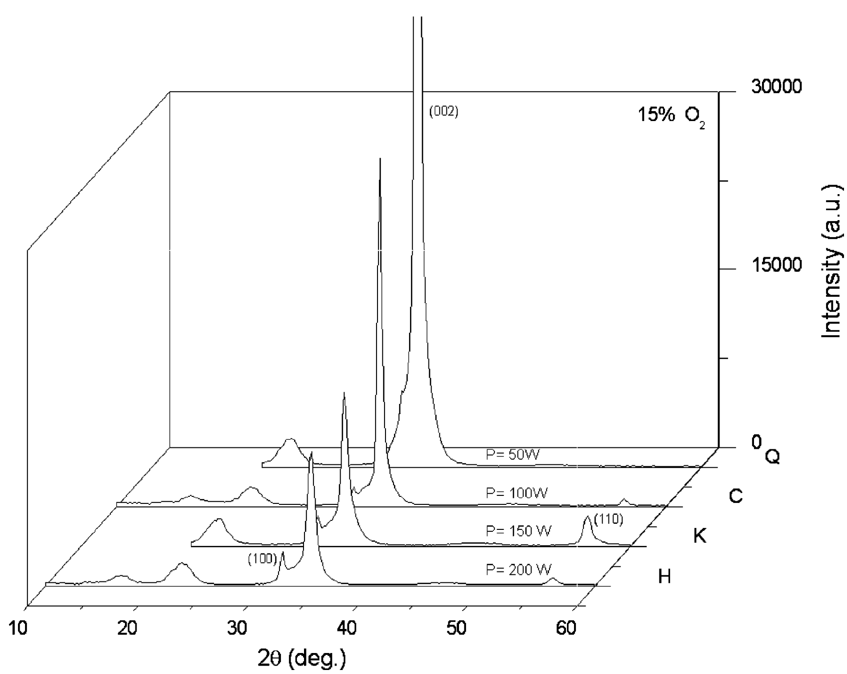

Fig. 1. X-ray diffraction patterns of ZnO films deposited at different RF powers in a 15% O_2 reactive plasma.