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Structural and optical properties of titanium oxide thin films deposited by filtered arc deposition

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Abstract

Thin films of titanium oxide have been deposited on conducting (100) silicon wafers by filtered arc deposition (FAD). The influence of the depositing Ti^+ energy on the structure, optical and mechanical properties of these films has been investigated. The results of X-ray diffraction showed that with increasing substrate bias the film structure changed from an anatase to rutile phase at room temperature with the transition occurring at a depositing particle energy of about 100 eV. The optical properties over the range of 300 to 800 nm were measured using spectroscopic ellipsometry and found to be strongly dependent on the substrate bias. The refractive index values at a wavelength of 550 nm were found to be 2.6 and 2.72 for the anatase and rutile films, respectively. The optical band gap as a function of the substrate bias was also determined and was found to be 3.15 and 3.05 eV for anatase and rutile phases, respectively. Hardness and stress measurements also confirmed the structural transitions. The hardness range of TiO_2 films was found to be between 11.6 and 18.5 GPa and the compressive stress was found to vary over the range of 0.7–2.6 GPa. Studies carried out in this paper showed that the properties of the FAD-deposited TiO_2 are sensitive to the energy of depositing Ti^+.

Keywords: Titanium oxide thin film; Filtered arc deposition; Hardness; Compressive stress; Optical band gap

1. Introduction

Titanium oxide (TiO_2) has a number of attractive properties, which include high refractive index, high dielectric constant, semiconductor properties and chemical stability. Crystalline TiO_2 thin films are of interest for use in a range of applications, including photocatalytic purification [1], solar energy conversion [2] and also has good blood compatibility [3]. There are three kinds of crystalline phases, anatase, rutile and brookite. The rutile structure has the highest refractive index and is thermodynamically more stable than the others.

TiO_2 films have been prepared by a variety of deposition techniques such as the sol-gel process [4], chemical vapor deposition [5], evaporation [6], various reactive sputtering techniques [7,8], ion beam assisted process [9], atomic layer deposition [10], pulsed laser deposition [11] and filtered arc deposition [12]. In most of these techniques additional heating during deposition or post heating is required to synthesis crystalline phases of TiO_2.

Filtered arc deposition (FAD) is a novel deposition method [13], where the degree of ionization and energy of the depositing species is higher than that of thermal evaporation and magnetron sputtering techniques. The average ion energy of Ti^+ is around 50 eV, which can be increased further by applying a negative bias to the substrate to accelerate the ions. The properties of depositing films may be influenced greatly by changing the negative substrate bias. In the present paper, TiO_2 films were prepared onto conducting (100) silicon substrates using FAD. X-ray diffraction (XRD), spectroscopic ellipsometry, stress and ultramicroindentation measurements were used to characterize the structural, optical and mechanical properties of the films.

2. Experimental

The FAD system used in this study has been described in detail [13]. The substrate used were (100) conducting silicon wafer (resistivity 0.05 Ω cm). The base pressure of the system was 2×10^{-4} Pa. The deposition conditions were as follows: arc current, 120 A; O_2 gas flow rate, 30 ml/min; pressure, 0.35 Pa; Ti^+ beam current, 200 mA, which was measured with a shutter of 100 mm diameter (−100 V bias). The range of substrate bias voltage applied to the substrate was 0 V to −400 V. The thickness of the film used in this analysis was about 500 nm.

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