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Deposition and modification of titanium dioxide thin films by filtered arc deposition

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Abstract

Thin films of titanium dioxide have been deposited on glass substrates and conducting (100) silicon wafers by filtered arc deposition (FAD). The influence of the depositing Ti^{+} energy, substrate types and substrate temperature on the structure, density, mechanical and optical properties have been investigated. The results of X-ray diffraction (XRD) showed that with increasing substrate bias, the film structure on silicon substrates changes from anatase to amorphous and then to rutile phase without auxiliary heating, the transition to rutile occurring at a depositing particle energy of about 100 eV. However, in the case of the glass substrate, no changes in the structure and optical properties were observed with increasing substrate bias. The optical properties over the range of 300–800 nm were measured using spectroscopic elliosometery, and found to be strongly dependent on the substrate bias, film density and substrate type. The refractive index values of the amorphous, anatase and rutile films on Si were found to be 2.56, 2.62 and 2.72 at a wavelength of 550 nm, respectively. The hardness and elastic modulus of the films were found to be strongly dependent on the film density. Measurements of the mechanical properties and stress also confirmed the structural transitions. The hardness and elastic modulus range of TiO_2 films were found to be between 10–18 and 140–225 GPa, respectively. The compressive stress was found to vary from 0.7 to 2.6 GPa over the substrate bias range studied. The composition of the film was measured to be stoichiometric and no change was observed with increasing substrate bias. The density of the film varied with change in the substrate bias, and the density ranged between 3.62 and 4.09 g/cm^3.

Keywords: Ellipsometry; Optical properties; Structural properties; Titanium oxide

1. Introduction

Titanium dioxide (TiO_2) has a number of attractive properties, which include a high refractive index, high dielectric constant and chemical stability. Crystalline TiO_2 thin films are of interest for use in a range of applications, including photocatalytic purification [1] and 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 vapour deposition [5], evaporation [6], various reactive sputtering techniques [7,8], ion beam assisted process [9], atomic layer deposition [10], pulse laser deposition [11] and filtered arc deposition (FAD) [12–14]. In most of these techniques additional heating during deposition or post heating is required to synthesis crystalline phases of TiO_2.

The cathodic arc is a low-voltage, high-current plasma discharge that takes place between two metallic electrodes in vacuum. The cathodic arc process is an ideal method for assisted film deposition, since the cathode spot is an intense source of ionized material with energies sufficient for self-densification when condensed onto a substrate surface. The main disadvantage of the arc process as a technique for thin film deposition has been the presence of microparticles in the emitted flux, which are ultimately incorporated into the coating. These macroparticles range in size up to a few micrometers in diameter and lead to a severe degradation in film quality, resulting in film porosity, and preclude its use from the production of high quality films suitable for electrical and optical applications. Various schemes and devices have been employed to reduce macroparticles, but the most successful are based on the use of curved plasma duct filter. FAD is a novel deposition method [15], where the degree of ionization and energy of the depositing species is higher than that of thermal evaporation and magnetron

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