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Plasma-enhanced chemical vapor deposition of amorphous silicon carbonitride: Deposition temperature dependence of bonding structure, refractive index, mechanical stress and their aging under ambient air

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Abstract

Amorphous silicon carbonitride deposited at temperatures between 200 °C and 395 °C by plasma-enhanced chemical vapor deposition has been characterized by Fourier transfrom infrared (FTIR) spectroscopy, X-ray photoelectron spectroscopy, ellipsometry, ultraviolet–visible–near-infrared reflectance-transmittance spectroscopy, residual stress measurements and etch tests in hydrofluoric acid (HF). The optical and mechanical properties have been measured both directly after deposition and after storage under ambient air. The bonding structure derived from FTIR spectra indicates that higher deposition temperatures lead to a denser material with a higher degree of crosslinking due to an increased dissociation of hydrogen molecules, thereby reducing the amount of hydrogen-terminated bonds. This results in an increased refractive index and a reduced compressive stress level as well as a better resistance against HF etching of the as-deposited layers. Diffusion of ambient moisture into the thin-films is identified as the main aging mechanism which affects layers deposited at lower temperatures more pronouncedly due to their higher degree of porosity. The resulting adsorbed water molecules cause an increase of layer thickness accompanied by a decrease of refractive index and an increase of compressive stress.

Keywords: Amorphous silicon carbonitride, a-SiCN:H, refractive index, mechanical stress, FTIR, aging

1. Introduction

The combination of optical, mechanical, tribological and electrical properties inherent to silicon carbonitride (SiCN) has lead to a considerable interest in this ternary compound during the last years. Proposed applications range from photodetectors for the ultraviolet [1, 2] and wear-resistant coatings [3] to low-k interconnects in integrated circuits [4, 5].

Successful deposition has been reported by a variety of methods including reactive sputtering [6, 7], hot-wire chemical vapor deposition [8] and plasma-enhanced chemical vapor deposition (PECVD), the latter both at microwave [9, 10, 11] and radio frequencies [12, 13, 14]. In chemical vapor deposition processes, silicon (Si), carbon (C) and nitrogen (N) can either be introduced separately as silane (SiH_4), methane (CH_4) and molecular nitrogen (N_2) or ammonia (NH_3) [1, 11, 12] or alternatively using organic precursors such as methylsilazanes [14, 13, 15]. For PECVD processes from hydrogen-containing precursors at moderate temperatures, the resulting layers are typically amorphous hydrogenated silicon carbonitride (a-SiCN:H) [10, 13, 12, 16].

Being a ternary compound SiCN allows to tailor its properties within certain ranges. This is a significant advantage for applications, e.g., as optical layers in microelectromechanical systems (MEMS) where not only the required refractive index but also mechanical stress within the thin-film as well as the etching behavior under typical etchants has to be carefully adjusted by the deposition conditions.

The dependence of the properties of a-SiCN:H on different deposition parameters has been subject to

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