Surface & Coatings Technology 202 (2008) 5379–5382

Contents lists available at ScienceDirect

Surface & Coatings Technology

journal homepage: www.elsevier.com/locate/surfcoat

Microstructure and mechanical properties of SiCN hard films deposited by an arc enhanced magnetic sputtering hybrid system

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ARTICLE INFO

Available online 14 June 2008

Keywords:
AEMS
SiCN films
Nanocomposites
Hardness
Friction coefficient

ABSTRACT

SiCN hard films have been synthesized on stainless steel substrates by an arc enhanced magnetic sputtering hybrid system using a silicon target and graphite target in mixed gases of Ar and N_2. The XRD results indicate that basically the SiCN films are amorphous. However, the HR-TEM results confirm that the microstructure of the SiCN films with a high silicon content are nanocomposites in which nano-sized crystalline C_3N_4 hard particles are embedded in the amorphous SiCN matrix. The hardness of the SiCN films is found to increase with increasing silicon contents, and the maximum hardness is 35 GPa. The SiCN hard films show a surprising low friction coefficient of 0.2 when the silicon content is relatively low.

1. Introduction

CN_x binary films have been theoretically predicted to possess attractive mechanical properties, such as super hardness and wear resistance [1], therefore, they have been widely investigated during the last decades [2,3]. However, the experimental evidence shows that it is difficult to form the crystalline β-C_3N_4 films. This is because of the lack of a large thermodynamic driving force using normal deposition techniques, and therefore it is not easy to obtain super hardness [4]. Recently, SiCN ternary films have been formed by the incorporation of silicon during the growth of the CN_x binary film system to promote the formation of crystallites. This has attracted much attention, since SiCN films possess high thermal stability and high chemical inertness, in addition to the well-known high hardness. Therefore, it is a very suitable coating material for applications in which wear resistance and corrosion resistance are required. So far, various methods have been performed to prepare SiCN films [5–7]. However, detailed investigations of chemical composition, microstructure, and mechanical properties, and especially the tribological behavior of this SiCN ternary film system have seldom been explored.

In the present work, SiCN films have been deposited by an arc enhanced magnetic sputtering hybrid system (AEMS). The dependence of the microstructure and mechanical properties of SiCN films on the silicon content have been explored and the results obtained are discussed.

2. Experimental

The SiCN films were deposited onto stainless steel substrates (1Cr18Ni9Ti) by AEMS. In the AEMS process, both arc discharge and plasma discharge are produced simultaneously so that the deposition rate and adhesion between substrate and film can be drastically improved. As an example, this hybrid system using arc ion plating (graphite cathode) and twin-sputtering (Si cathode) has been used for the deposition of SiCN films. High purity argon was used as the sputtering gas, and high purity nitrogen was used as the reactive gas. Before loading into the processing chamber, the substrate (10 mm × 10 mm × 5 mm) was cleaned in an ultrasonic bath of acetone, washed in deionized water and dried in nitrogen atmosphere. Prior to deposition, the chamber was evacuated to a base vacuum of 2.5×10^{-3} Pa, and then an Ar plasma was employed for 10 min sputter cleaning to improve further the adhesion. During processing, the silicon target power was changed continuously from 1 to 7 kW, while the other parameters of graphite target power, N_2 and Ar gas flow rate, substrate bias voltage, deposition pressure, temperature and time were kept constant of 12 kW, 25 sccm, 30 sccm, −100 V, 0.2 Pa, 300 °C and 120 min, respectively, as a result SiCN films with different silicon contents could be produced.

X-ray diffraction (XRD) and high-resolution transmission electron microscopy (HR-TEM) were used to study the chemical compositions as well as structural and morphological characteristics of the SiCN films. The binding energy of the SiCN films was determined with an X-ray photoelectron spectroscopy (XPS). The hardness of the SiCN films (2–3 μm) was measured by nano-indentation tests. The maximum indentation load was 50 mN in order to avoid the effect of the substrate. Five nano-indentation areas were performed for each sample, and the average value taken as the film hardness. The friction coefficient was evaluated by means of the pin-on-disk test in 35–45% humid air at room temperature (25 °C) without lubricant.

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doi:10.1016/j.surfcoat.2008.06.057

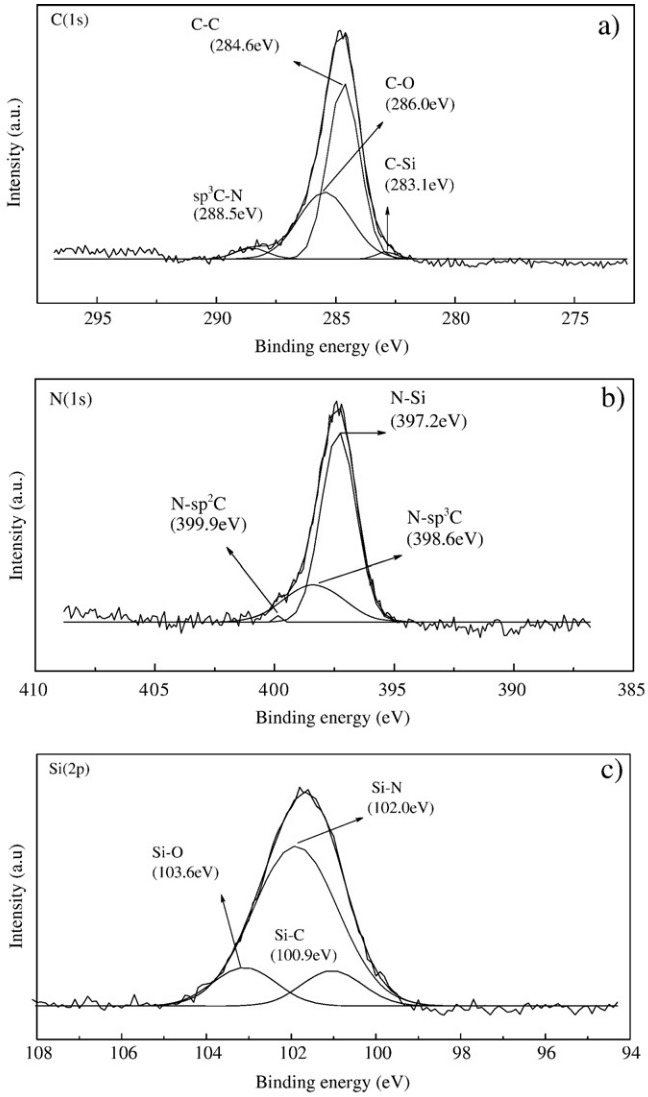

Fig. 1. Typical deconvoluted Gaussian spectrum of the SiCN films with 38 at.% silicon content, (a) C (1s) core level, (b) N (1s) core level, and (c) Si (2p) core level.

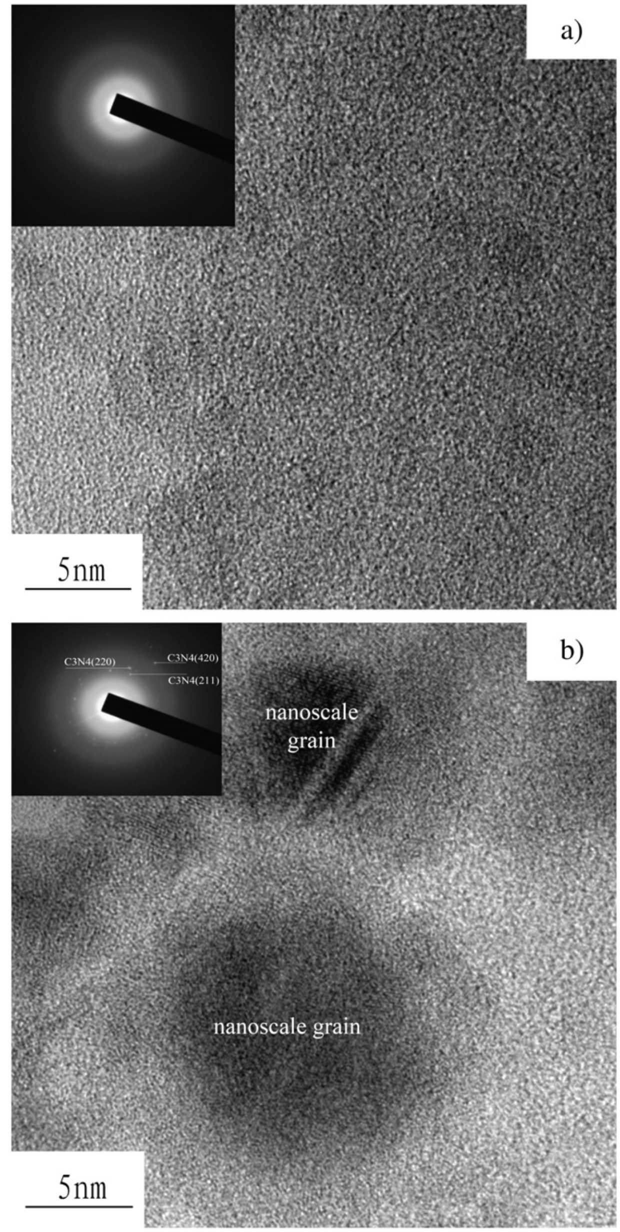

Fig. 3. HR-TEM images and the corresponding electron diffraction patterns of the SiCN films with (a) 16 at.% Si and (b) 38 at.% Si.

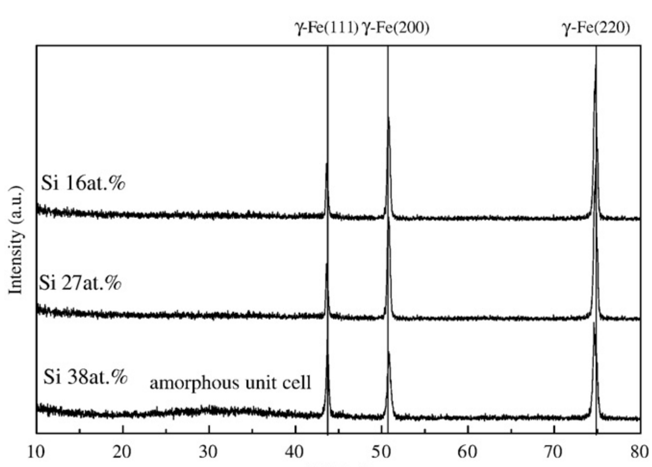

Fig. 2. XRD patterns of the SiCN films with different silicon contents (23–26 at.% carbon content, and the balanceable element is nitrogen).

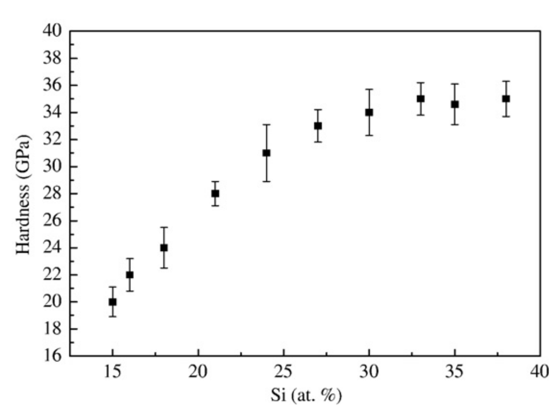

Fig. 4. Relationship between hardness and silicon content of the SiCN films (23–26 at.% carbon content, and the balanceable element is nitrogen).