Introduction

Controlled ion bombardment of growing thin films can be used to modify and improve the film structure and properties. Recently, higher energetic species (up to hundreds of eV) were found in the plasma by pulsed targets in magnetron sputtering. In this study, an electrostatic quadrupole plasma mass spectrometer (EQP) has been used in a pulsed closed unbalanced magnetron sputtering (P-CFUBMS) system to investigate the effect of different pulsing parameters (frequency, duty cycle) on the ion energies and ion fluxes present in the intrinsic plasma during Cr-Al-N film deposition.

Experimental Setup

The Hiden mass/energy electron-impact quadrupole plasma analyzer (EQP) was used to measure the ion energy distributions (IED) in an effort to understand the effects of pulsing configuration and parameters on the energy and flux of the ions arriving at the growing film.

Effect of Pulsing on the Ion Energy and Ion Flux:

The 'A' ion energy region corresponds to the negative pulse period (sputtering period). The 'B' ion energy region is the energy gained from the potential in the oscillating reverse positive pulse period. The 'C' ion energy region is the kinetic energy gained from the fast and high positive voltage overshoot at the beginning of the positive pulse period.

The pulsed plasma exhibits higher ion flux at longer reverse time (lower duty cycle) under the same pulsing frequency.

The improved film density and reduced grain size under the increased ion energy and ion flux bombardment is possibly related to the ion energy and ion flux change.

Cr-Al-N Film Microstructure:

The Cr-Al-N films deposited at 300 kHz and 5.0 kHz (using a high ion flux with energies in the 'B' region) show improved film density, decreased grain size, and few defects. On the other hand, pulsed bombardment with low energies in the 'C' region produces films, such as the film at 150 kHz and 1.0 kHz, with roughened surfaces, intergranular residual damage, distorted lattice, and many dislocations (shown in the HR-TEM image).

Cr-Al-N Film Properties:

Due to the improved film density and reduced grain size under the increased ion energy and ion flux bombardment.

Due to the strain hardening caused by high residual stress and high defect densities in the films.

Conclusions:

1. Pulsing both the magnetrons in the CFUBMS had a significant effect on both the ion energies and ion flux within the plasma. The pulsed ion energy and ion flux strongly depend on the pulsing parameters.

2. The effects of the increased ion energy and ion flux can be both detrimental and beneficial to the growing film. The Cr-Al-N films deposited using a high ion flux with energies in the 'B' region have a good combination of hardness and fracture toughness. Ion bombardment with excessive ion energies in the 'C' region may have a detrimental effect on the tribological properties and toughness of the films.

3. There is an advantage in keeping the maximum pulsed ion energy less than 130 eV and increasing the ion flux in the 70–90 eV range to obtain improved film structure and properties.