# Effect of Pulsing Parameters on the P-CFUBMS of Chromium Aluminum Nitride Coatings

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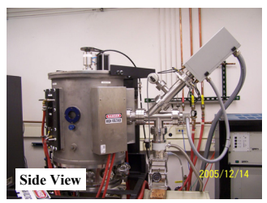
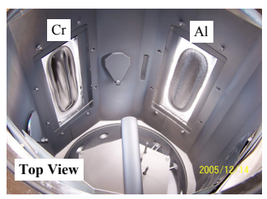
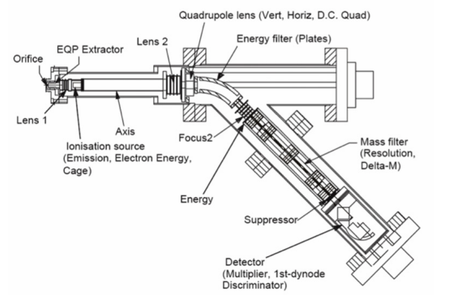
## Introduction

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 eV) were found in the plasma by pulsing the target(s) in magnetron sputtering [1-5]. 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

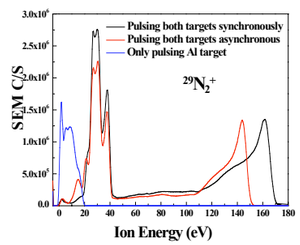


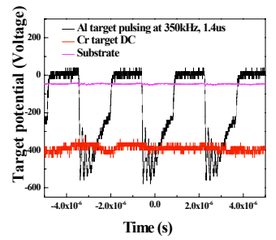



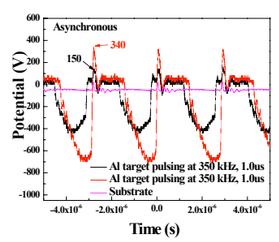




- The Hiden mass/energy electrostatic quadrupole plasma analyzer (EQP) was used to measure the ion energy distributions (IED) in an effort to understand the effects of pulsing configuration and parameters on the energy and flux of the ions arriving at the growing film.

## Effect of Pulsing on the Ion Energy and Ion Flux:

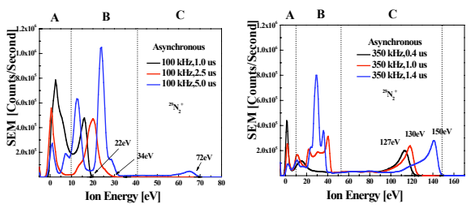



- When both targets are pulsed, the ion energy and ion flux are much higher than when pulsing one target.
- The positive voltage overshoot at the beginning of the positive pulse period increases the ion flux and energy in the plasma

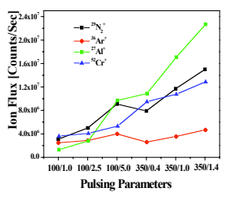
## Effect of Pulsing on the Ion Energy and Ion Flux:

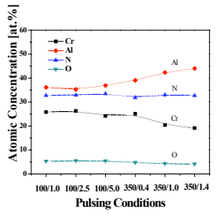






The 'A' ion energy region corresponds to the negative pulse period (sputtering period).
The 'B' ion energy region is the energy gained from the potential in the oscillating reverse positive pulse period
The 'C' ion energy region is the kinetic energy gained from the fast and high positive voltage overshoot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



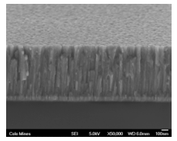

- The pulsed plasma exhibits higher ion flux at longer reverse time (lower duty cycle) under the same pulsing frequency
- The $^{27}Al^+$ ion flux exhibits a faster rate of increase at 350 kHz when the reverse time increases from 0.4 to 1.4 μs than do all other ion species
- The increased ion fluxes at 100 kHz are mainly from the 20-40 eV 'B' region.
- The increased ion fluxes at 350 kHz are largely from the 100-150 eV 'C' region.
- The variation of the Cr and Al contents of the films is possibly related to the ion energy and ion flux change

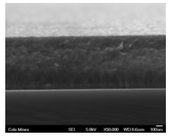
## Cr-Al-N Film Microstructure:

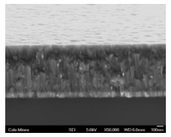
**100 kHz and 1.0 μs**
**Ion energy=72 eV**
**Main ion flux from 'A' region**

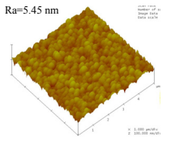
**100 kHz and 5.0 μs**
**Ion energy=122 eV**
**Main ion flux from 'B' region**

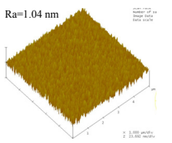
**350 kHz and 1.0 μs:**
**Ion energy= 180 eV**
**Main ion flux from 'C' region**

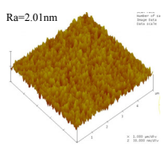




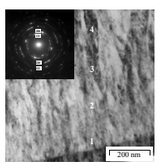


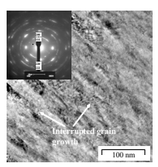


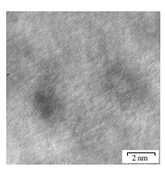



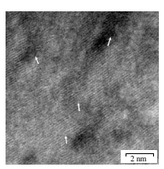




The effects of the pulsed ion energy and flux can be either beneficial or detrimental to the growing film. The Cr-Al-N films deposited at 100 kHz and 5.0 μs (using a high ion flux with energies in the 'B' region), show improved film density, decreased grain size, and few defects. On the other hand, pulsed bombardment with ion energies in the 'C' region produces films, such as that for 350 kHz/1.0 μs, with roughened surfaces, intergranular residual damage, distorted lattice, and many dislocations (white arrows in the HR-TEM image).



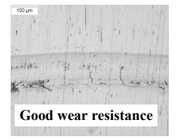



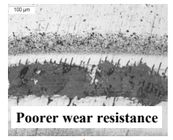



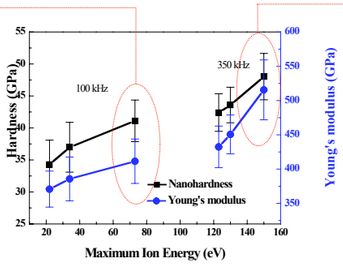

## Cr-Al-N Film Properties:

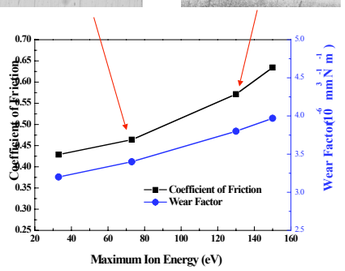
Due to the improved film density and reduced grain size under the increased ion energy and ion flux bombardment

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.