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Ion fluxes in medium frequency pulsed DC magnetron sputtering

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ABSTRACT

The ion fluxes which bombard the substrate during deposition by asymmetric medium frequency pulsed DC magnetron sputtering have been measured as a function of substrate position and pulse frequency. It has been found that, particularly at higher pulse frequencies, the ion flux is dominated by very high energy fluxes which are determined by the positive overshoot voltage in the pulse off period. The behaviour of the ion fluxes on the magnetron centre line and in an offset position has been compared and it is shown that on the centre line there is an additional mid energy ion flux which is not present in the offset position and is thought to arise from the ion flow directed along the magnetic field lines from the racetrack region to the substrate or probe position because of the unbalanced magnetron configuration.

1. Introduction

Pulsed dc reactive magnetron sputtering using asymmetric bipolar pulses is a widely used process which gives arc free deposition resulting in improved film quality [1]. The energy of ions which are accelerated across the plasma sheath and strike the substrate depends on variations of the plasma potential through the cycle of the voltage pulses applied to the target. Asymmetric bipolar power supplies typically give a large fast positive voltage overshoot when switching from its negatively biased "on" state to its positively biased "off" state which raises the plasma potential to a large positive value, producing a rapid expansion of the plasma sheath at the substrate, causing it to be bombarded with ions of very high energy [2,3]. The bombardment of the substrate by these ions may have a significant effect on the growing film, for example, by modifying the film crystallography, removing defects, roughening the surface and enhancing the properties such as adhesion, hardness, wear resistance, frictional resistance, and corrosion resistance [4–9]. It was previously shown by energy resolved mass spectrometry that the ion flux to the substrate measured at a position offset from the centre line of the magnetron target gave rise to significant ion bombardment at high energy up to ~250 eV and that the ion flux increased markedly at higher pulse repetition frequencies >250 kHz [10].

In this paper we have measured the ion fluxes on the centre line of the target as a function of pulse frequency and target to probe distance and we show that there are significant differences between these and the fluxes measured in the offset position which can be attributed to the flow of ions directed by the unbalanced magnetron configuration.

2. Experimental

Chromium nitride was sputter deposited using a single planar chromium target of 99.7% purity and dimensions of 20×7 cm^2. The magnetron was of the type II unbalanced configuration, that is, the strength of the outer magnetic poles was greater than the inner pole as described by Window and Savvides [11]. The base pressure before deposition was approximately 2×10^{-7} Pa. The sputtering gas was an argon/nitrogen mixture. An initial Cr adhesion layer was deposited followed by a CrN layer. The operating pressure during deposition of the adhesion layer was 1.9 Pa and it was 2.1 Pa during the chromium nitride deposition. The pressure was controlled by an automatic downstream pressure control valve and the Ar flow was controlled by a mass flow controller. The film stoichiometry was fixed using optical emission feedback from the chromium emission line at 358 nm to control the nitrogen flow using a piezo-electric valve. The line intensity during nitride deposition was set to 60% of the intensity during deposition of pure chromium. The target current density was ~21 mA/cm^2. The power supply was an AE Pinnacle Plus unit. Depositions were done with pulse frequencies from 10 to 350 kHz with the pulse off time kept constant at 1.1 µs. The energy of gas ions (argon Ar^+, and nitrogen N_2^+) and metal ions (Cr^+) bombarding the substrate was monitored using a Hiden EQP 300 energy analyzer with grounded orifice of 50 µm diameter. The energy range of the instrument was 1000 eV maximum with an energy resolution of 0.5 eV. The probe was placed in a position either on the target centre line or in an offset position as shown in Fig. 1 and the target to probe separation in the centre line position was varied from 5 cm to 15 cm. These configurations were intended to measure the fluxes which would bombard a grounded substrate during film deposition if it were placed in the same position.

3. Results and discussion

The potential applied to the magnetron target is asymmetrical pulsed dc. A typical measurement of the voltage wave form is shown in

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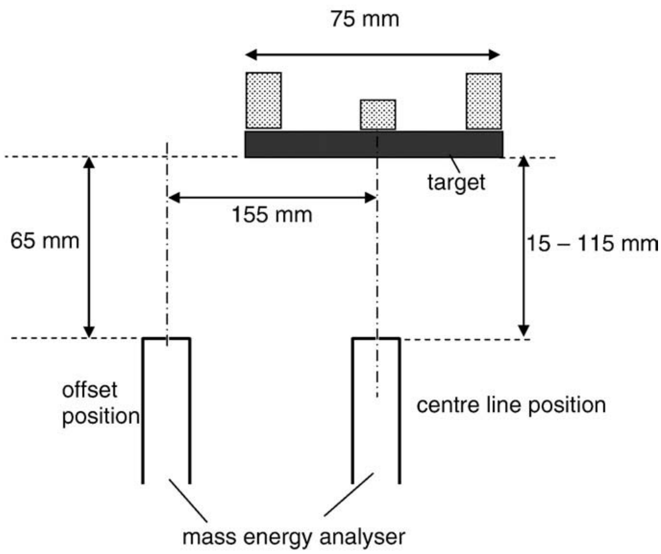

Fig. 1. Experimental configuration.

Fig. 2. From the start of the “on” cycle at $t=0$, there is a steep drop in target potential to approximately −700 V, then a rise to ~−450 V. In the “off” period there is a significant overshoot which can be several hundred volts positive before the wave form settles down to a positive potential of ~40 V. The different pulse phases give rise to different populations of ion energy. During the on phase low energy ion bombardment of a grounded substrate or probe is observed, because of the low plasma potential and hence the low sheath potential at the substrate, whereas during the off phase the plasma potential rises as the target voltage goes positive, leading to a high sheath potential at the probe or substrate giving energetic ion bombardment. As previously published, when the probe was placed off the centre line of the target, the ion energy distribution showed a higher level at high energies, consistent with the bulk of the ion bombardment taking place during the off period where the substrate sheath potential was high. Fig. 3 shows these results for Ar^+ ions (the others have similar shapes).

The results for the probe on the centre line of the target are somewhat different. As shown in Fig. 4a, b and c, there is a much larger spread of ion energies with significant peaks at lower energies. As an illustration, the Ar^+ ion fluxes in the centre and offset positions at one frequency (350 kHz) are compared in Fig. 5. The two curves are

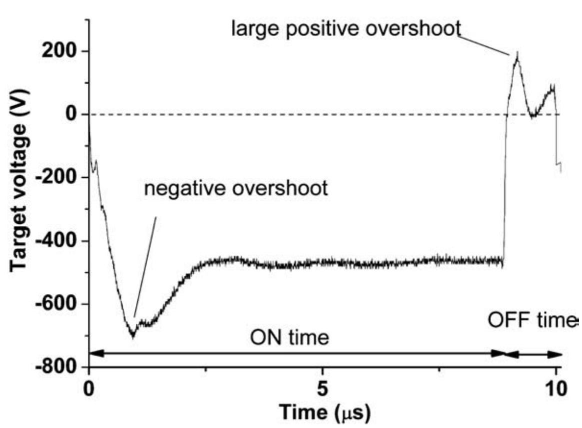

Fig. 2. Typical target voltage waveform for pulse frequency = 100 kHz and off time of 1.1 μs.

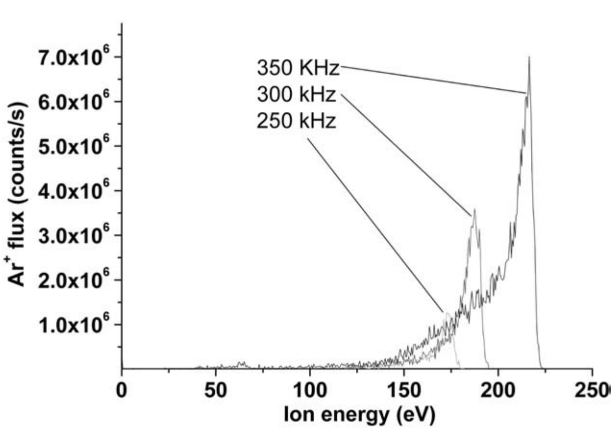

Fig. 3. Ar^+ ion distribution for offset probe position.

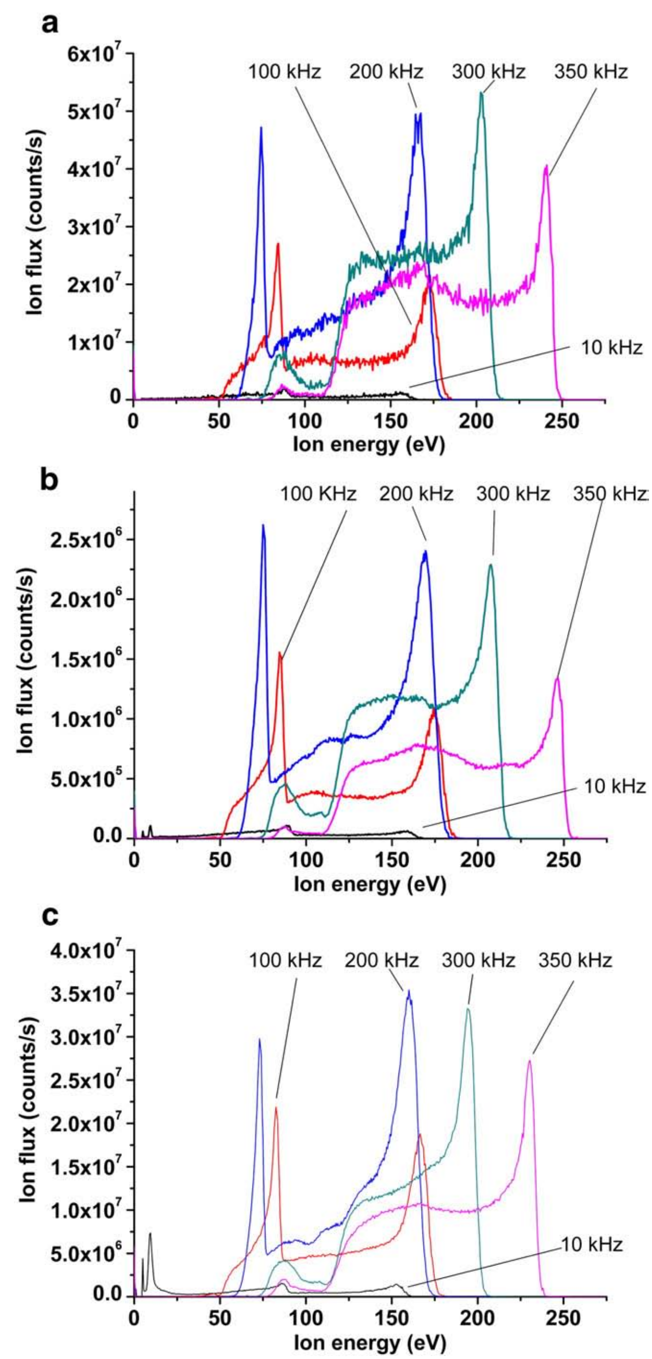

Fig. 4. a) Ar^+ ion fluxes, b) N_2^+ ion fluxes, c) Cr^+ ion fluxes as a function of pulse frequency. centre line probe, probe – target distance 65 mm.