Variations on the Closed Field Unbalanced Magnetron Sputter Ion Plating Configuration

K. Cooke, J. Hampshire, D.G. Teer (Teer Coatings Ltd)

1. Introduction

- Closed field unbalanced magnetron sputter ion plating (CFUBMSIP) [1-3] is ideally suited to the rapid and reliable deposition of multilayer coatings. The technique readily accommodates complex alloy structures, deposited from multiple sources of single metal targets, either directly or by reactive methods. Graded interfaces are routinely and easily formed to ensure that stress induced in the coating is dissipated away from the coating substrate interface [4].
- Complex coatings are required for many challenging technological applications, including: highly elastic, superhard, superlattice coatings [5]; tough, hard coatings for cutting tools [6, 7]; and, optical coatings for filters, etc [8]. Repeating nanolayer structures with carefully controlled and maintained "periods" or "wavelength", ? , are easily produced by rotating the substrate sequentially past the various coating sources. Stoichiometry is readily controlled via automatic feedback of the reactive gas flow using the optical emission from a selected metallic species in plasma of a magnetron source.
- The closed field magnetic configuration is a pre-requisite to the efficient achievement of the high plasma and relative ion flux densities at energies consistent with ideal film growth. While the "classic" arrangement of four or six magnetrons with alternating magnetic polarities is well known [see e.g. 1-3], other configurations in which at least one pair of magnetrons have opposite polarity [1] can be used to advantage.
- The CFUBMSIP process is summarised and some practical examples of the application of the closed field geometry are given.

2. Closed Field Unbalanced Magnetron Sputter Ion Plating (CFUBMSIP)

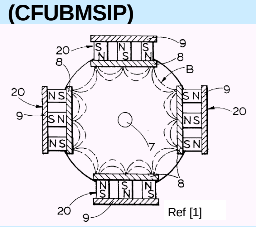

Fig. 2.1: A fully closed configuration [1]

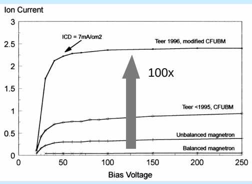

Fig. 2.2: The development of CFUBMSIP

- The CFUBMSIP process is now widely recognised as a state of the art technique for hard coatings [3]. CFUBMSIP acts to increase the ion current density in magnetron sputter ion plating. Unbalanced magnetrons are used in a configuration where at least one pair of unbalanced magnetrons is of opposite magnetic polarity. This traps the plasma, preventing the loss of ionising electrons and so providing significant plasma enhancement. The ion current is maximised at a relatively low substrate bias voltage (e.g. –50V), so that deposition occurs under high density bombardment by low energy ions, the ideal conditions to grow dense films.
- Ion current densities (i.e. the current drawn per unit area of a negatively biased substrate) can be increased 100 fold by the application of CFUBMSIP techniques (when compared to sputtering from a conventional, balanced magnetron source).
- Benefits include efficient argon ion etch pre-cleaning of substrates as well as in the deposition process itself. Pulsed DC Bias is now routinely applied [9, 10] and further improves cleaning and process stability.
- Typical industrial coating units now have up to 6 magnetron sources, which in principle could each provide a different component in an alloy coating.

3. Some alternative closed field arrangements

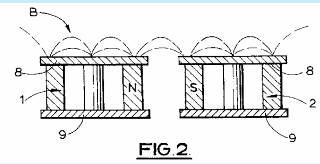

Fig. 3.1: Closure between two coplanar magnetrons [1]

- Sometimes a co-planar arrangement of sources is desirable (for example to coat a continuous, flat substrate). In this case partial closure can be achieved by ensuring adjacent magnetrons have alternating magnetic polarities. As shown schematically in fig. 3.1, the magnetic flux bridging the gap between the magnetrons will tend to prevent charged plasma species from escaping via that gap and being lost.

- In a system with three magnetrons, as in fig. 3.2, then to close the magnetic fields one magnetron must be of opposite polarity. An auxiliary magnet can be introduced to facilitate the full closure of the magnetic fields.
- It is important that such an auxiliary magnet is both within the chamber and is negatively biased or electrically floating. If the magnet were positioned outside the chamber then the plasma would still be drawn to the earthed chamber wall where some of the charged constituents would be neutralised. Similarly if the auxiliary magnet were earthed then some plasma current would be dissipated at the magnet
- While full closure of the magnetic fields (as in fig. 2.1) is obviously most effective at reducing losses from the plasma, partial closure, as illustrated in fig. 3.1, can also be used.

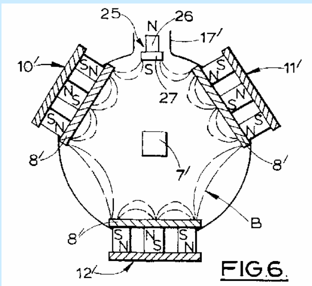

Fig. 3.2: An auxiliary magnet used to fully close the fields of an odd number of magnetrons [1]

- A Teer Coatings UDP 850, 4 magnetron system, in the fully closed configuration had I_{bias} 25% higher under pre-cleaning conditions (high bias voltage/low magnetron power) and I_{bias} 50% higher with the magnetrons at high power (7A) & an intermediate pulsed DC bias voltage (approx -100V), when compared with a similar system in the partially closed configuration.

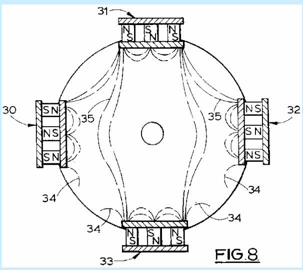

Fig. 3.3: Closure between opposed magnetrons [1]

- The arrangement shown in fig. 3.3 can be advantageous if, for example, only the diametrically opposed, closed field magnetrons are used during a particular stage of the coating process. An enhanced plasma region still encloses the substrate region.

4. A simple configuration – coplanar magnetrons.

- A Teer Coatings UDP450 chamber was modified to accept a coplanar pair of similar magnetrons mounted horizontally in the chamber lid. The pair of magnetrons, each approx 330x134mm, were configured as either "open" (identical magnetic polarity, "N+N") or "closed" (opposite polarity, "N+S"). For these experiments the four magnetrons normally mounted vertically in the cylindrical chamber wall were removed and replaced by blanking flanges, one having a large window to allow direct observation of the magnetrons. The magnetrons were operated with independent DC power supplies.
- The substrate was a horizontal steel plate, some 300mm ?, positioned at either 120mm or 270mm below the magnetrons. The substrate could be biased with DC or pulsed DC.
- The effect of the magnetic configuration on the bias current was investigated for different typical operating conditions of the magnetrons and bias supply.

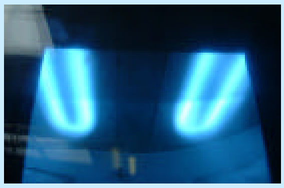

Fig. 4.1: Identical polarity, "open" configuration

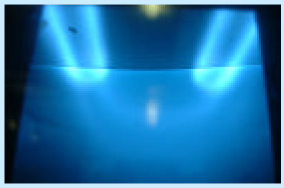

Fig. 4.2: Opposed polarity, "closed" configuration

- Figures 4.1 & 4.2 clearly demonstrate an increase in plasma luminosity linking the magnetrons in the closed field condition. In the open configuration the space between the magnetrons is dark and clearly represents a "sink" for plasma species that are lost from the discharge.

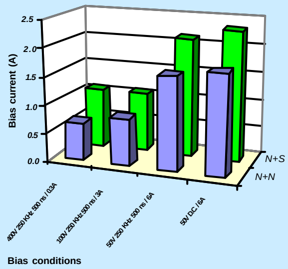

Fig. 4.3: Effect of magnetic configuration on bias current (120 mm source to substrate distance)

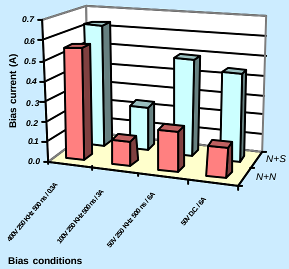

Fig. 4.4: Effect of magnetic configuration on bias current (270mm source to substrate distance)

- Under typical substrate cleaning conditions (low magnetron power and a high, negative, pulsed DC bias potential on the substrate) the substrate bias current is enhanced under the closed field conditions, and this effect is much more marked (i.e. + 60%) for the shorter source to substrate distance, where there is more interaction with the magnetron plasmas.
- In a typical transition mode (intermediate magnetron power and moderate pulsed DC substrate bias voltage) the relative increase in bias current is greater (+92%) at the higher source to substrate distance.
- Under deposition conditions (high magnetron power/low substrate bias) the relative increase in substrate bias current is again much greater (+145%) at the higher source to substrate distance, and this effect is further enhanced when using simple DC substrate bias (+193%).
- At the shorter (120mm) source to substrate distance the individual magnetron plasmas have a more direct interaction with the substrate, whereas at the larger (270mm) source to substrate distance the plasma that develops in the closed field region between the magnetrons is increasingly important – there is less opportunity for plasma species to be lost in the closed field case, enhancing plasma density which supports the increased bias current drawn at the substrate under otherwise identical bias conditions.

6. Conclusions

- CFUBMSIP has proven advantages in the deposition of high quality coatings for many critical applications, including cutting & forming tools, wear components and optical systems. The beneficial aspects of the process are derived from the retention of plasma within the deposition environment.
- In addition to the fully-closed configuration, other variants of the technique provide enhancements over traditional, non-closed field arrangements of multiple magnetrons, and a detailed understanding of a system's characteristics can be used to dramatically modify the substrate environment, including the ion flux, as indicated by the variation in the observed substrate bias current.

7. References

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Teer Coatings Limited
West Stone House, Berry Hill Industrial Estate,
Droitwich, Worcestershire, WR9 9AS, United Kingdom
Tel: +44 (0) 870 220 3910 Fax: +44 (0) 870 3911
E-mail: kevin.cooke@teercoatings.co.uk
Web: http://www.teercoatings.co.uk