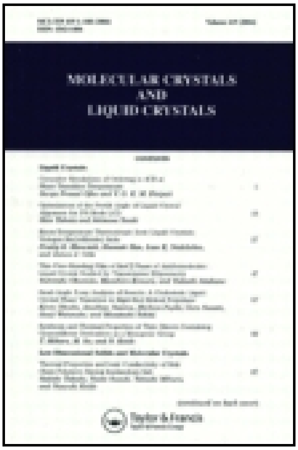

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Cathode Unit of Magnetron Sputter for High Target Utilization

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Magnetron sputtering has become one of most useful methods for depositing thin films. However this coating technique has low target utilization and target life time. In this paper a new cathode unit was designed and tested with the simulation of magnetic field to extend the life time of target. The Cu target utilization was increased up to 45% compared to the conventional sputtering cathode. The thickness variation of thin films deposited was also improved in this method. Discharge property, thin films thickness and erosion depth were measured for the whole life time of target. These results were compared with the data obtained with a conventional cathode unit used in the magnetron sputter.

Keywords: erosion profile; magnetic circuit; magnetic field; magnetron sputtering cathode; target utilization

INTRODUCTION

Over the last decades, magnetron sputtering has become one of the most important methods for depositing thin films. The introduction of magnetic field resulted in low discharge voltage and stable

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manufacturing process of thin films [1–3]. However this coating technique had some shortcomings. These are low target utilization (15∼25%) by erosion in narrow area, variation of thickness in thin films and short life time of target.

To overcome these problems, studies on moving magnetic circuit [4,5] and a time dependent magnetic field of the coil [6] have been reported. Bosscher and Lievens [4] developed a new planar magnetron sputter source that can increase the target utilization over 50% by moving a rectangular magnetic circuit below the target. Iseki [5] reported a magnetron sputtering system with a moving circular type magnet that had unbalanced magnet structure. The system yielded up to 80% of target utilization and the uniformity of sputtered film was within 5% over an area 80 mm in diameter with 5 inch circular target. Kukla [2] developed a time dependent magnetic field from the coil in place of the constant magnetic field from the permanent magnet that could increase the target utilization up to 45∼50%. But these sputter systems are large, complex and high priced due to moving magnetic circuit design and using the coil in place of the permanent magnet. A simple and low price cathode unit having high target utilization, low thickness variation and long target life time has been required for the thin film coating industry.

In this work we made a new cathode unit which gave wide erosion area of target by designing a new magnetic field. The design of cathode unit, erosion depth and I–V properties were discussed in comparision with the conventional cathode.

EXPERIMENTAL

New cathode unit with double magnetic field was fabricated and tested with Cu target of $200 \times 600 \times 6$ mm in comparision with a conventional cathode unit with Al target of 127×457 mm and thickness of 6 mm. Both of the cathode units were equipped in the batch type magnetron sputter system. The distance between the glass substrate and target was 70 mm. After the vacuum chamber was evacuated below 1×10^{-5} torr, the target was pre-sputtered in 5 N argon gas for 5 min in order to remove the surface oxide layer of the target. The sputtering experiments were carried out under the conditions of 1∼5 mTorr pressure and 1∼3 kW power utilizing both newly designed and conventional cathode units.

Magnetic Field Design

In a conventional magnetron sputter the plasma electrons are confined by a magnetic field. This results in a higher charge carrier density in the plasma inducing a lower discharge voltage. Three rows of permanent magnets with alternating polarity positioned under the target backing plate create a tunnel-like magnetic field as shown in Figure 1. The sputtering capability of the target is mainly affected by the design of the magnetic field. Therefore the position of the magnets in relation to the target material as well as the magnet force are very important. In a conventional magnetron sputter the magnetic field on top of the target is semi-circle like tunnel as shown in Figure 1. The electrons in the tunnel-like plasma generate two apexes between the target and substrate. The highest plasma density is generated at the position where the tangents of the magnetic field lines are parallel to the target surface [7,8]. Wendt *et al.* [7] investigated the radial distribution of current in a cylindrically symmetric cathode. They have developed a simple model for the distribution of incident ions at the cathode in the form of an integration equation. In agreement with the model the current distribution was peaked at the radius at which the tangents of magnetic field lines were parallel to the target surface. They also showed that erosion width of the target became wider as the magnetic field strength was decreased

By inserting three magnets between the conventional magnets, we fabricated a new cathode unit with four apexes of magnetic field on top of the target. As shown in Figure 2 the maximum plasma density on top of target was divided by two regions. By adjusting the shape and height of magnetic field apexes, uniform plasma density on top of target could be obtained. The heights of the fields in the new cathode were about 20 mm under the similar process conditions reported by Rossnagel and Kauman [9]. Rossnagel and Kauman [9] measured

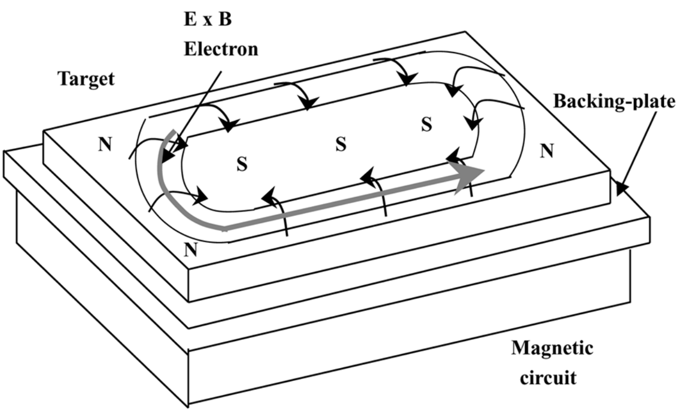


FIGURE 1 Schematic view of a rectangular planar magnetron.

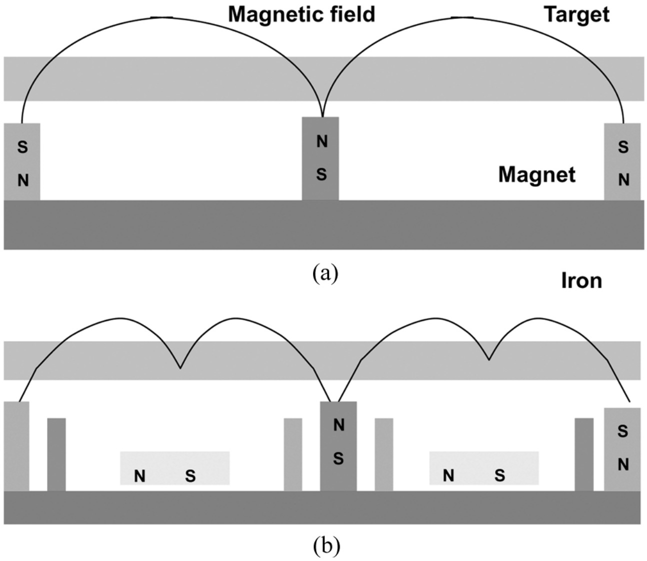


FIGURE 2 Shape of magnetic fields in relation to the structure of magnets in different cathode units. (a) conventional cathode unit and (b) new cathode unit.

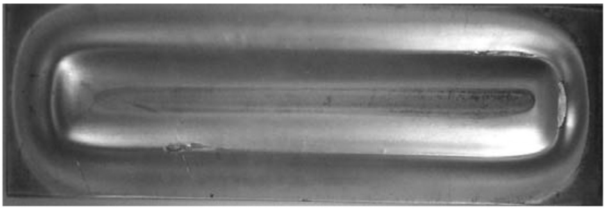
plasma potential, electron temperatures, and electron densities at low magnetic field (165 G) by Langmuir probes and showed high energy electrons over 15.6 eV (Ar atom ionization energy) [10] within 10 mm on top of the target at 5 mTorr pressure.

RESULTS AND DISCUSSION

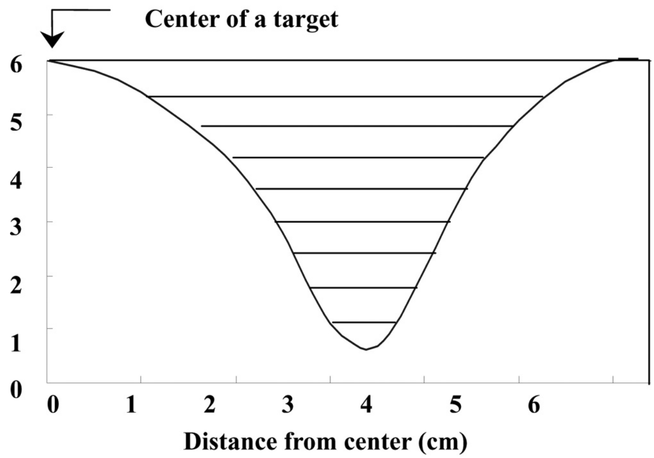
Figure 3 shows the photograph of Al target eroded in the sputter with a conventional cathode unit (a) and erosion profile measured (b).

Erosion experiment of Al target was conducted under the process conditions of 3 Kw power and 3 mTorr pressure. One of the symmetrical erosion profile was measured from the center of the Al target. Al target utilization was about 25%. The target utilization factor (%) is defined as the amount of sputtered target compared to the initial target material.

The experimental results with the new cathode unit are shown in Figure 4 in which Cu target was used. The sputtering condition was same as that of the conventional cathode unit, but the Cu target utilization was increased up to 45%. It was also noted that the erosion profile was wide and spread to give longer target life time. Figure 5 shows the thickness variation of thin films through the life time of



(a)

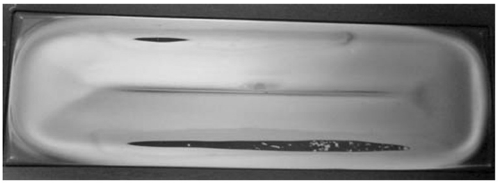


(b)

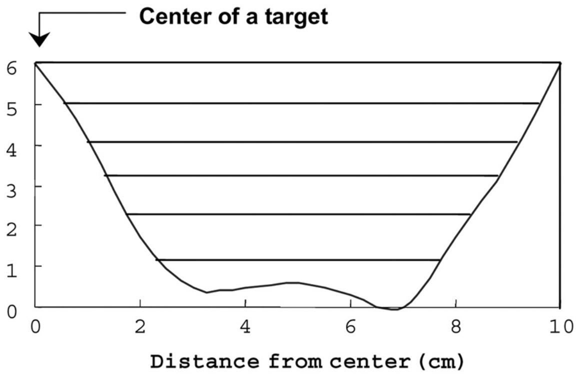
FIGURE 3 Photograph of Al target eroded in the conventional cathode unit (a) and erosion profile of Al target in conventional cathode unit (b).

target. The thickness of the thin films was measured at the center of the substrate. Life time of Cu target used in the new cathode and Al target used in the conventional cathode were 397 kWh and 208 kWh, respectively. Coating conditions of sputter system were 3 kW power and 3 mtorr pressure in both cases. Substrates for the deposition of Cu and Al thin films were coated in static state for 5 min and in rotating mode for 20 min, respectively. The thickness uniformity of Cu thin films measured from the start to the life time of target was about 5% with the new cathode design. However in the case of Al thin film obtained with the conventional cathode, the thickness uniformity was increased up to 20%.

Figure 6 shows the variation of erosion depth in sputter system with different cathodes. In the new cathode design erosion depth was proportional to the integration power up to 397 kWh. However in the conventional cathode erosion depth increased rapidly as



(a)



(b)

FIGURE 4 Photograph of Cu target eroded in a new cathode unit (a) and erosion profile of Cu target in new cathode unit (b).

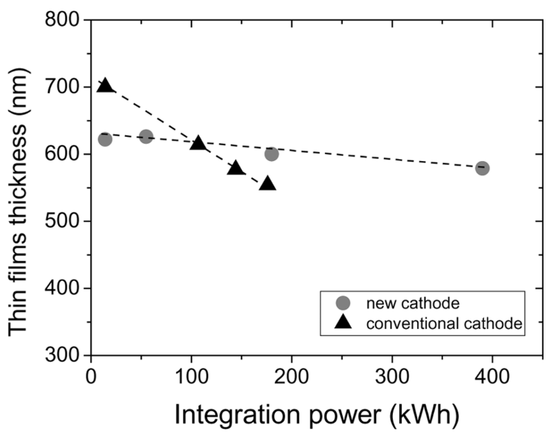


FIGURE 5 Variation of deposited film thickness in the sputter system with different cathode units.

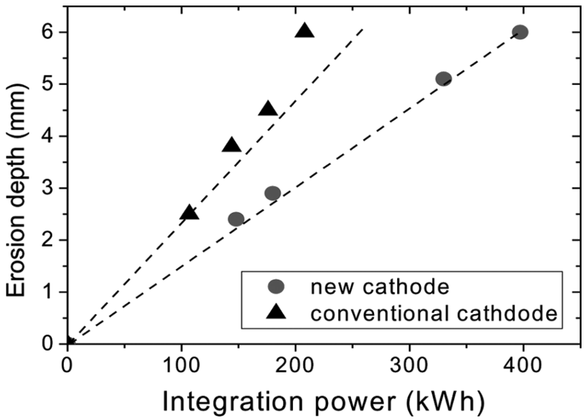


FIGURE 6 Variation of erosion depth in the sputter system with different cathode units.

integration power increased. This may be explained by the localized sputtering at the apex of the magnetic field in the conventional cathode unit. Since the plasma density was distributed more evenly on the target in the new cathode, the target erosion became broader resulting in higher target utilization and longer life time.

Figure 7 shows the variation of discharge voltage through the life time of target. In the new cathode the discharge voltage was decreased

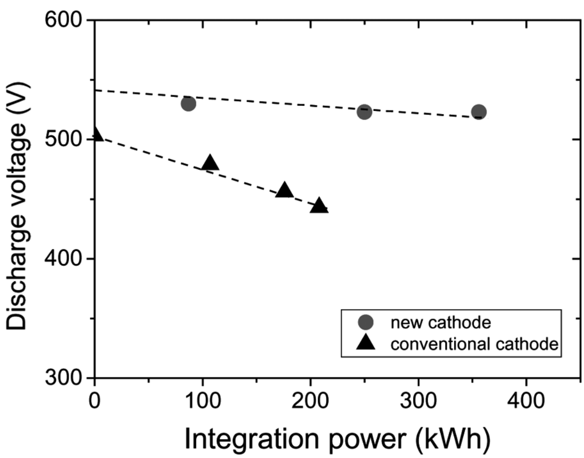


FIGURE 7 Variation of the discharge voltages in the sputter system with different cathode units.

about 2% from about 530 volt to 520 volt through the life time of target. In the conventional cathode the discharge voltage was decreased up to 12% from 500 volt to 440 volt for the life time. This data may also be explained by the difference in the distribution of the plasma density originated by the structure of the magnets in the cathode units.

CONCLUSIONS

A new cathode unit for magnetron sputter was developed by forming four apexes of magnet field on top of target. The highest plasma density was divided by two regions and the height of magnetic field apexes was about 20 mm above the target surface. The target utilization was increased up to 45% in the magnetron sputter with the new design cathode unit. The thickness uniformity of thin films was also improved within 5%. The erosion depth was proportional to the integration power. These results indicate that the width of erosion in the sputter with new cathode was almost constant for the life time of target.

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