ENHANCEMENT OF THE USAGE OF CATHODE MATERIALS IN A MAGNETRON SPUTTER

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A planar magnetron sputter source with a new type of magnetic field distribution based on the magnetic multi zero-crossing points concept is being developed for research aimed at full-target sputtering. Conventional racetrack-type magnetron sputter has only one zero crossing point of the magnetic field perpendicular to the cathode surface and the maximum erosion occurs at this point. Making multi zero-crossing points, we obtained broader plasma distribution than the conventional type device. We confirmed this with the experimental results and compared with the particle-in-cell (PIC) plasma simulation. The modified magnetic-field distribution results in the broadened plasma and erosion profiles.

Keywords: magnetron sputter, magnetic field, particle-in-cell simulation, plasma, target erosion

1. Introduction

As the microelectronics industry grows exponentially, fabrication of thin film process becomes a crucial point of concern. Nowadays, wide area flat panel displays become widespread and the processing of the wide area display panels become big issue. The deposition uniformity of each layers of the panels, coating layer thickness control, and the productivity of the panels are very crucial for the processing of display panels. As the price of raw materials become higher, the efficiency of the usage of the deposition materials also become important concern.

Planar magnetron sputtering [1-5] is a well-established technology, successfully used in a wide range of applications, many of which have been scaled up for industrial use. Magnetron sputter operates at a low pressure and a low voltage taking the advantage of magnetic field. Applied magnetic field confines energetic electrons near the cathode. These confined electrons ionize neutral gas and form high density plasma near the cathode surface. Ions inside the plasma are accelerated toward the cathode surface with high energy by the applied cathode potential. The ion bombardment sputters out target materials and produces secondary electrons which maintain discharge. The target utilization of magnetrons currently produced is low of about 30-50%. In principle, there are two ways how to achieve full erosion on the target. The first method is to design a magnetron with full erosion target, i.e., a target without a center, in which is not sputtered. The second is to control the sputtering region dynamically on the target surface during discharge using an appropriate magnetic skill. The first method resulted in the realization of magnetron sputter sources, for instance, toroidal, rectangular magnetron [6] and magnetic null discharge sputter [7]. However, some of these methods are somewhat complicated structurally. The second method, if it can be realized, will be very convenient and effective for full target erosion but, there has been nearly no report on this. This study addresses the latter method.

Many research activities about magnetron sputter have been carried out by modeling. There are three-dimensional (3-D) particle-in-cell/Monte Carlo (PIC/MC) simulation results [8] which are computationally costly. Thus we use a PIC/MC two-dimensional (2-D) simulation code OOPIC [10]. In Section 2, the simulation results are shown for the magnetron geometry. The magnetic field distributions with a given magnet geometry are in Section 2.1 and the profiles of the plasma quantities are in Section 2.2. The erosion profiles of experiment and simulation are compared in Section 3, and the summary with a conclusion is given in Section 4.

2. Experiment and Simulation Results

2.1 Magnetic field distribution

The system that is used to obtain data is a

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conventional racetrack-type planar magnetron device. The schematic with magnetic field distribution is shown in Fig. 1. It is well-known that the zero crossing points of the magnetic field component perpendicular to the cathode surface are the points of maximum plasma density and maximum erosion [4, 11]. We have shown a magnetic-field distribution perpendicular to the cathode surface obtained by simulation method in Fig. 2. The magnetic field lines are calculated by 2 dimensional (2D) modeling software comsol [12]. The magnetic field component (By) that is perpendicular to the cathode surface is compared. The positions of field lines start from -3mm to +3mm around the cathode surface at intervals of 1mm distance. At zero crossing points of the magnetic field, field lines are monotonically increasing or decreasing.

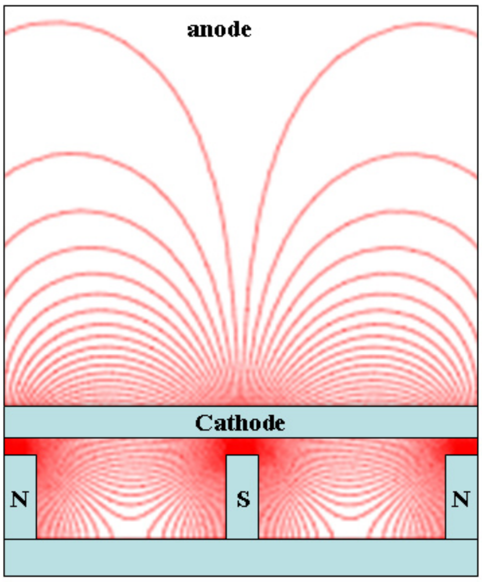

Fig. 1 A schematic of a magnetron sputter

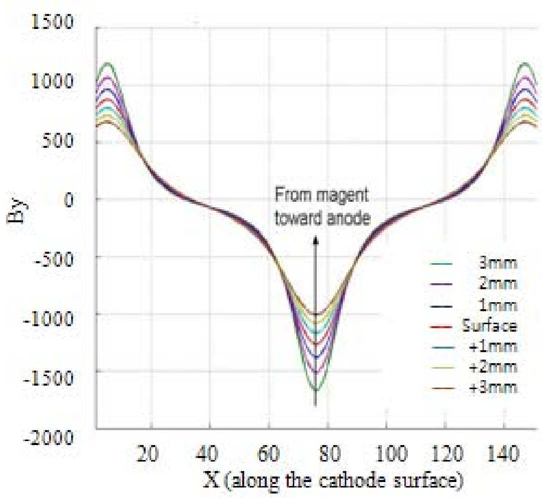

Fig. 2 Original magnetic field component perpendicular to the cathode surface

In the modified magnetic field as shown in Fig. 3, the field lines cross a zero field point three times and make flat region in between maximum and minimum field points. The modified magnetic field lines confine electrons longer and side spread than the original magnetic distribution. This results in the increased and broad plasma density and erosion width of the cathode.

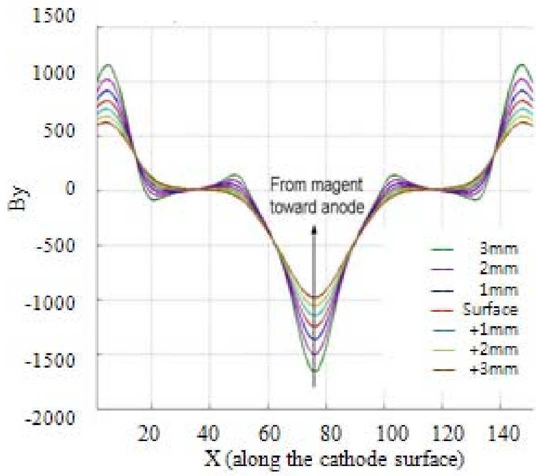

Fig. 3 Modified magnetic field component perpendicular to the cathode surface

2.2 Plasma distribution

We have modeled and simulated the plasma distributions in the sputtering device to confirm the effects of the modified magnetic field. We used PIC-MCC method to track the particles of plasma under given magnetic field distribution [4, 10]. The electron distribution in our system under the conventional magnetic field is shown in Fig. 4. The magnetic field used in the simulation is the same with the data as in Fig.2. The system size is given in the figure in MKS unit.

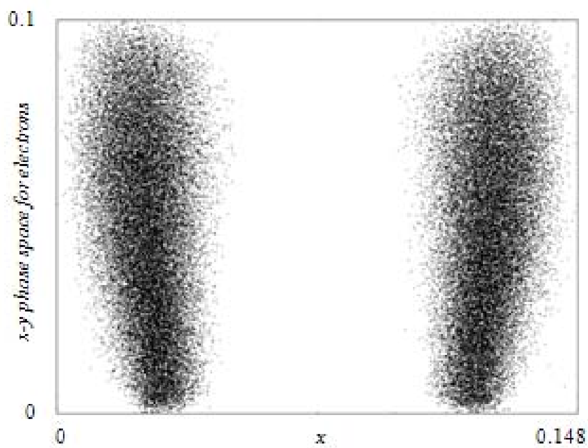

Fig. 4 The electron distribution by PIC simulation under the conventional magnetic field (Fig. 2).

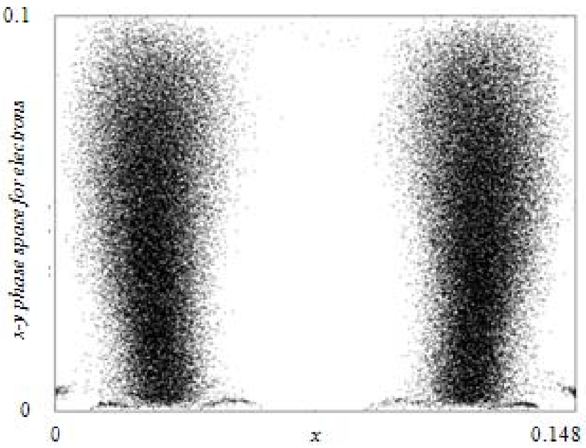

Fig. 5 The electron distribution by PIC simulation under the modified magnetic field (Fig. 3).

When the modified magnetic field is used as a input to the modeling of the system, the distribution of electron near the cathode surface changed as shown in Fig. 5. The electron density distribution is wider compared with the results using the conventional magnetic field and small additional electron striations appeared near the surface. We think that this is due to the modified magnetic field distribution as shown in Fig. 3. The flattened and multiple zero-crossing points of the modified magnetic field provide electrons more chance to stay around the cathode surface than the conventional magnetic field. The modified electron distribution results in the broader ionization region and wider erosion width of the cathode compared with the original one. As a result, ion plasma distribution by modified magnetic field also becomes broader than the one by the conventional magnetic field. We can imagine that the erosion profile is directly affected by the broadened ion distribution.

3. Erosion Profiles

As we mentioned previous section, the plasma profiles using the modified magnetic field showed wider distribution than the plasma profiles using conventional magnetic field. In order to investigate the results, we compared the erosion profiles by the two magnetic fields and the one experimentally measured. The erosion profiles of the simulation are obtained by inverting the flux toward the cathode surface. The normalized erosion profiles of simulation and experiment are shown in Fig. 6 with the conventional and modified magnetic fields on the surface. The line with x-mark is the erosion by simulation using the conventional magnetic field, the line with +-mark by simulation using modified magnetic field, and diamond mark line is experimental data. The line with circle is the original magnetic field and the line with square is the modified magnetic field. Even though the erosion width of the simulation data is shallower than the experimental one, the different erosion widths of the simulation show the effects of the magnetic fields apparently. As expected, the ion flux toward cathode surface under the influence of the modified magnetic field become wider than that of the conventional magnetic field. As a result, we could obtain much higher usage of the cathode material.

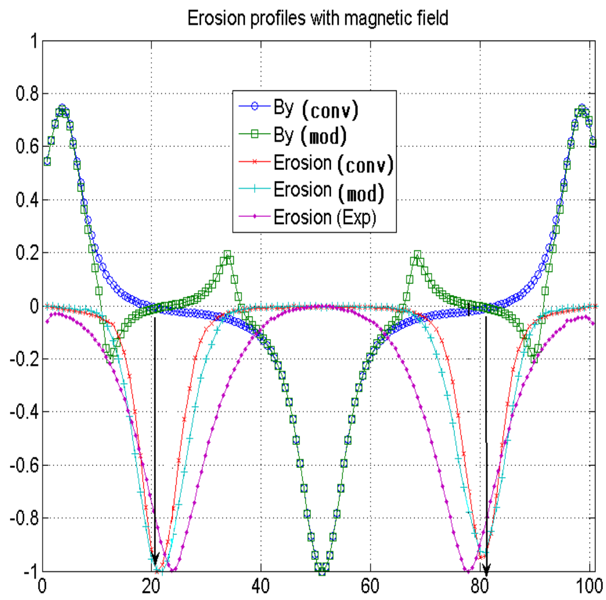

Fig. 6 The line with x-mark is the erosion by simulation using the conventional magnetic field, the line with +-mark by simulation using modified magnetic field, and diamond mark line is experimental data. The line with circle is the original magnetic field and the line with square is the modified magnetic field.

In our experiment, the usage of the cathode with the modified magnetic field become around 1.5 times higher than the one with the conventional magnetic field. There are several reasons for the shallower erosion profiles of the simulation. The one reason is that the simulation time is shorter than the experiment time because PIC-MCC simulation spends much time. As a result, the plasma distribution has not reached the final steady state which is not easy to in the simulation because of the charge accumulation. The second reason is that the response of the cathode material is not accounted in our estimation. The third reason is that the modified electric field in the eroded region affects the plasma profiles and hence resulted in the modified progress of the erosion by modified ion flux toward the cathode surface. There might be other reasons that are not included in the simulation and estimation of the erosion profiles. The difference of the peak position between experiment and simulation originates from the difference of the by magnetic fields. When we checked the zero-crossing points with the maximum erosion points, the zero-crossing points of experiment and simulation coincide with the erosion peak points of the experiment and simulation.

4. Conclusion

We proposed a new magnetic field distribution in our sputtering system to extend the plasma distribution on the cathode surface. It is well-known that the conventional racetrack-type magnetron sputter has only one zero crossing point of the magnetic field perpendicular to the cathode surface and the maximum erosion occurs at this point. We modified the magnet geometry and obtained multi zero-crossing points which results in a broader plasma distribution than the conventional type device. The electron distribution especially just in front of the cathode surface became broad by the modified magnetic field. Moreover additional electron striation occurred beside the main density distributions. This resulted in the broadened ionization in front of the cathode surface and the broader ion flux toward the cathode. We confirmed this by comparing the erosion profiles of the experiment and simulation. The modified magnetic-field distribution results in the broadened plasma and erosion profiles. The modified magnetic field was effective to increase the usage of the cathode material.

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