CHARACTERIZATION OF DIAMOND-LIKE CARBON THIN FILMS DEPOSITED BY FACING TARGETS SPUTTERING OF GLASS-LIKE CARBON

Atsushi SUZUKI*, Yoichi HOSHI*, Tsutomu ISOBE** and Jack H. JUDY*

* The Center for Micromagnetics and Information Technologies
Department of Electrical Engineering, University of Minnesota
200 Union Street Southeast, Minneapolis, Minnesota 55455, USA

**Kao Corporation, 2606, Akabane, Ichikai-machi, Haga, Tochigi, Japan

Abstract--- In this paper we have attempted to clarify the effect of the kinetic energy of the sputtered particles on the formation of diamond-like carbon thin films using a Facing Target Sputtering System(FTS) which allows deposition of films at a very low gas pressure such as 0.2mTorr. Glass-like carbon is a kind of amorphous carbon which has very small crystallites and its structure is very uniform compare to graphite. Therefore, we have also tried to evaluate the potential of glass-like carbon as sputtering targets. The optical properties of the carbon films were measured with an optical ellipsometer. The structure of the carbon films were evaluated from Raman spectroscopy. The electrical resistivity was measured using a four point probe technique. The mechanical properties were measured with a microscratch tester. The above experimental results indicate that the structure of FTS deposited carbon films changes from less amorphous to diamond-like as the argon gas pressure is decreased and their adhesion and uniformity was significantly improved. FTS carbon films about 300Å thick were also deposited on textured Co-Cr-Ta/Cr/Ni-P/Al 3.5"rigid disks for the characterization as wear resistant overcoats. The friction of the carbon films were measured using a computer-controlled constant linear velocity drag tester with a thin film head slider. The results show that the friction coefficient decreased from 0.95 to 0.45 as the argon gas pressure was decreased from 10mTorr to 0.2mTorr. Carbon films deposited at 0.2mTorr Ar pressure show significantly lower friction and much greater durability than those deposited at 10mTorr Ar pressure. These results support the conclusion that FTS deposited carbon films have excellent potential as high-durability overcoats.

INTRODUCTION

Sputtered carbon thin films have been used as protective layers on thin film media because of their expected low friction and high hardness. However, the mechanical properties usually obtained by conventional DC magnetron diode sputtering are not satisfactory. In this paper we report on the properties of diamond-like carbon thin films deposited using a Facing Targets Sputtering System(FTS) with glass-like carbon targets. Glass-like carbon targets are very uniform and should prevent cone formation[1] on the surface of the targets and provide greater reproducibility than graphite targets.

EXPERIMENT

Figure 1 shows a schematic diagram of the FTS apparatus used in this experiment. Glass-like carbon targets of 10cm diameter and 4mm thickness in size were used. These targets were bonded to water-cooled copper backing plates. The targets distance and the substrate position from the center of the targets were arranged as shown in Fig. 1. Pure argon gas were used in the sputtering gas. The sputtering gas pressure was varied from 0.2mTorr to 10mTorr. The discharge current was fixed to 0.5A and the voltage applied to the targets was 420 to 500V. No substrate bias was applied. Carbon films about 5000Å thickness were deposited on silicon wafer substrates and glass plates for characterizations. The optical

Fig.1 A schematic diagram of the Facing Targets Sputtering System

properties of the carbon films were characterized by an optical ellipsometer. The electrical resistivity was measured using a four point probe technique. The structure of the carbon films were characterized by Raman spectroscopy[2]. The surface morphology of the carbon films were characterized by scanning electron microscopy(SEM) and atomic force microscopy (AFM). The mechanical properties of the carbon films were measured with a microscratch tester[3]. Carbon films about 300Å thickness were deposited on textured Co-Cr-Ta/Cr/Ni-P/Al 3.5" rigid disks for the characterization as wear resistant overcoats. The friction of the carbon films were measured using a computer-controlled constant linear velocity drag tester using a thin film head slider. No lubrication was applied. The tribology test conditions of the drag test are shown in table I.

RESULTS AND DISCUSSION

It should be noted that sputtering can be performed successfully at argon sputtering gas pressures as low as 0.2mTorr by FTS. Figure 2 shows the dependence of the refractive index(n) and extinction coefficient(k) of argon sputtering gas pressure on the carbon films. The refractive index decreased slightly as the argon sputtering gas pressure

Table I Tribology test conditions

Substrate	3.5" CoCrTa/Cr/NiP/Al
Carbon layer	300Å
Test mode	Dragging test
Head	Thin Film Head
Load	12g
Linear velocity	25.5cm/sec
Number of Passes	5000pass

Fig. 2 Changes in optical constants n, k for sputtered carbon films at various argon sputtering gas pressure

increased above 2mTorr. Since the mean free path of the sputtered particles at the argon sputtering gas pressure above 1mTorr was less than the distance between the target and substrate, the decrease in the optical constant of carbon films was probably caused by the decrease in the kinetic energy of the sputtered particles incident to the substrate or the increase of the number of particles that arrive to the substrate with a large incident angle.

Fig. 3 AFM images of carbon films; (a) the carbon film sputtered at 0.2mTorr argon sputtering gas pressure, (b) the carbon film sputtered at 10mTorr argon sputtering gas pressure

Figure 3 shows the effect of argon gas pressures for the carbon film surface roughness by using AFM. The grain size of the carbon film was 50 to 100nm for argon sputtering gas pressure of 0.2mTorr. At an argon sputtering gas pressure of 10mTorr, the grain size was increased to 100 to 150nm. The surface roughness of the carbon films increased from 6.4nm to 14.8nm as argon sputtering gas pressure increase from 0.2mTorr to 10mTorr. SEM observation showed that the cross section of carbon films sputtered at 0.2mTorr had a very smooth structure. On the other hand, carbon films sputtered at 10mTorr argon sputtering gas pressure showed columnar structure on the cross section of the films. These results suggest that the lower the argon sputtering gas pressure during the sputtering, the better the film surface roughness and uniformity.

Fig. 4 Raman spectra of carbon films sputtered at (a) 0.2mTorr argon sputtering gas pressure, (b) 10mTorr argon sputtering gas pressure

Figure 4 shows the effect of the argon sputtering gas pressure on the Raman shift of the carbon films. It was obvious that both carbon films are amorphous. As the argon sputtering gas pressure decreased from 10mTorr to 0.2mTorr, the band at 1350cm^{-1} was weakened. Since the bands at 1350cm^{-1} correspond to the interlayer shear vibration of graphitic crystalline[2], the weakened band suggest that the size of the graphitic crystalline is reduced. As the argon sputtering gas pressure was reduced from 10mTorr to 0.2mTorr, the structure of the carbon film

Fig. 5 Changes in resistivity for sputtered carbon films at various argon sputtering gas pressures

changed from a less amorphous carbon film, which has larger graphitic crystalline than diamond-like carbon film, to a diamond-like carbon film, which has smaller graphite crystallites and much more uniform film structure.

The resistivity of FTS deposited carbon films was found to increase from 0.09 ohm cm to 0.5 ohm cm as the argon sputtering gas pressure was increased from 0.2 mTorr to 10 mTorr as shown in Fig. 5. Because less amorphous films have lower uniformity and density compared to the diamond-like carbon, this result shows that they also have higher resistivity than diamond-like carbon film.

The adhesive force of the carbon films was determined using a microscratch tester Fig. 6 shows the dependence of the adhesive force on the argon sputtering gas pressure. The adhesive force of carbon films were improved from 0.027 N to 0.047 N as the argon sputtering gas pressure was decreased. This result suggests that the lower the argon sputtering gas pressure, the higher the kinetic energy of the sputtered

Fig. 6 Typical scratch loading curves of carbon film deposited on Si substrates at different argon sputtering gas pressure

carbon particles bombarding the substrate. Therefore, carbon films bombarded by high energy carbon particles show a higher adhesive force.

The dynamic friction coefficients of carbon films are shown in Fig. 7. As the argon sputtering gas pressure was decreased from 10 mTorr to 0.2 mTorr, the friction coefficient of the carbon films decreased from 0.95 to 0.45 after a 5000 pass drag test. In the case of carbon films deposited at 10 mTorr argon sputtering gas pressure, the initial friction coefficient was 0.80. During the continuous dragging test, the friction coefficient fluctuated and an increase of the friction coefficient up to 0.95 was observed. This friction coefficient increase was probably caused by the increase of the contact area between the head slider and the carbon overcoat. On the other hand, the carbon film deposited at 0.2 mTorr indicated a friction coefficient around 0.40-0.45 and was very stable during the drag tests. The friction coefficient difference between these two films was probably

Fig.7 Typical friction coefficient curves during a 5000 pass drag test Carbon films deposited 300Å thickness on CoCrTa/Cr/NiP/Al textured rigid disks at different argon sputtering gas pressures

caused by the structure, uniformity, density and adhesive force difference for these carbon films. In the case of the carbon film sputtered at 10mTorr argon sputtering gas pressure, the film structure was less amorphous. Therefore, the structure was not as uniform as diamond-like carbon. Figure 8 shows surface profile of the two carbon films after the drag test. In the case of the carbon film deposited at 0.2mTorr argon sputtering gas pressure showed less wear depth compare to the 10mTorr argon sputtering gas pressure carbon film. This result correlates with the results of the microscratch test. These results support the observation that carbon films with higher uniformity and higher adhesive force not only exhibit lower friction of coefficient but also have greater durability.

Fig. 8 Stylus profiles of worn carbon film on CoCrTa/Cr/NiP/Al textured rigid disks after a 5000 pass drag test The carbon films sputtered at (a) 0.2mTorr argon sputtering gas pressure, (b) 10mTorr argon sputtering gas pressure; 1, 2 and 3 are wear region caused by the thin film slider rails

CONCLUSION

The effects of the kinetic energy of the deposition particles during the carbon sputtering using FTS system were investigated. In the case of the low argon sputtering gas pressure, the kinetic energy of the deposition particles have high energy. The carbon films having a diamond-like structure and also have a uniform and dense structure, a smooth surface, and good adhesion. On the other hand, carbon films deposited at high argon sputtering gas pressure showed a less amorphous carbon structure, a rough surface, and poor adhesion. In conclusion, FTS deposited diamond-like carbon films have low friction and have excellent potential as high durability overcoats.

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REFERENCES

- [1] C.W. Chen et al., J. Vac. Sci. Technol., "Surface-defect formation in graphite targets during magnetron sputtering" A8(4), pp.3157 -3162, Jul/Aug 1990.
- [2] Diane S. Knight et al., J. Mater. Res., "Characterization of diamond films by Raman spectroscopy", Vol.4, No.2, pp.385-393, Mar/Apr 1989.
- [3] T.W. Wu, J. Mater. Res., "Microscratch and load relaxation tests for ultra-thin films" Vol. 6, No. 2, pp.407-426, Feb 1991.