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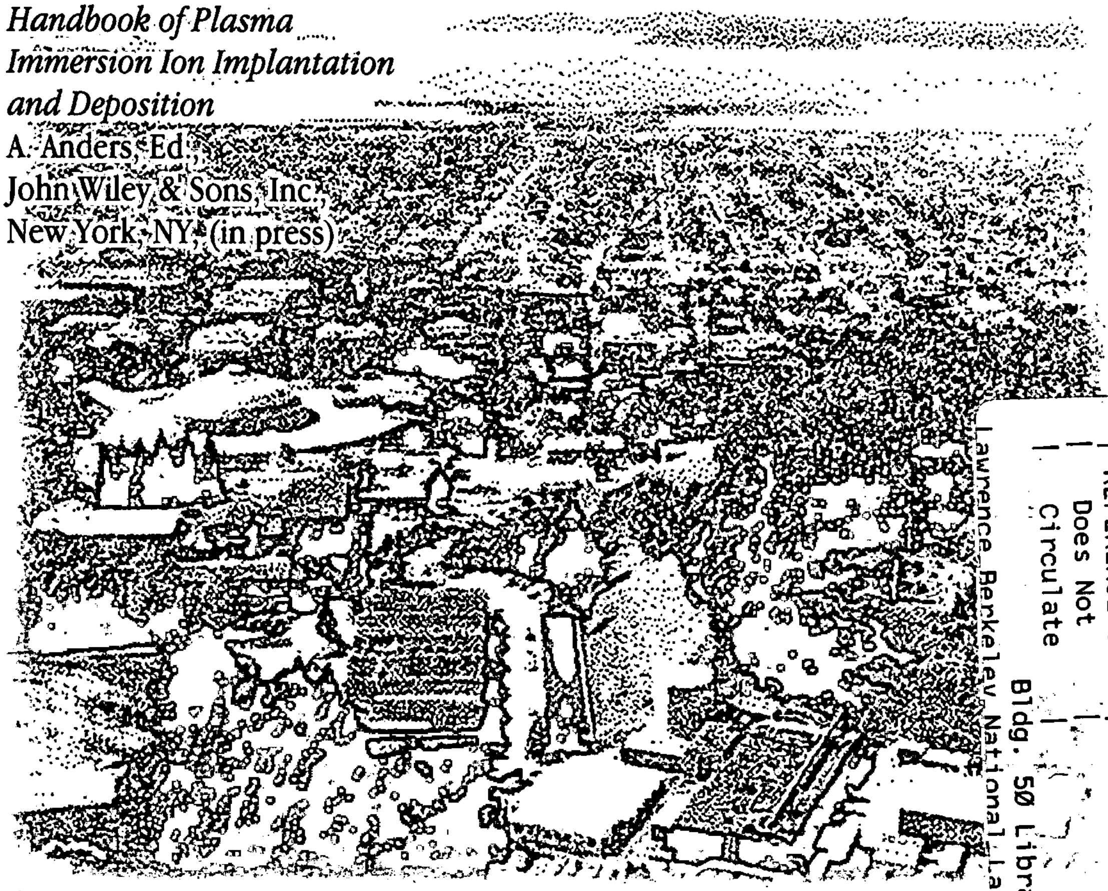

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Amorphous hard carbon for tribological applications in the magnetic storage industry

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10.3. Amorphous hard carbon for tribological applications in the magnetic storage industry

10.3.1. Properties of present hard carbon overcoats on hard disk and sliders

The disk drive industry is one of the fastest growing industries today with an amount of disk drive units shipped per year of about 100 millions in 1997. The storage density for these disk drives is growing at an amazing rate of 60% per year (Murdock et al. 1992). The hard disk typically consists of an aluminum or glass substrate, a nickelphosphate underlayer to provide the required texture to the disk, on top of which a chromium film is grown to provide a seeding layer for the growth of the required crystalline structure of the magnetic layer, which can be, e.g., a CoCrPt alloy. The hard disk is covered by a hard carbon overcoat and a lubricant.

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The slider is typically fabricated from TiC/Al_2O_3 and often also coated with an amorphous hard carbon overcoat. The typical fly height (physical spacing) between the slider and the disk is of the order of 25 nm. To reach the goal of higher storage densities it is necessary to reduce the magnetic spacing (distance between the magnetic layer of the disk and the magnetic element of the slider). This can be done by reducing the thickness of the hard carbon overcoat, but the challenge is to achieve this without compromising the tribological properties of the head disk interface. The hard carbon overcoat material which has dominated the disk drive manufacturing over the last decade is amorphous, hydrogenated carbon (CHx) typically formed by dc or rf sputter deposition using a carbon target in a hydrogen/argon or methane/argon mixture. The properties of these films are summarized, e.g., by Tsai et al. 1988. These films have served well so far, but for thicknesses smaller than about 10 nm they do not protect the disk well enough and lead to disk drive failure. Recently, sputter deposited films containing carbon and nitrogen (CN_x), or carbon, nitrogen, and hydrogen (CN_xH_y) have been used. They have very good properties regarding the interaction between the film and the lubricant, but these films are also limited to a thickness of about 7-10 nm.

Numerous other deposition methods such as variations of the sputter technique (Marchon et al. 1992, Cho et al. 1990, Wang et al. 1996a, Wang at al. 1996b), plasma enhanced CVD (Iechika et al. 1994), or mass selected ion beam deposition (Lempert at al. 1993) of amorphous hard carbon of various kinds (a-C, CH_x, CN_x, CN_xH_y) have been tested for hard disk and slider coatings. Among them, cathodic arc deposited hydrogen-free amorphous carbon films give some of the best results with respect to tribological and wear properties (Gupta and Bhushan 1996, Tsui at al. 1995). Also, this method usually involves pulsed substrate biasing. Therefore, we will describe in the scope of this book as an example of an emerging application the use of cathodic arc deposited carbon films for the head/disk tribology.

10.3.2. The properties of amorphous hard carbon films prepared by cathodic arc deposition using pulsed substrate biasing

Cathodic arc deposited amorphous hard carbon films have been studied by a number of groups in the world over the last two decades. Of critical importance to the application as a hard carbon overcoat of computer hard disks and sliders are the high hardness and high elastic modulus, the inertness to chemical reactions, the high smoothness of the films, good adhesion, and a low coefficient of friction. A detailed overview on the film properties is given in chapter 4.9. Further conditions which are of essential importance to head/disk applications include low particle contamination. Because every macroparticle which is deposited on a disk surface or slider can lead to catastrophic failure of the disk drive it is necessary to apply the best macroparticle filter method (S-filter) which is described in detail in chapter 7.5.

The wear characteristics of cathodic arc deposited amorphous carbon films have been studied by a number of authors. It was generally found that the films show a superior wear behavior compared to sputter deposited CH_x films. Tsui et al (1995) compared cathodic arc deposited films using -100V pulsed substrate biasing to sputtered films of various hydrogen content and found a 250% higher hardness, 152% higher elastic modulus, 50% higher critical load for failure in a scratch test for the cathodic arc deposited films in comparison to the best sputtered films. The coefficient of friction is slightly higher for cathodic arc deposited film but more stable during the wear test. Gupta and Bhushan (1996) did an extensive study to compare cathodic arc deposited films using -100 V pulsed substrate bias with a variety of amorphous carbon films deposited by ion beam deposition, rf-plasma enhanced chemical vapor deposition, and rf sputtering. They measured hardness, elastic modulus, scratch resistance, adhesion, and stress by nanoindentation and microscratching using a nanoindenter. The data were acquired on 400 nm thick films deposited on (100) single-crystal silicon substrates. The nanoindenter was operated at loads from 0.2 to 10 mN, the scratch tests were performed by ramping up the load from 1.5 to 45 mN. The stress was determined from the bending of the substrate before and after coating.

Figures 10.3.2.-1 to 10.3.2.-4 show that the cathodic arc deposited films show the highest value for all the parameters (data taken from Gupta and Bhushan 1996).

Nano-wear tests performed on cathodic arc deposited amorphous hard carbon films of 10 nm thickness deposited on (100) Si wafers were reported by Bhatia et al. 1997. In this case the pulsed bias was varied from -2kV for the first 10% of the deposition process for improved adhesion, and -100V for the remaining 90% of the deposition. A nano-wear test was performed on this film using a point contact microscope. Typical CH_x films show a wear rate of 7.5-25 nm (depending on the hydrogen content) after only 12 cycles and a load of 28μN. For the cathodic arc deposited films a load of 100μN was hardly enough to modify the film surface. The wear depth of 1 nm for 30 cycles indicates that the scratch resistance of this film is superior. Wear depth versus wear cycles for two different loads is plotted in Figure 10.3.2-5. It is interesting to note that the nano-wear test on cathodic arc carbon using 200μN load shows three distinct zones which can be identified as the carbon film, the SiC interface and the Si substrate. The existence of a SiC interface is known from previous TEM investigations.

These wear tests demonstrate the superior properties of cathodic arc deposited films using pulsed substrate bias. The following chapter describes the results of a number of applications of cathodic arc films to the head/disk tribology.

10.3.3. Cathodic arc deposited films for tribological applications in the magnetic storage industry

10.3.3.1. The coating of sliders

Recently, manufacturers have started to provide sliders which are coated with various carbon films for improved wear performance and reduced corrosion. Typically, these are sputter deposited CH_x or CH_xN_y thin films. Two new, different surface modifications of slider surfaces were tested and described by Komvopoulos et al. 1994, Anders at al. 1997, and Bhatia et al. 1997, applying cathodic arc deposition using pulsed substrate bias.

Komvopoulos et a. 1994 describe cathodic arc deposition combined with a high voltage pulsed biasing of -2 kV of the substrate to modify the surfaces of two-rail sliders consisting of 70% Al_2O_3 and 30% TiC. The pulsed biasing leads to the typical superposition of deposition (between bias pulses) and ion implantation (during bias pulses) for the PIIID process. A total dose of 2×10^{16} ions/cm^2 with 30% implantation phase and 70% deposition phase was applied to the sliders using carbon, titanium, and silver ions. The implantation/deposition process was simulated using the Monte Carlo code T-DYN 4.0 (Biersack et al. 1991). This code is well-suited to describe the PIIID process of condensing species such as metals or carbon because it considers the alternating implantation and deposition phases typical for this process as well as modification of the substrate due to sputtering, implantation and deposition. Figure 10.3.3.1.-1 shows the calculated depths profiles for this surface modification process for the three different implanted/deposited species. As mentioned before, the total ion energy E_i is given by $E_i = E_0 + ZeV$ where V is the bias voltage, e is the elementary charge, and Z the mean ion charge state which is 1 for C, 2.05 for Ti, and 1.77 for Ag (Brown et al. 1988). The "natural" ion energy E_0 corresponds to a directed ion velocity of about 10^4 m/s and is for C ions about 20 eV, for Ti about 80 eV, and for Ag about 180 eV.

The modified heads were tested by continuous sliding against unlubricated CH_x coated hard disks with a low sliding speed of 3 cm/s and a normal load of 0.16 N in air of 40% humidity and 27°C. The coefficient of friction of unmodified heads in comparison to PIIID modified heads is shown in figure 10.3.3.1.-2. At the beginning the coefficient of friction is about 0.2 and comparable for unmodified and modified sliders. For the unmodified slider the coefficient of friction increases drastically during the first 1000 revolutions and then remains very high (about 1.3) for the rest of the testing. The modified sliders show a very stable and low coefficient of friction over the entire testing. This testing demonstrates that a surface modification using PIIID can drastically improve the tribological behavior of sliders.

In another experiment a thin coating (2 nm) of cathodic arc hard carbon was applied to sliders of 70% Al_2O_3 and 30% TiC (Bhatia et al. 1997, Anders et al. 1997). For the first 10% of the deposition time a high pulsed bias of -2 kV was applied to improve the adhesion of the film whereas a low bias of -100V was applied for the rest of the coating to form a film with a high sp^3 content. The wear durability of the sliders with and without cathodic arc carbon coatings was compared in Contact Start Stop (CSS) tests. They were performed on mechanically textured disks coated with 15 nm CH_x and lubricated with 1 nm perfluoropolyether, with a normal load of the sliders 60 mN. The average friction force and the touch down velocity were recorded for 100,000 cycles. Figures 10.3.3.1.-3 and 10.3.3.1.-4 show the average friction force and the touch down velocity as functions of the number of cycles. While the uncoated sliders failed after 7500 cycles, the sliders coated with cathodic arc carbon completed 100,000 CSS cycles without failure. The uncoated sliders showed debris on the rails of the slider when examined under a microscope, and there was a visible wear track on the surface of the disk. The coated slider rails contained minimal debris, and there was no visible wear track on the surface of the disk. The stiction increased from 17 mN initially to 32 mN after 100,000 cycles. All these experiments show that the cathodic arc deposited amorphous hard carbon can improve the tribological behavior of sliders considerably.

10.3.3.2. The coating of disks

The coating of hard disks puts stronger requirements on the coating apparatus than slider coatings because the disk surface is much larger, and better film homogeneity and cleanliness is required. Not much has been reported in the literature on the coatings of hard disks by cathodic arc deposition using pulsed substrate bias. Bhatia et al. 1997 and Anders et al. 1997 report on the coating of disks with cathodic arc amorphous hard carbon of 10 nm thickness. The disks were lubricated with 1.5 nm of perfluoropolyether. Wear tests using sliders in contact with the disk at a speed of 13 m/s were performed with a normal load on the sliders of 0.4 mN. The worn volume at the face of the slider was measured using an Atomic Force Microscope (AFM) and is shown in figure 10.3.3.2.-1 as a function of time, comparing the cathodic arc carbon coated disk with a disk coated with a 10 nm CH_x film. The worn volume of the slider in contact with the cathodic arc coated disk is a factor of almost 20 lower than the worn volume of the slider in contact with the sputter coated disk. This suggests a superior performance of cathodic arc carbon for contact recording applications.

10.3.3.3. Requirement on the filtered cathodic arc source for industrial application in the disk drive industry

Although cathodic arc deposition is widely used in industry for the deposition of hard and decorative coatings such as TiN, the film quality of cathodic arc amorphous hard carbon films has not been sufficient for applications in the microelectronics and disk drive industry. Recently, a small number of companies have started to work on the commercialization of cathodic arc sources for high-tech applications. The successful industrial application of filtered cathodic arc sources to the disk driver industry requires a source which complies with industrial standards regarding maintenance, durability, deposition rate, particle contamination, homogeneity and repeatability of film properties. Ideally, the filtered cathodic arc source would be able to simply replace the present sputter sources with respect to the above mentioned parameters as well as footprint.

The most important aspect is macroparticle contamination. This demands the use of the best filter methods available. High deposition rate such as 2-5 nm/s are required to replace the existing sputter sources. Also film homogeneity with variations in the thickness less of than 5-10% over a typical disk diameter of about 10 cm is necessary. The source should run for many hours without maintenance, be reliable and robust in design. The future of cathodic arc deposited carbon films in the disk drive industry depends on the availability of high quality deposition equipment.

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Captions for Figures

Figure 10.3.2.-1: Hardness of amorphous carbon films deposited by cathodic arc deposition, ion beam deposition, rf-plasma enhanced chemical vapor deposition, and rf sputtering. Data taken from Gupta and Bhushan 1996.

Figure 10.3.2.-2: Elastic modulus of amorphous carbon films deposited by cathodic arc deposition, ion beam deposition, rf-plasma enhanced chemical vapor deposition, and rf sputtering. Data taken from Gupta and Bhushan 1996.

Figure 10.3.2.-3: Critical load for scratch test of amorphous carbon films deposited by cathodic arc deposition, ion beam deposition, rf-plasma enhanced chemical vapor deposition, and rf sputtering. Data taken from Gupta and Bhushan 1996.

Figure 10.3.2.-4: Compressive stress of amorphous carbon films deposited by cathodic arc deposition, ion beam deposition, rf-plasma enhanced chemical vapor deposition, and rf sputtering. Data taken from Gupta and Bhushan 1996.

Figure 10.3.2.-5: Wear depth versus wear cycles for two different loads on cathodic arc deposited amorphous carbon film using pulsed substrate bias.

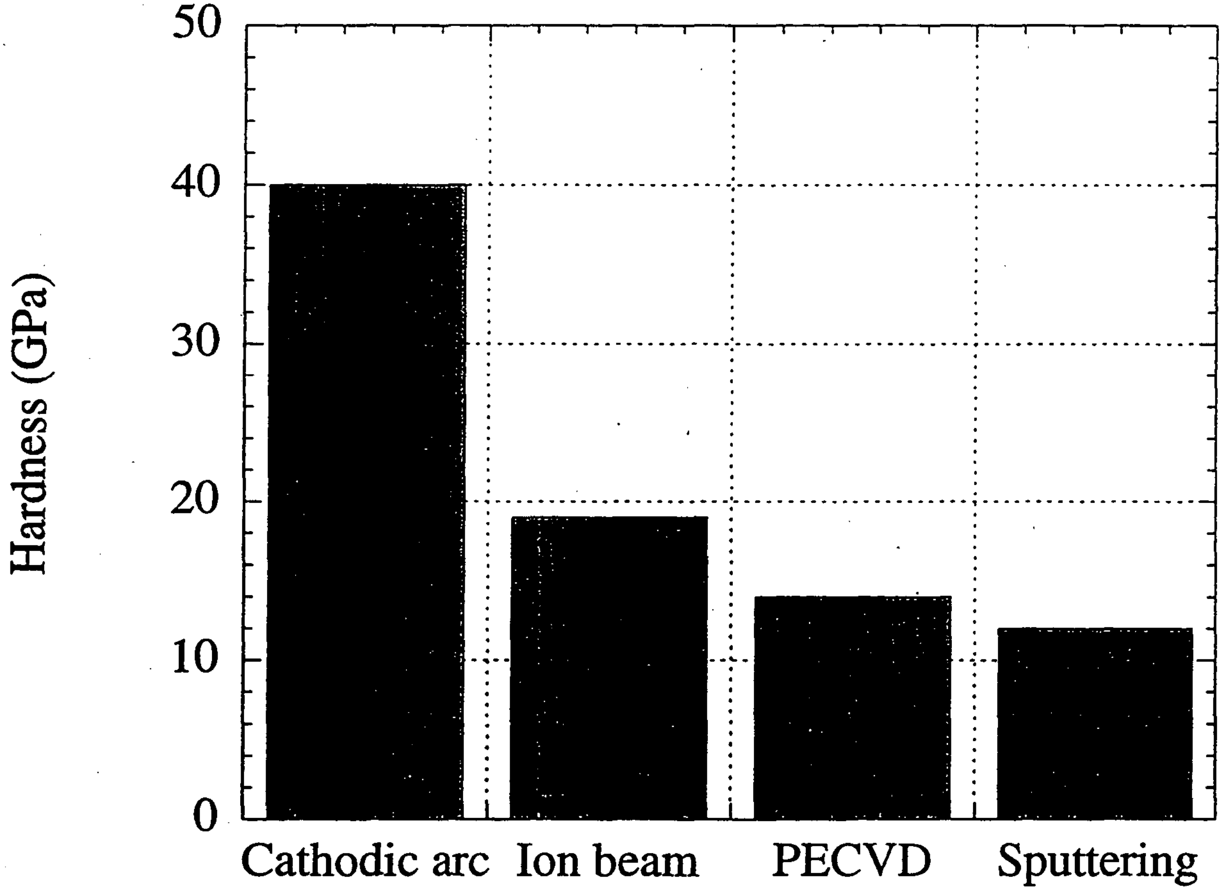
Figure 10.3.3.1.-1: Simulated depth profile for immersion ion implantation of C, Ti, and Ag, using -2 kV bias with a duty cycle of 30% into a slider consisting of 70% Al_2O_3 and 30% TiC. Total dose $2x10^{16}$ ions/cm^2.

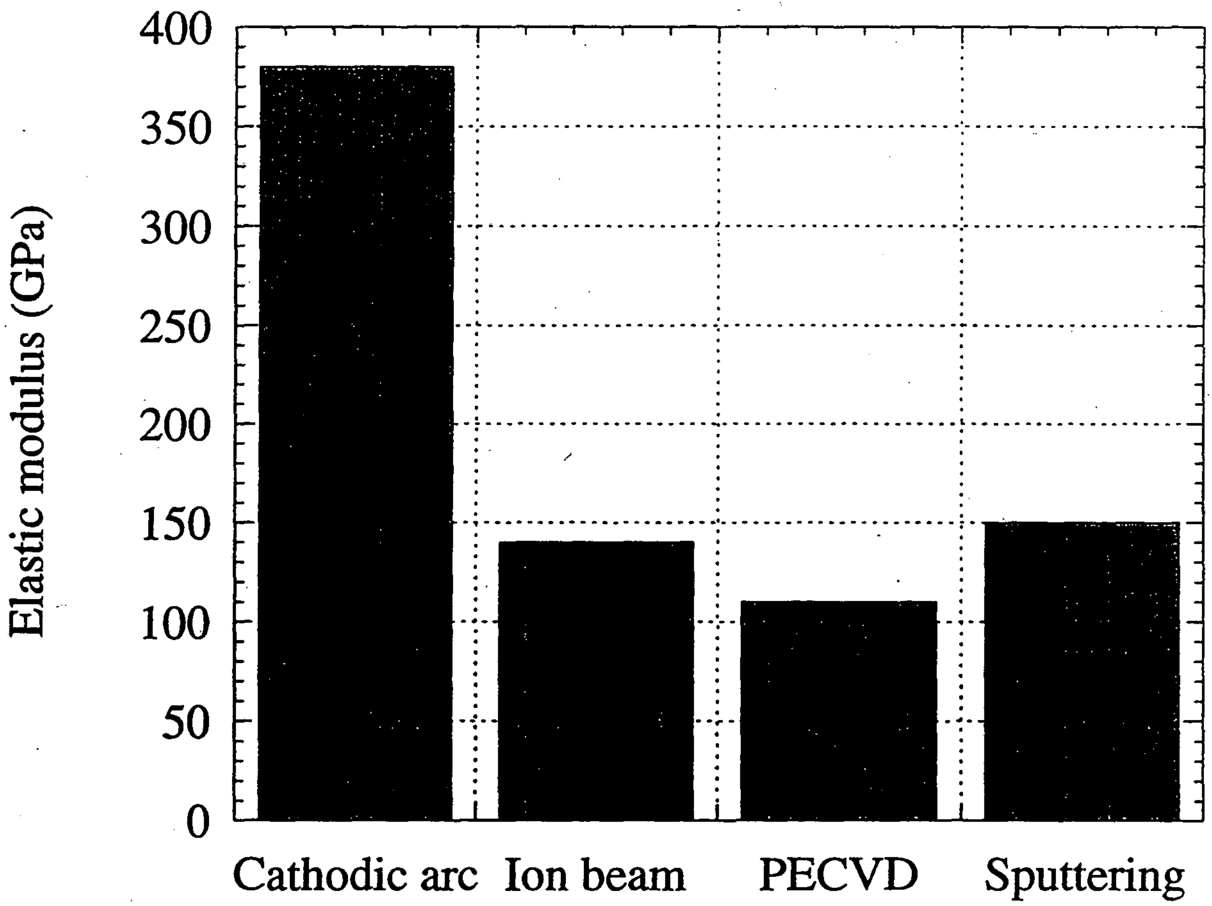
Figure 10.3.3.1.-2: Coefficient of friction as a function of the number of revolutions during continuous sliding test for unmodified and PIIID modified sliders.

Figure 10.3.3.1.-3: Average friction force as a function of number of cycles for the uncoated and coated slider.

Figure 10.3.3.1.-4: Touch down velocity as a function of number of cycles for the uncoated and coated slider.

Figure 10.3.3.2.-1: Worn volume at the longitudinal facet of the slider as a function of time for a cathodic arc coated and sputter coated disks.


Hardness (GPa)
50
40
30
20
10
0
Cathodic arc
Ion beam
PECVD
Sputtering


Elastic modulus (GPa)
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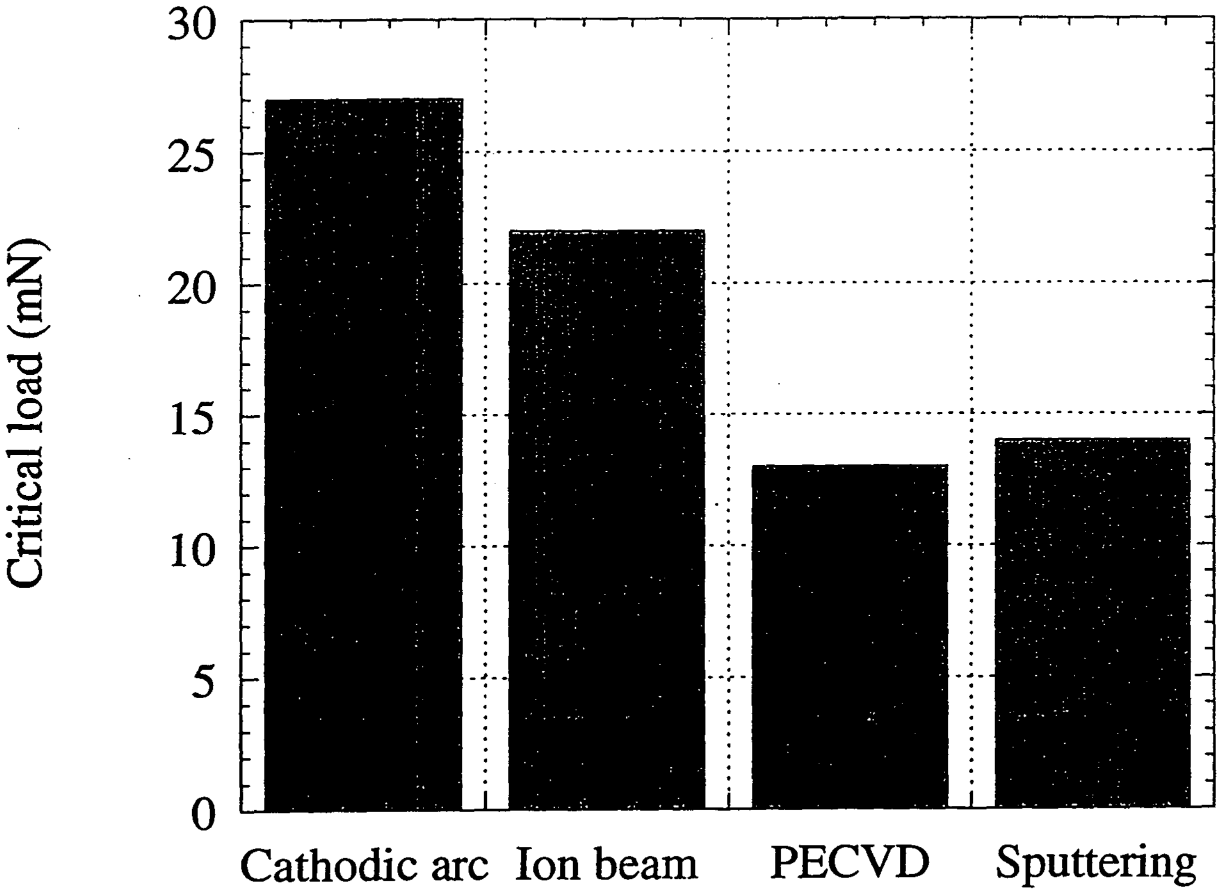
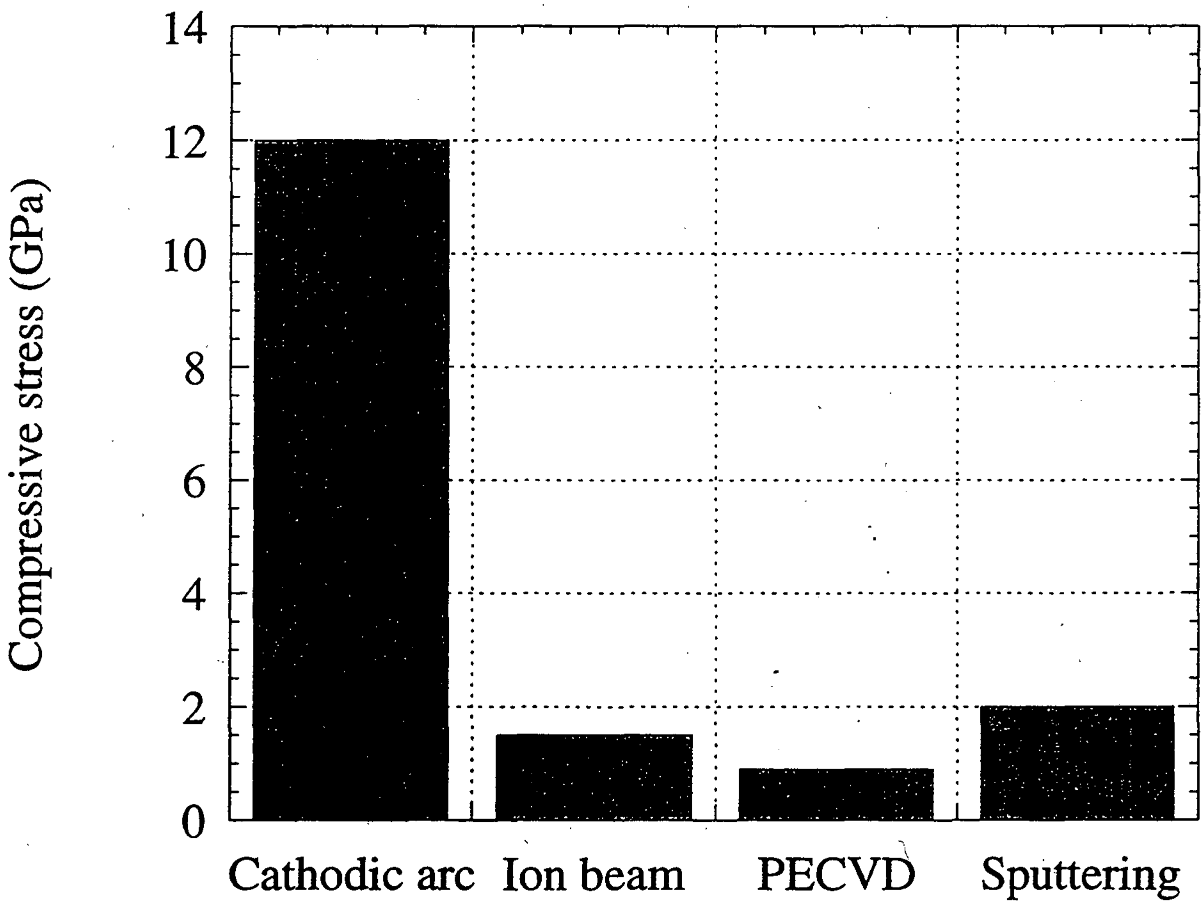
350
300
250
200
150
100
50
0
Cathodic arc
Ion beam
PECVD
Sputtering



Critical load (mN)
30
25
20
15
10
5
0
Cathodic arc
Ion beam
PECVD
Sputtering


Compressive stress (GPa)
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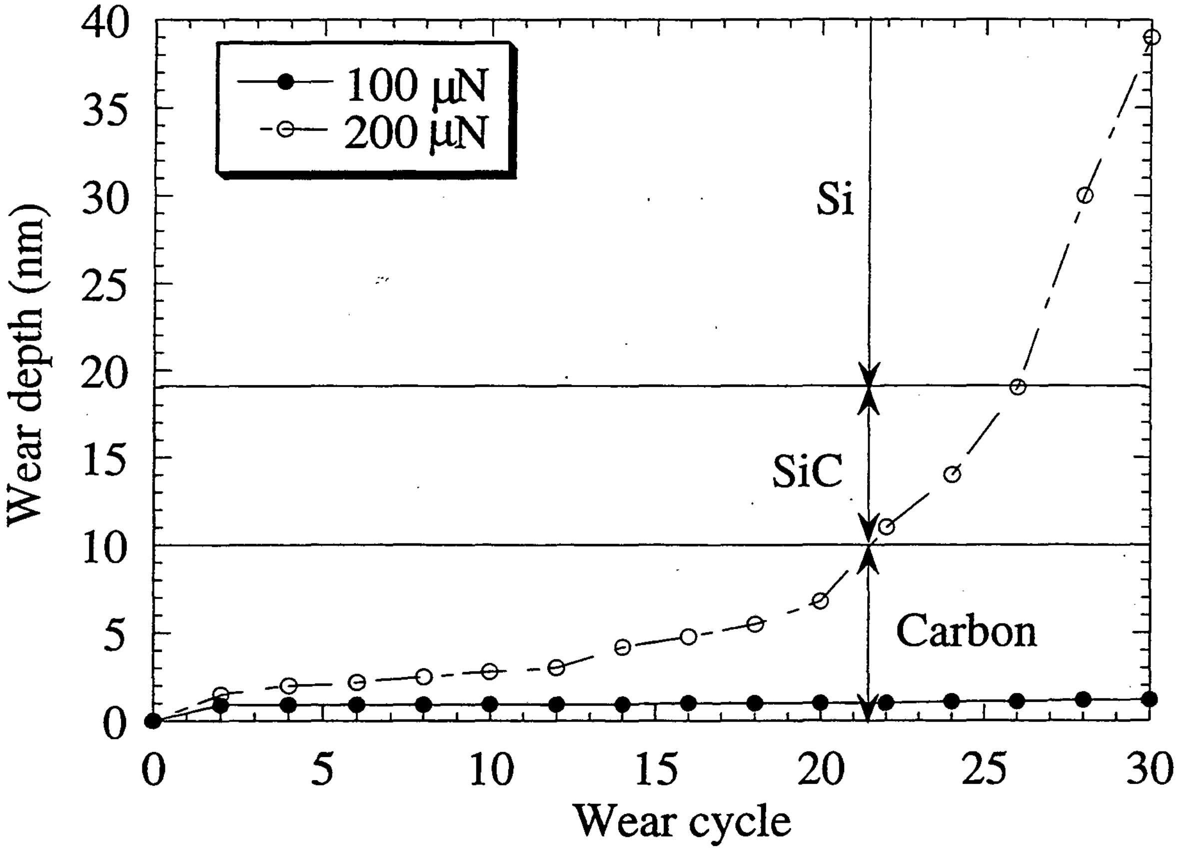
2
4
6
8
10
12
14
Cathodic arc
Ion beam
PECVD
Sputtering


Wear depth (nm)
Wear cycle
100 µN
200 µN
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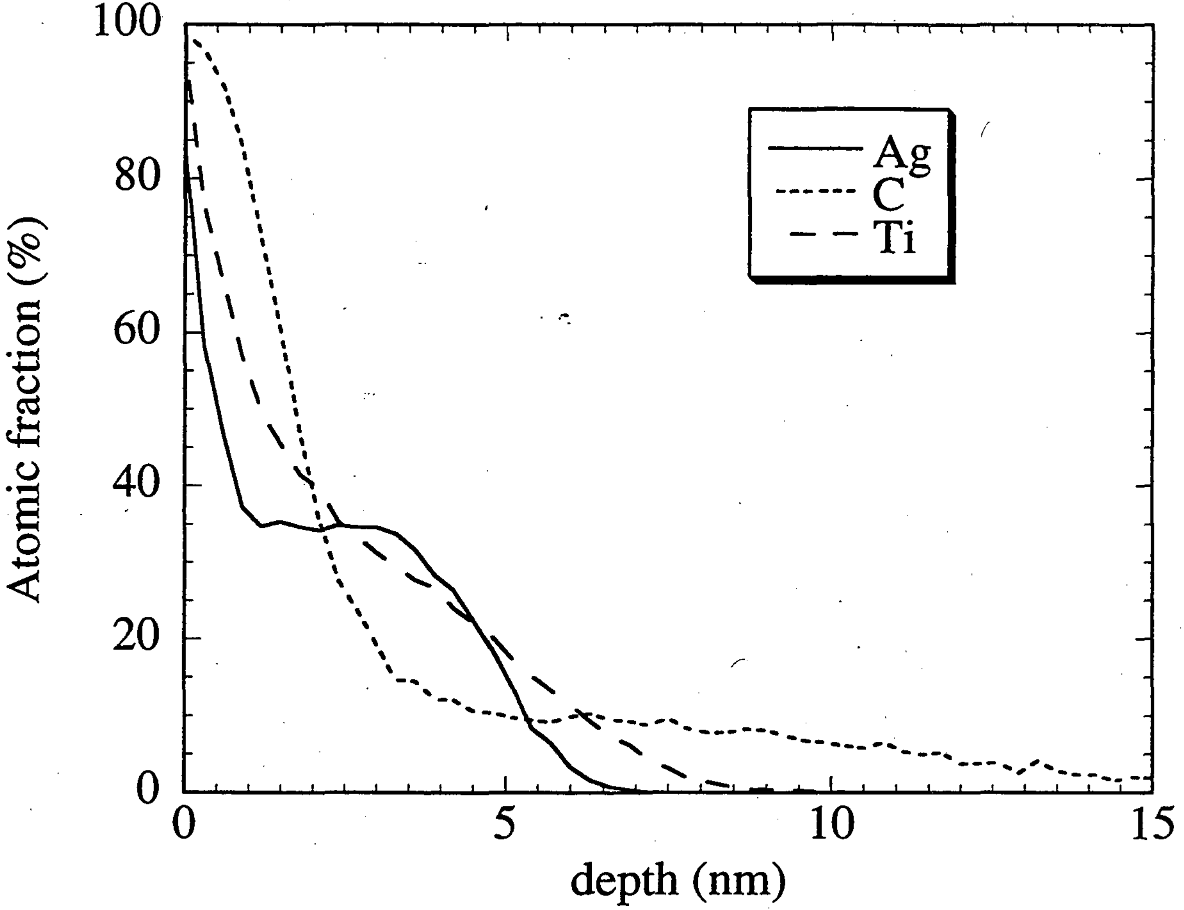
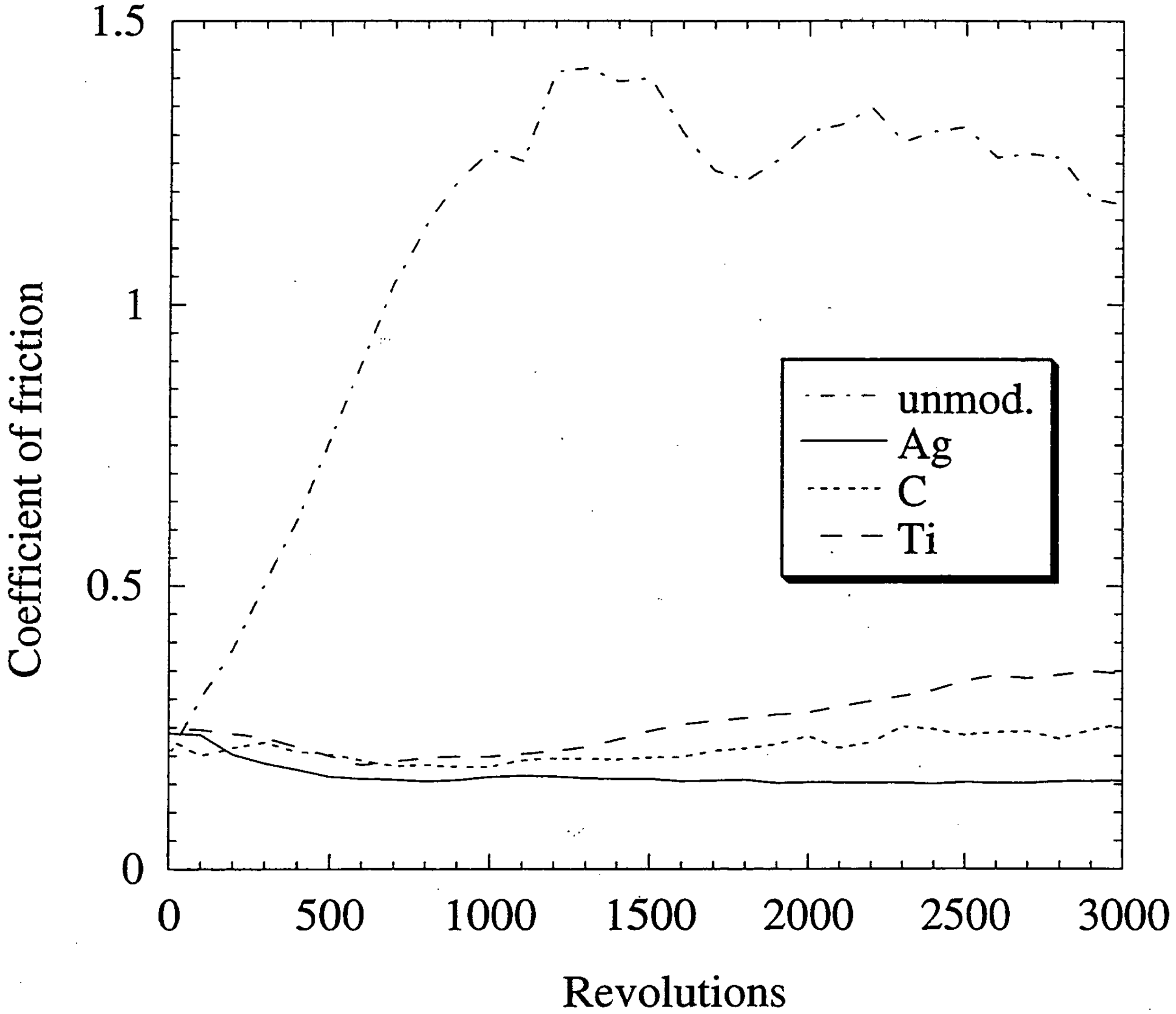
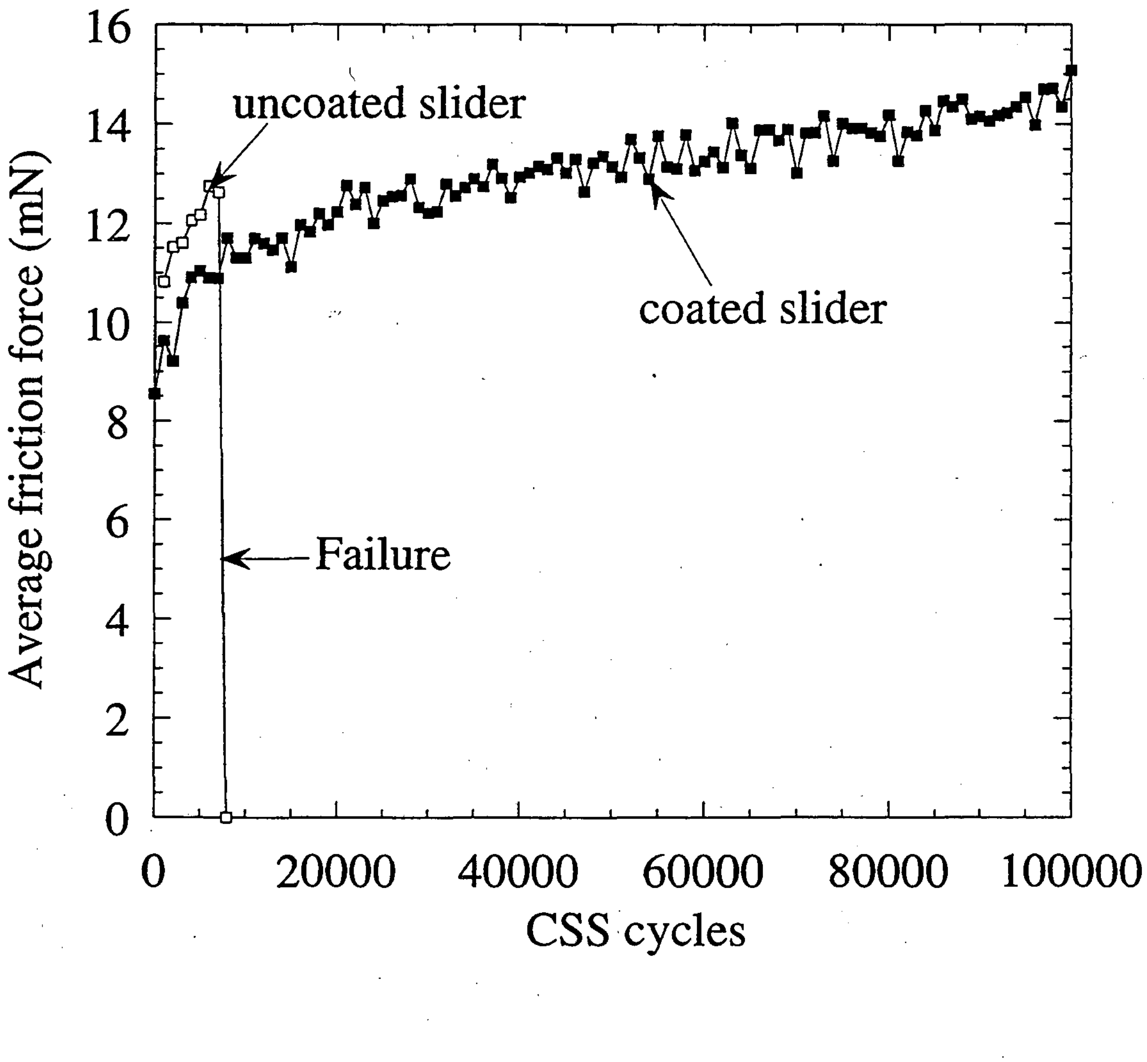
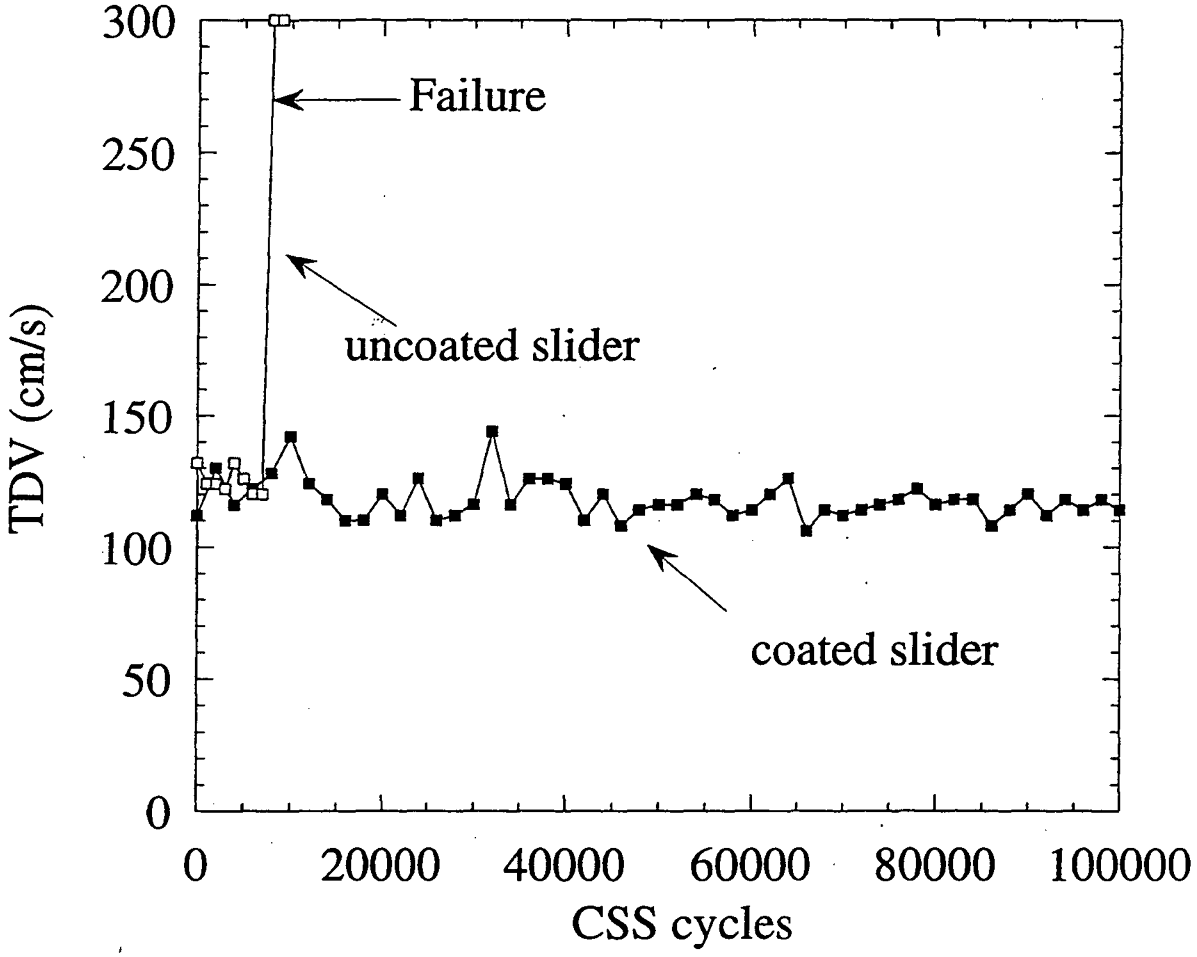
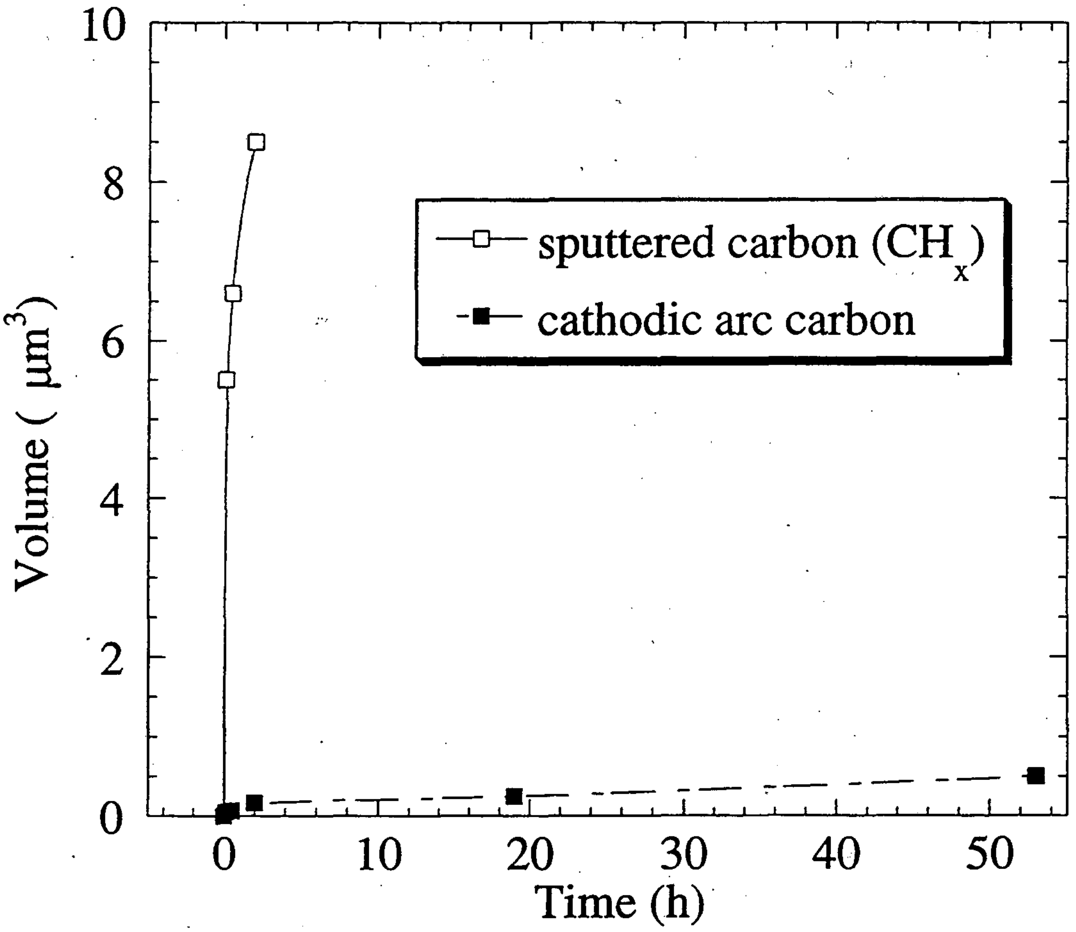
SiC
Carbon
0
5
10
15
20
25
30
35
40
0
5
10
15
20
25
30


Atomic fraction (%)
100
80
60
40
20
0
0
5
10
15
depth (nm)
Ag
C
Ti


1.5
1
0.5
0
Coefficient of friction
0
500
1000
1500
2000
2500
3000
Revolutions
unmod.
Ag
C
Ti


uncoated slider
coated slider
Failure
Average friction force (mN)
CSS cycles
0
2
4
6
8
10
12
14
16
0
20000
40000
60000
80000
100000


300
250
200
150
100
50
0
TDV (cm/s)
0
20000
40000
60000
80000
100000
CSS cycles
Failure
uncoated slider
coated slider


Volume (μm^3)
10
8
6
4
2
0
-5
0
10
20
30
40
50
Time (h)
sputtered carbon (CH_x)
cathodic arc carbon

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