PECVD Carbon Overcoat for Magnetic Media

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1. ABSTRACT

Different modes of carbon deposition are described and the basic properties of these layers have been investigated. The paper starts with the description of sputtered layers as they are presently used for magnetic media overcoats. By adding substrate bias and doping of the sputter gas graphitic, polymerlike or diamondlike carbon films can be prepared. Crucial roles play the presence of hydrogen in the sputtergas and the Ar-ion bombardment for the achievement of hard and dense films.

The second part of the paper describes experimental set-ups to perform the carbon overcoat deposition by PECVD. Concepts of both process - single disk static and pallet type dynamic coating - are presented. They are proposed as devices for the deposition of the recently required ultrathin (< 10 nm) hard carbon layers as protection top coats on magnetic disks as well as metal evaporated tapes.

2. INTRODUCTION

Driven by the steady demand for ever higher data storage capacities one is searching for all the factors limiting the achievable storage densities and is trying to eliminate them.

In magnetic recording the linear density D_{50} is given by the following equation:

$$D_{50} \approx 1 / \left[g^2 + 4(d+a)(d+a+\delta)\right]^{1/2} \qquad (1)$$

with
g = magnetic head gap length
d = head medium spacing
δ = recording layer thickness
a = $2 \cdot \delta \cdot M_r/H_c$ = transition length
M_r = remanent magnetization
H_c = media coercivity

The typical layer structure applied for longitudinal recording on hard disks is shown in figure 1.

According to equation (1) high recording densities are achieved by increase of coercivity and decrease of all other factors. The head medium spacing d is composed of the protective carbon overcoat/lubrication layer thickness t and the head flying height h: d = t + h. Therefore a gain of recording density can be achieved by reduction of both lengths t and h. The influence of the reduction of the carbon layer thickness t is demonstrated in figure 2. The D_{50} value has been measured on a flexible disk with the recording head in contact with the medium, therefore eliminating the influence h of the flying height [1]. The D_{50} value decreases linearly with increase of carbon thickness, as it is predicted from equation (1), calculating D_{50} as function of d.

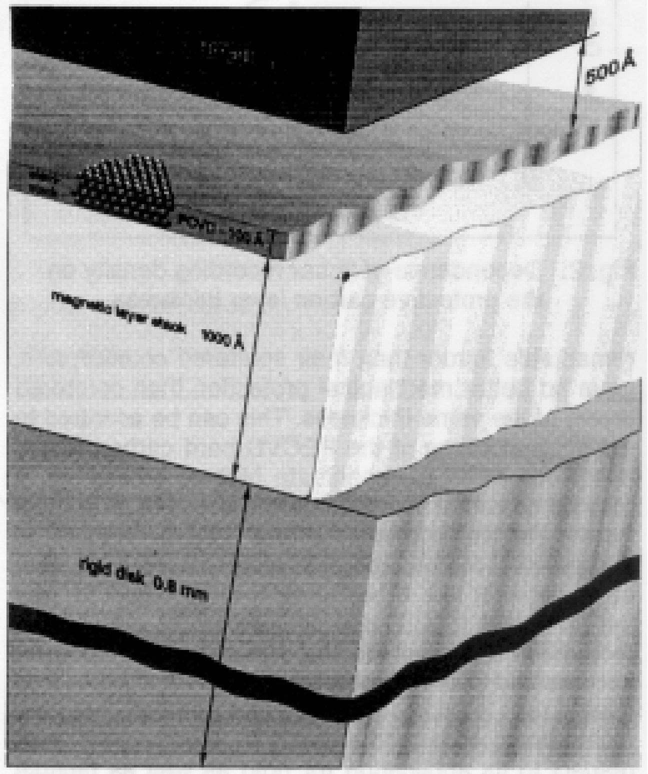

Fig. 1: Layer structure for longitudinal recording

One reason for considering the PECVD technique as an alternative top-coat of disks is therefore the development of layers being thinner than 10 nm, a thickness range where sputtered layers do not meet the demands of sufficient wear protection. An early hint on the though possible protective function of those "ultrathin" layers on even relatively soft substrates has been the finding [2] that a 5 nm thick siliconoxicarbide PECVD layer on aluminum (80 nm) coated plastic material endowed pertinent front surface mirrors a remarkably better resistance against cleaning procedures than a 60 nm thick one did. On the other hand, 40 nm thick hard hydrogenated carbon PECVD

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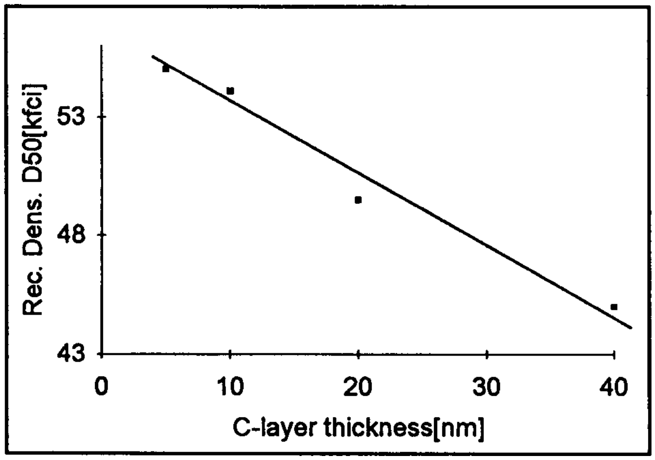

Fig. 2: Dependence of linear recording density on the protective carbon layer thickness

layers on data storage media of several provenances, in spite of being remarkably harder than their sputtered counterparts, gave no better mechanical protection than sputtered layers of the same thickness. This can be ascribed to the internal stress of the PECVD hard carbon layers being one order of magnitude higher. Adding up, it may be assumed that the internal stress of a top coat looses its importance for the tribomechanics at thicknesses below approximately 10 nm and that other aspects like tribochemical ones begin to play the dominant role. These considerations evoked the motivation to further develop the classical device for ion assisted plasma enhanced processes. Here it is used for making hard hydrogenated carbon (sometimes called "diamond" - like carbon) with respect to its application for rigid as well as flexible magnetic data storage media.The challenge for an optimized overcoat is therefore to be thinnest and to exhibit at the same time the appropriate structural, tribomechanical, and tribochemical properties to fly the head at low heights and withstand the head contacts during the start/stop procedures.

3. SPUTTERING TECHNOLOGY

The standard deposition process in the magnetic disk manufacturing industry is sputtering. In most cases a DC-magnetron is used employing a carbon target. The deposition of the thin film layer stack is performed e.g. in a single disk sputter system as shown in figure 3. The disks are indexed from station to station. The eleven process stations are equipped with heaters, magnetrons or other process tools. Deposition of the films is performed in static mode simultaneously on both sides of the disks by circular DC-magnetron cathodes [3].
The layer thickness uniformity over the disk area is ± 4 %. The carbon sputtering rate is a factor of 8 slower than the rate for metal layers such as Cr or Co-alloy. The relation between the applied power and deposition rate is linear with a rate of 1 nm/s at 1.2 kW sputter power. Key characteristics of a good carbon layer are:

- amorphous state even in the nanometer scale
- low friction and low wear

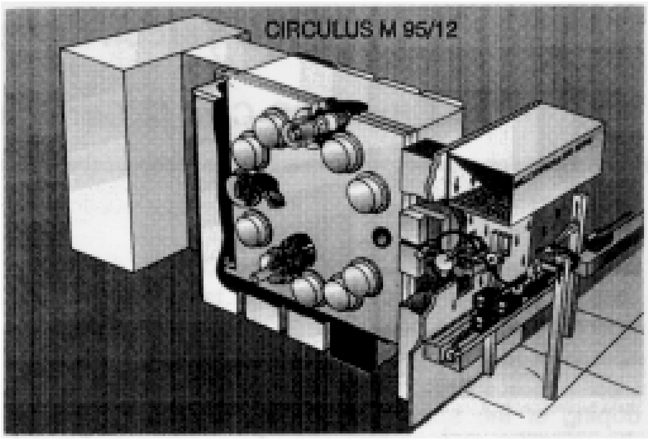

Fig. 3: Single disk sputtering system with 11 process stations

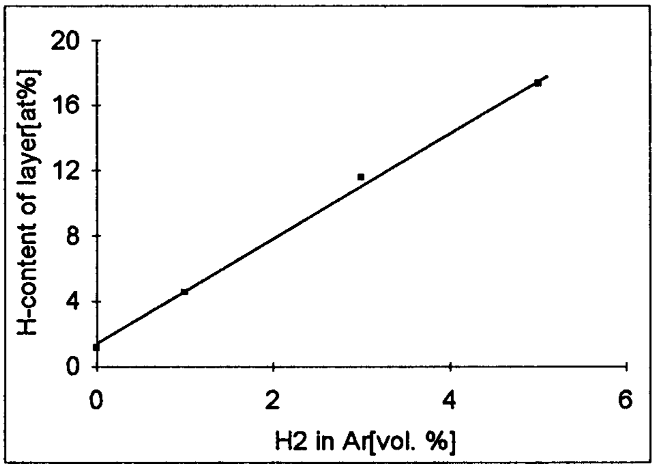

Fig. 4: Dependence of H-content in the layer on the doping of the sputtergas

- good adhesion of the lubricant

Often the carbon is sputtered in an Ar/H_2 gas. Figure 4 shows the relation between the atomic hydrogen content in the layer and the Ar/H_2 gas mixture of the sputter gas. Hydrogen doping turns out to be a simple reactive sputter process: the incorporated hydrogen is proportional to the gas doping and inverse proportional to the sputter rate [4].

Figure 5 shows the SEM cross section of a highly doped thick carbon layer exhibiting a columnar structure. The typical mass density of these layers is 1.6 - 1.8 g/cm^3 (for comparison: graphite: 2.265 g/cm^3, diamond: 3.515 g/cm^3) and the hardness is in the range of 14-17.000 N/mm^2. The incorporation of hydrogen into the layer can easily be detected by measurement of the electrical resistivity with specific resistivities of 1Ωcm for undoped films and 10^3 to 10^5 Ωcm for highly doped ones. The infrared absorption spectra exhibit the typical C-H stretching bonds. The Raman spectrum consists of two broad structures at 1550 cm^{-1} (G-peak) and 1350 cm^{-1} (D-peak). Especially the D(Disorder)-peak gives information on the short range ordering and an ideal amorphous C-layer exhibits no D-peak [5].

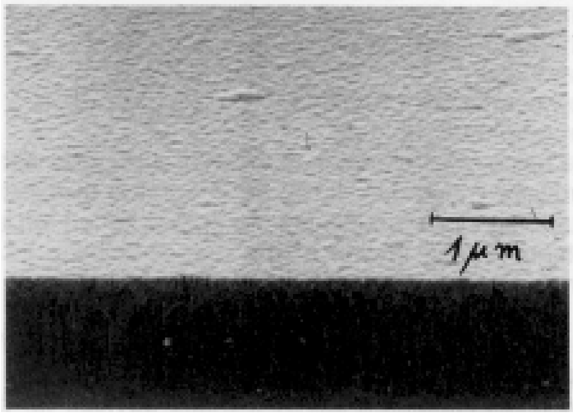

Fig. 5: SEM cross section of a thick hydrogenated sputtered carbon layer

The properties of the carbon changes dramatically if the layer is bombarded by energetic ions during growth.
In magnetron sputtering the substrate can easily be biased to voltages of up to - 500 V.

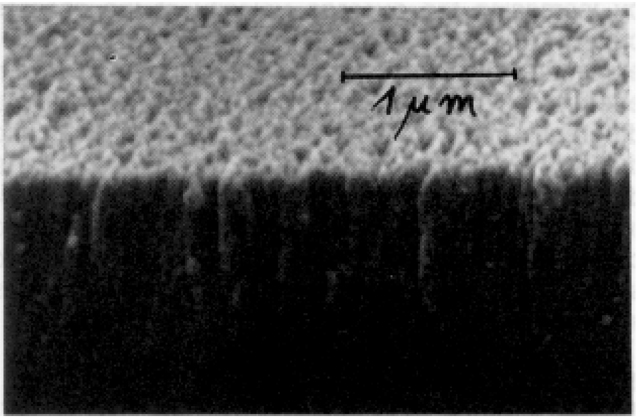

Fig. 6: SEM cross section of a sputtered DC-biased film

Figure 6 shows the SEM cross section of a DC-biased film (-400V, 2.5 µbar). The carbon is powderlike with a low mass density of 1.43 g/cm^3 and a low hardness of 5000-7500 N/mm^2. The reverse occurs in the presence of hydrogen. The chemical etching of graphitic parts in the sputtered layer is synergetically enhanced by a simultaneous Ar-ion bombardment [6] transfering the structure into the diamondlike version. The SEM-cross section reveals a structureless, smooth film. The mass density amounts to 2.2 g/cm^3 and the hardness to 24500 N/mm^2. Unfortunately these dense films suffer from high internal stresses and thick layers tend to delaminate [7].
Very similar results both for non- and hydrogenated films are obtained, if RF-bias is used instead of DC-bias. For the hydrogenated film a maximum of hardness and density can be found as function of the RF-power. Unfortunately also these films suffer from high stress. Stress reduction can be achieved by increase of the sputter pressure and figure 7 shows the SEM-picture of such a film. The film has been prepared under presence of 5 % hydrogen in the sputter gas with a total pressure of 13 µbar. The applied RF-bias power was 50 W. The film is also structureless as the one prepared under low pressure but the mass density is reduced to 1.59 g/cm^3, being therefore comparable to the density of sputtered films.

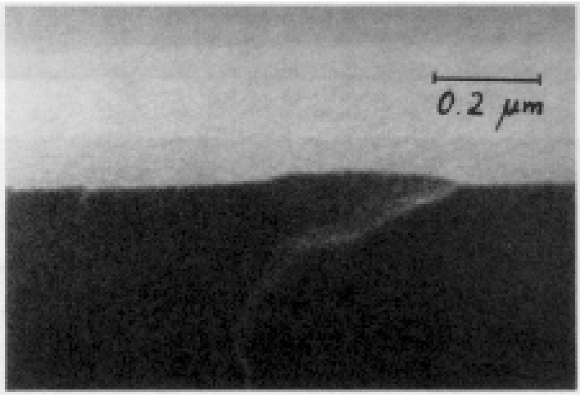

Fig. 7: SEM cross section of a sputtered RF-biased film with hydrogen doping of the sputtergas

Substitution of hydrogen by a hydrocarbon gas like C_2H_2 results in a drastic increase of the carbon deposition rate, since now the deposition is a result of both processes, sputtering and PECVD. The increase of rate is linear in the C_2H_2 flow as shown in figure 8, but the film tends to get softer with a considerable reduction of the density (ρ = 1.43 g/cm^3 H_v = 7500 N/mm^2). In a similar fashion as discussed above for hydrogen a substrate bias is required to make the films hard and dense (ρ = 2.29 g/cm^3, H_v = 24.400 N/mm^2). Figure 9 shows the corresponding SEM pictures for both cases.

The conclusion from the above data is that the presence of hydrogen - either by H_2 or hydrocarbon gas - and the Ar-ion bombardment of the growing film greatly determine the properties of the deposited carbon films. This necessity of film biasing decides therefore the experimental set-up for the CVD-carbon deposition.

4. PECVD-CARBON

The plasma enhanced chemical vapour deposition (PECVD) is a process far away from thermal equilibrium of the gas. The molecules from a gaseous source are excited and fragmented in a low pressure gas discharge. The plasma assistance allows to deposit films at temperatures much lower than in thermal equilibrium CVD. Metallic, semiconductive and dielectric layers as SiN films in the microelectronics can be deposited. The deposition of diamondlike carbon films (or i: C-H) has a long tradition especially as hard, scratch resistant, and antireflective layers in IR-optics.
The attractive features of these diamondlike carbon films are:
- chemical inertness
- hardness
- low coefficient of friction
- amourphous structure

The basic requirement is to develop a process with a hardware

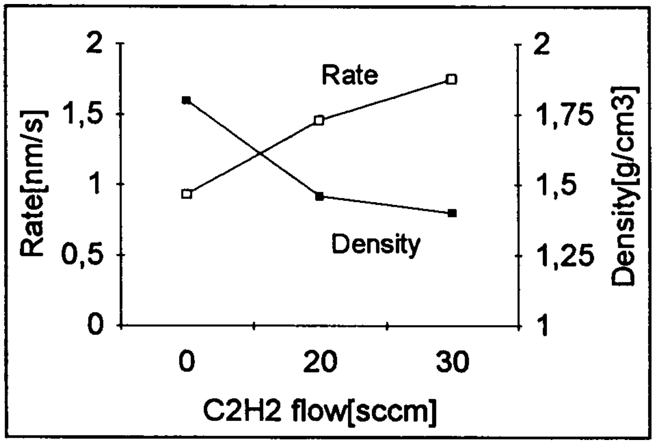

Fig. 8: Carbon deposition rate versus C_2H_2 flow

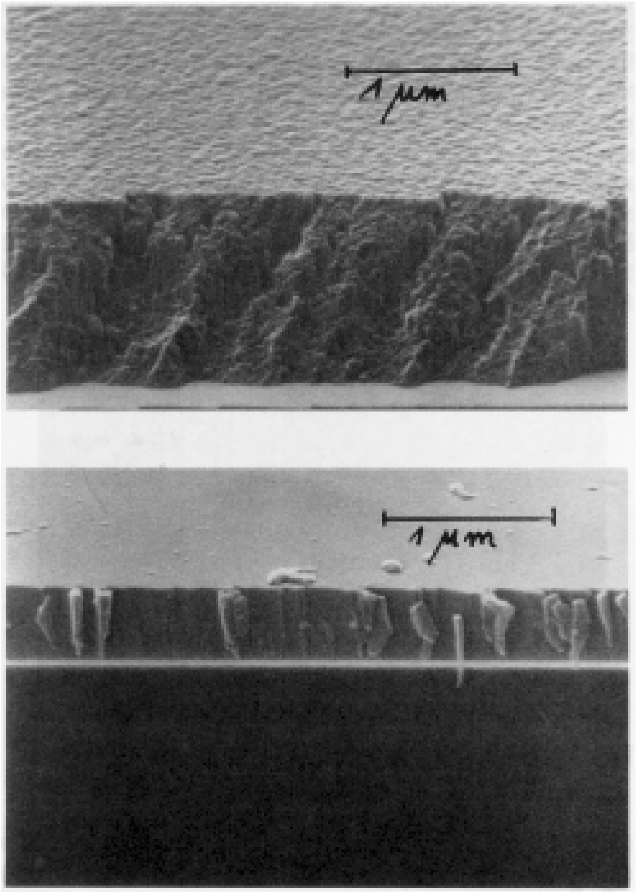

Fig. 9: SEM cross sections of C_2H_2 - doped films.
Top: without bias
Bottom: with RF-bias of 150 W

which can easily be integrated in existing sputtering system concepts. As shown above ion assistance during growth of the non-conducting i:C-H film is a prerequisite to achieve diamondlike films.

4.1 Use of asymmetric glow discharges for PECVD-deposition of hard carbon

The basic concept underlying many devices for depositing hard carbon layers is the asymmetric rf-discharge between electrodes of unequal (effective) surface areas. One of the electrodes is connected via a coupling capacitor, whereas the other one may be connected directly to the rf-power supply. In general the current to the smaller electrode is, with respect to the current to the larger one, only partly balanced out by increasing the charge density in front of the smaller one. The other part is balanced by increasing the average velocity of the charges crossing the dark space gap in front of the smaller electrode. This acceleration, which can lead to ion energies of several hundred eV, is due to the large difference of the mobilities of electrons and ions and due to the fact that the circuit is not able to carry a direct current. Therefore the instant swamp of electrons to the smaller electrode pushes down the so called rf-bias potential of the smaller electrode to such a degree that the average flux of the, at this stage, fast ions is equal to that of the electrons.

4.2 Static deposition mode

The most simple approach uses an asymmetric RF-discharge in which the disks (being the smaller electrode) are on cathodic potential. This concept is most suitable for single disk coating machines. The small coating chamber as shown in figure 10 has been built to fit into the sputter system of fig. 3.

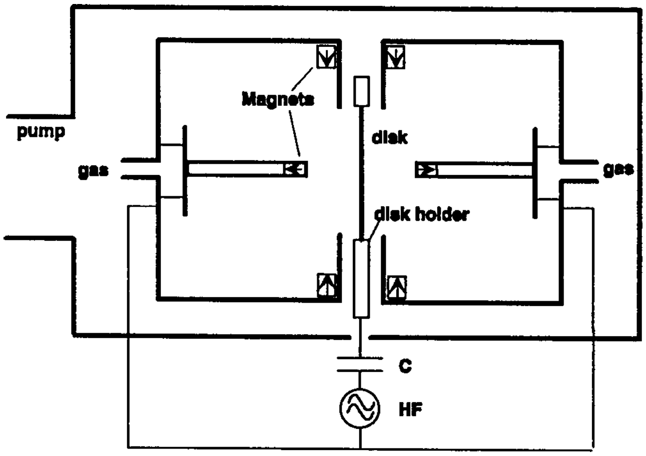

Fig. 10: Small volume CVD-chamber for single disk coating

The gas is fed symmetrically into the small volume chambers on both sides of the metallic disk. The disk is powered via the disk holder by a RF-power supply with an intermediate impedance matching network. The blocking capacitor C serves for DC-decoupling of the disk holder. Since the disk area A_p is small compared to the chamber area A_c the disk is charged to a negative DC-bias voltage, which gives the required Ar-ion bombardment of the growing film.

To reduce losses of the electrons and to confine the plasma to the disk area an outer ring and a central pole of permanent magnets were installed, which results in a magnetic field parallel to the disk surface. Then a stable operation of the source

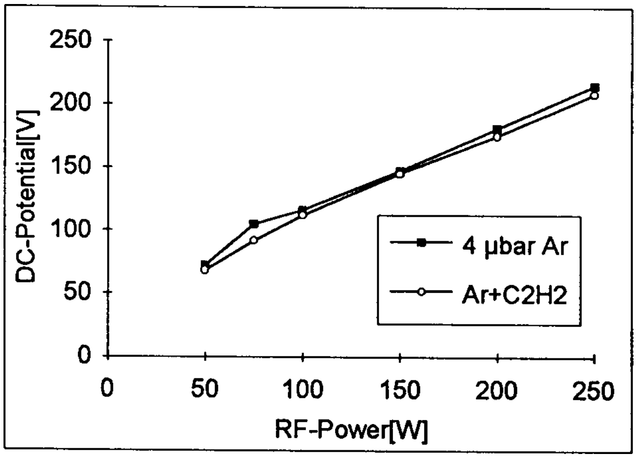

Fig. 11: DC-substrate bias voltage versus the applied RF-power

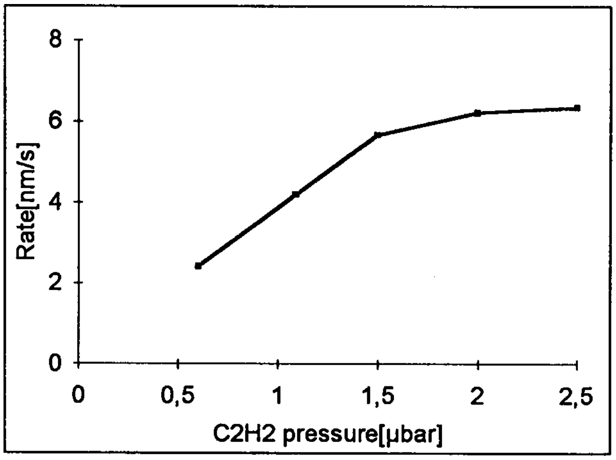

Fig. 12: Carbon deposition rate versus C_2H_2 pressure

was possible and the discharge is glowing only in the vicinity of the disk. The figure 11 shows the DC-voltage on the substrate versus the applied RF-power, exhibiting relative low DC-bias voltages to prevent damage of the deposited carbon film by too energetic Ar ions.

The next figure 12 shows the carbon deposition rate versus the acethylen pressure, with a linear increase of rate at lower C_2H_2 pressures. The rates are very high. The radial thickness uniformities are about ± 5 %.

But there remain still some factors to be improved. The control of the front/rear deposition is still a problem due to different plasma intensities on both disk sides. Also the disk holding requires special designs, since due to the fact that all protruding parts or edges undergo an increased ion bombardment, these parts are etched more than the planar disk surface. Therefore the requirement of both disk side coating and uniform layer properties up to the outer diameter of the disk necessiate very careful and detailed design and a thorough investigation to make this process suitable for production applications.

4.3 Description of the set-up for dynamic top coating of rigid disks

The alternative approach in the manufacturing of hard disks is to use large in-line systems working with dynamic coating. Here the disks are set into carriers holding several tens of disks. These pallets are moved through the sputtering system and deposition is achieved by passing the substrates perpendicular to a sputter cathode with typical transportation speeds of 0.3 to 0.6 m/min. Especially in high throughput systems one carrier is following directly the other, so that the deposition source being constantly on is coating a continuous band of substrate carriers.

Unfortunately the approach as described above for the static single disk process is not easy to apply to the dynamic PECVD process, since, in this case, the carriers have to be powered by RF, which is difficult due to the carrier movement. It is much more advantagous to have the carrier on ground potential.

The set-up used for dynamical coating of magnetic disks with hard carbon is based on Leybold's rf-*Hollow Etching Anode* [8]. In order to adopt this setup for dynamical coating in an industrial inline machine it had to be changed essentially [9, 10]. The resulting arrangement is shown in figure 13 which is referred to in the following.

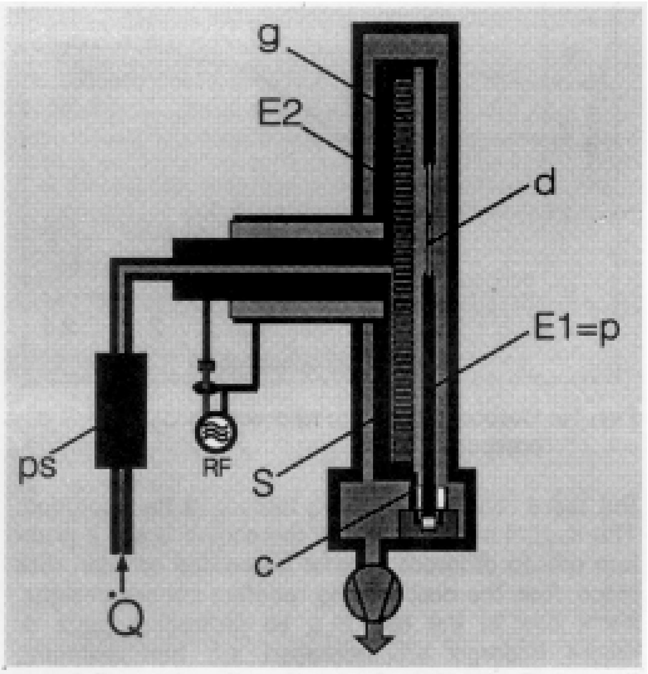

Fig. 13: Schematic cross sectional view of the Hollow Anode coating station for rigid disks

The coating station is made up of a hollow electrode *E2* and a planar electrode *E1*. The electrode *E1* covers the hollow electrode like a lid its bucket. *E2* is shrouded by a grounded dark space shield which is connected to the outer conductor of the rf-coax guide. The dark space shield bears a brim like projection *C* ("coupling plate") flushing with the rims of the hollow electrode and is running parallely with the planar electrode *E1*. The clearance between the coupling plate *C* and the planar electrode *E1* is between two and three millimeters. This clearance ascertains on one hand a reliable plasma confinement and on the other hand it is large enough to make possible a plain, uncritical design of the coating station.

The *E2* electrode is connected to the rf-power supply via a coupling capacitor. Further, there is a capacitive rf-coupling between the coupling plate *C* and the planar electrode *E2* which is strong enough to bear the rf-power for sustaining the glow inside the hollow electrode *E2*. The area of the plane electrode *E1* is smaller than that of the hollow one *E2*. Due to its asymmetry the glow as well as the anode *E2* are, with respect to ground and with respect to the electrode *E1*, on positive potentials. These rate from 50 V to 2kV, depending on power, pressure etc. Thus the disks *d* set into the planar electrode *E1* are exposed to a flux of positively charged ions emerging out of the glow and are, thereby, etched rsp. coated by the assistance of fast ions. Because *E1* is at or near ground potential, it can, acting as a pallet, be conveyed by a normal pallet drive system as frequently used in sputter machines. In figure 14 a schematic sketch of two loaded pallets as have been used, is shown. An essential advantage of the described set-up is the ability to process both glass as well as metal disks. Gas feed (*Q*) is directly accomplished into the hollow anode *E2* by an electrically insulating pressure stage *ps* ; additional gas exchange takes place through gasconductive side walls of the anode *E2* and its shroud.

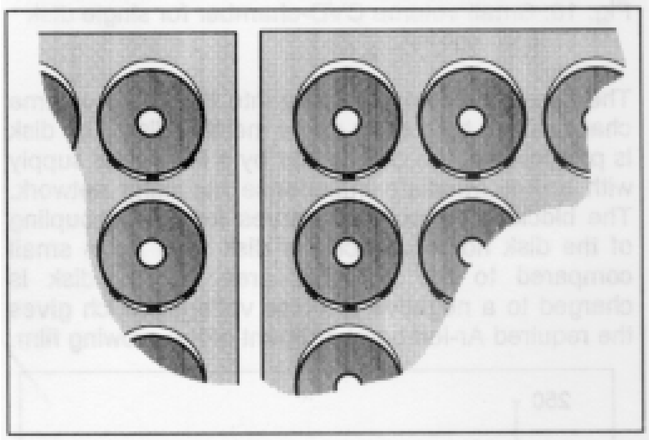

Fig. 14.: Sketch of two out of a continuous row of pallets for industrial processing of rigid disks

The Hollow Anode PECVD coating station has been successfully operated in a Leybold's A400 vertical machine for dynamic coating.

Data of performance of the Hollow Anode PECVD coating station are summarized in table I. Data concerning the properties of layers precipitated by the Hollow Anode are displayed in table II. Figure 15 displays a fracture of an about 1 µm thick hard carbon layer. The layer shows an amorphous,ceramic behaviour and is abviously free of columns. The smoothness of the surface is worth to note, too.

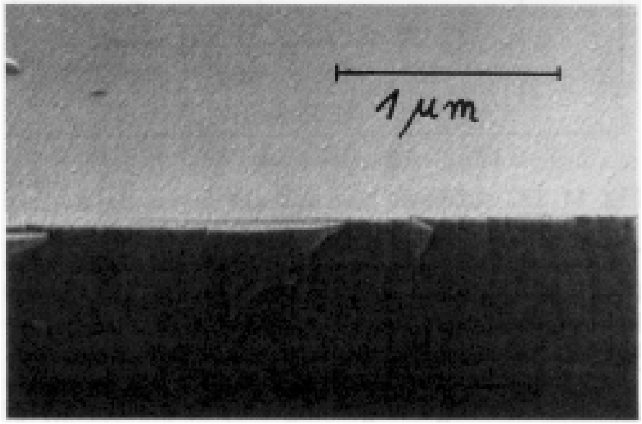

Fig. 15: SEM cross section of a 1 µm thick hard hydrogenated carbon layer made by ion assisted PECVD using the Hollow Anode

Figures 16 and 17 show typical distributions of deposition rates (normalized to the measured maximum), mapped along two perpendicular directions on disk (vertical rsp. horizontal arms of a rectangular cross). The increase of the deposition rate within the clamping area of the disk is reduced remarkably by lowering the working pressure. The uniformity (relative half deviation between maximum and minimum value) of the rate distribution on the recording area was < ± 10 % if process pressure was < 1 Pa.

Table I: Typical Parameters of Operation	
working pressure range	**0.5 Pa - 2.0 Pa**
power density related to area of smaller electrode	**$0.5\ W/cm^2$-$4.5\ W/cm^2$**
rf-self bias of plasma (substrate at ground)	**0.2 kV - 1.8 kV**
etch rate (polycarbonate, silver) at $1\ W/cm^2$	**2 Å/s rsp. 7 Å/s**
deposition rate	**10 Å/s-30 Å/s**
spatial uniformity of rates (on non perforated pallet)	**< ± 2 %**

Table II: Typical properties of deposited Hard Carbon (i-C:H) layers/[1]	
mass density	**$2.2\ g/cm^3$**
refractive index	**2.0**
hardness (Vickers)	**$3000\ kg/mm^2$**
dynamic friction coefficient	**0.1**
dangling bond ratio	**1/250 e*/C**
hydrogen content	**25 at%**
stress	**600 MPa**
youngs modulus	**250 GPa**
specific resistance	**0.1 MΩ·cm**

[1] mechanical properties have been measured at layer thickness > 1 µm on silicon wafers.

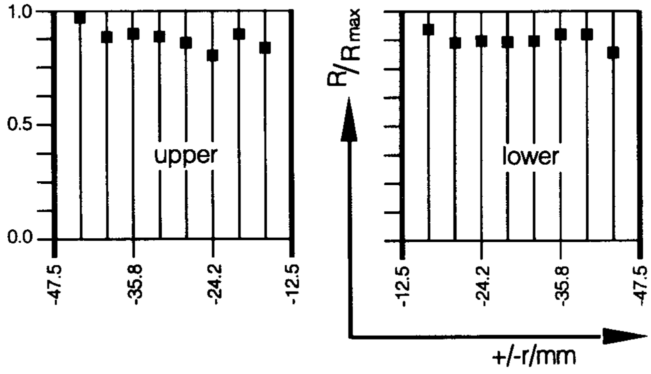

Fig. 16: Distribution of the relative deposition rate R/R_{max} along the vertical radii - r rsp + r of a rigid disk at a process pressure of 0.8 Pa.

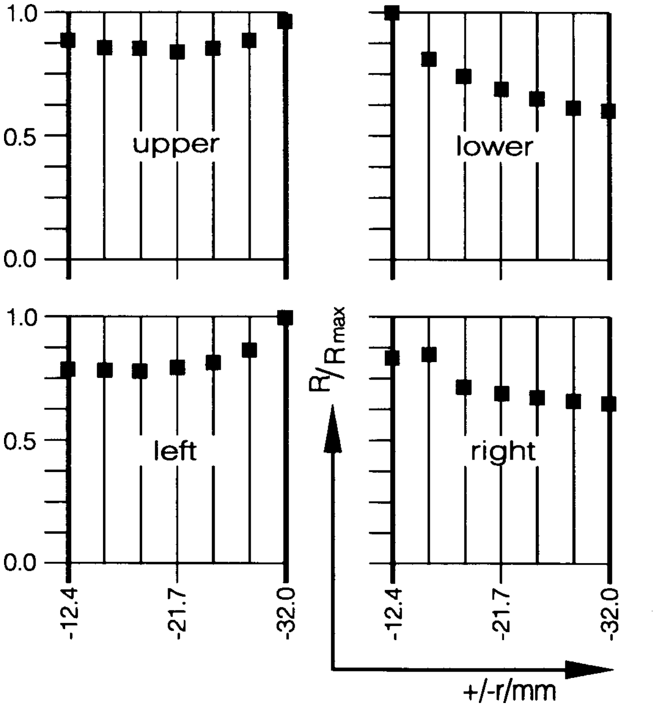

Fig 17: Distribution of the relative deposition rate R/R_{max} along the vertical ("upper"/"lower") and horizontal ("left"/ "right") radii r. Direction of pallet movement was from right to the left. Process pressure was 1.2 Pa.

4.4 Description of the set-up for top coating of ME tape
Leybold has developed a PECVD coating station for ion assisted coating rsp. ion assisted etching of plastic web. It is proposed to apply it to the top coating of magnetic ME tape with ultrathin top layer. The system, based on the above mentioned Hollow Anode is depicted schematically in figure 18.

The coating drum *D* is displayed in broken lines. Further, a partial cross cut is made in the middle of the system in a way that the front part of the coating drum *D* is cut away. The web *W* to be coated (rsp. etched) runs around the coating drum *D*. Paraxially along the coating drum *D*, in the immediate proximity of its circumferential surface the hollow electrode *H* is disposed.

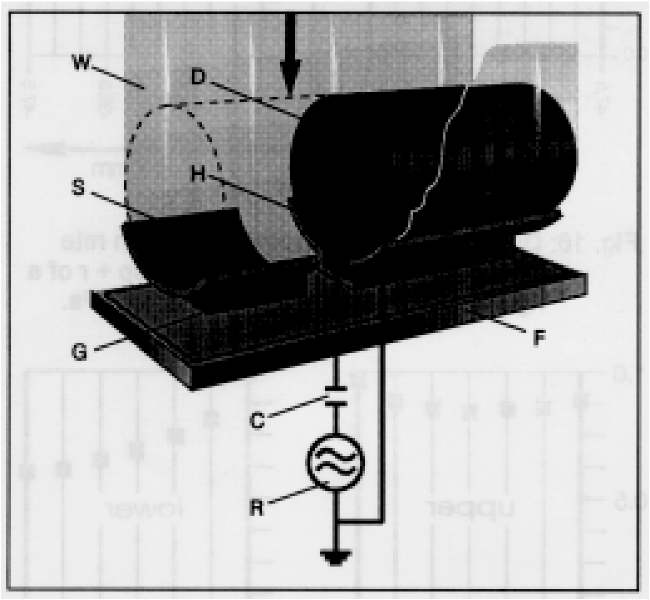

Fig. 18: Schematic view of the Hollow Anode web coating station

The hollow electrode *H* is presently up to 1 m in length and 0.1 m in width. The hollow electrode as well as a part of the coating drum's surface is shrouded by a grounded shield *S*. Hollow electrode *H* and shield *S* sit on a flange *F*. The hollow electrode is the electrode with the larger area. The section area of the coating drum *D* which appears in front of the aperture of the hollow electrode *E* becomes the smaller electrode. The hollow electrode, connected via a capacitor *C* and an impedance matching network (not shown) to the 13,56 MHz radio requency power supply, acquires the superimposed rf - and with respect to ground and coating drum *D* - positive DC bias potentials. The shield S, the coating drum *D* and the web *W* are grounded. Data of tables 1 and 2 apply for Hollow Anode Web coating station too. But in this case the maximum static deposition rate of hard carbon layers reaches 8 nm/s at present. The uniformity of the deposition rate along 800 mm coated width of the web is typically < ± 5 %.

5. Conclusion

The properties of deposited carbon layers are strongly related to the presence of hydrogen and ion bombardment during deposition. The addition of hydrogen during DC-magnetron sputtering of the carbon results only in relative small structure changes. An additional Ar-ion bombardment by applying a substrate bias transfers the layers to high density and hardness. In this respect the properties of PECVD carbon layers are very similiar. Crucial roles for the design of PECVD-coating stations - either static or dynamic coating of magnetic disks - is the plasma confinement and the achievement of uniform ion fluxes over the whole substrate surface. The hardware for top coating of ultrathin carbon layers on rigid rsp. flexible magnetic data storage media is available for qualification.

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