Investigation of hydrogenated amorphous carbon coatings for magnetic data storage media by atomic force microscopy

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Thin films of hydrogenated amorphous carbon for magnetic data storage media have been examined by atomic force microscopy. The topography of several coatings has been imaged with a lateral resolution of a few nanometers. Histograms of the height distribution and rms values have been calculated to characterize the roughness of the surfaces quantitatively. Variations of these microscopic properties could be related to changes in the macroscopic behavior like friction and wear.

Hydrogenated amorphous carbon (*a*-C:H) coatings are used as protection layers for magnetic data storage media[1] as well as for active layers for magneto-optic recording media.[2] They are well known for their high hardness, low electrical conductivity ($\sigma \approx 10^{-9}\ \Omega^{-1}\,\mathrm{cm}^{-1}$), high refractive index, as well as their inertness. The low electrical conductivity prohibits the application of the scanning tunneling microscope (STM). The recently developed atomic force microscope (AFM), however, offers a good possibility to study the topography of insulating surfaces.[3] In contrast to its predecessor, the stylus profilometer, the lateral resolution is in the nm range. For several layered samples like highly oriented pyrolytic graphite (HOPG) or highly oriented pyrolytic boron nitride (HOPBN), even atomic resolution could be achieved.[4–6] As was first demonstrated by Martin *et al.*[7] it was also possible to determine the interaction force between the probing tip and the sample as a function of distance. Mate *et al.*[8] applied a slightly altered method to measure frictional forces between the probing tip and the HOPG surface on an atomic scale.

One of the major problems for modern thin-film storage media is the control of their surface properties. The increasing requirements on the areal bit density can only be fulfilled by a reduction of the flying height of the read/write head. Therefore, smoother surfaces are necessary. Present thin-film technology achieves a surface roughness of about 200 Å (peak to valley) and better. Conventional surface profilometers are no longer capable of resolving the microscopic surface structure. In contrast to profilometers the AFM has the resolution to measure the surface roughness on this scale. Furthermore, the macroscopic friction and wear properties can be related to these microscopic measurements.

The films were produced by a chemical vapor deposition (CVD) process. As substrates we used conventional aluminum disks (130 mm in diameter) coated with a plated CoNi magnetic layer. Laser Raman studies were performed in order to characterize the deposited carbon films. All of the disks show the same Raman spectrum which can be clearly identified as amorphous hydrogenated carbon.[1] The friction and wear properties of the disks were checked by measuring the tangential force on a slider in contact with the rotating disk (normal force on the slider: 0.15 N, relative velocity between head and disk: 38 cm/s). The test continued until 2000 revolutions were accumulated on the same track. The coefficients of friction at the beginning and at the end of the test have been measured (starting/final friction).

The starting friction coefficients were very similar (0.1–0.2) for all the disks we have tested. The values of the final friction coefficients could be divided up into two groups. The disks of the first group showed higher final friction coefficients (0.53–0.7) compared to the other group (0.33–0.38). Scanning electron microscope pictures revealed a severe damage of the disk surface (high wear rate) for those with the low final friction values in contrast to the other group where nearly no damage of the disk surface (low wear rate) could be found.

The design of our AFM instrument is described elsewhere in detail.[6,9] All the measurements were performed in air. For the AFM studies small samples (about 2 cm in diam) have been punched out of the disks. As a force sensor we have used microfabricated SiO_2 cantilevers with a spring constant of 0.1 N/m.[4] The repulsive force between the lever and the sample was chosen between 10^{-8} and 10^{-7} N. $z_t(z_s)$ plots have been recorded by slowly approaching and retracting the sample towards the probing tip, where z_t is the movement of the STM tip and z_s is the movement of the sample.[6] These plots were used primarily to test the proper working of the lever-tip-sample assembly. In addition, we calculated the maximum adhesive force between the probing tip and the sample to be about 10^{-8} N. This value is quite a small fraction compared to the value of 7×10^{-8} N on HOPG. Both experiments were performed with probing tip geometries of about 1000 Å.

The AFM measurements have been performed on typical examples of the two groups showing different friction and wear behavior. We illustrate our results by two samples which are representative for the disks with small and large wear rate (high and low final friction). Figures 1(a) and 1(b) show an area of 4800 × 6000 Å. Hillocks of 300–1000 Å width and 50–100 Å height can be observed. In Fig. 1(c) the corresponding height distribution is shown as a histogram. The rms value was determined to be 36 Å. Figure 2 is an

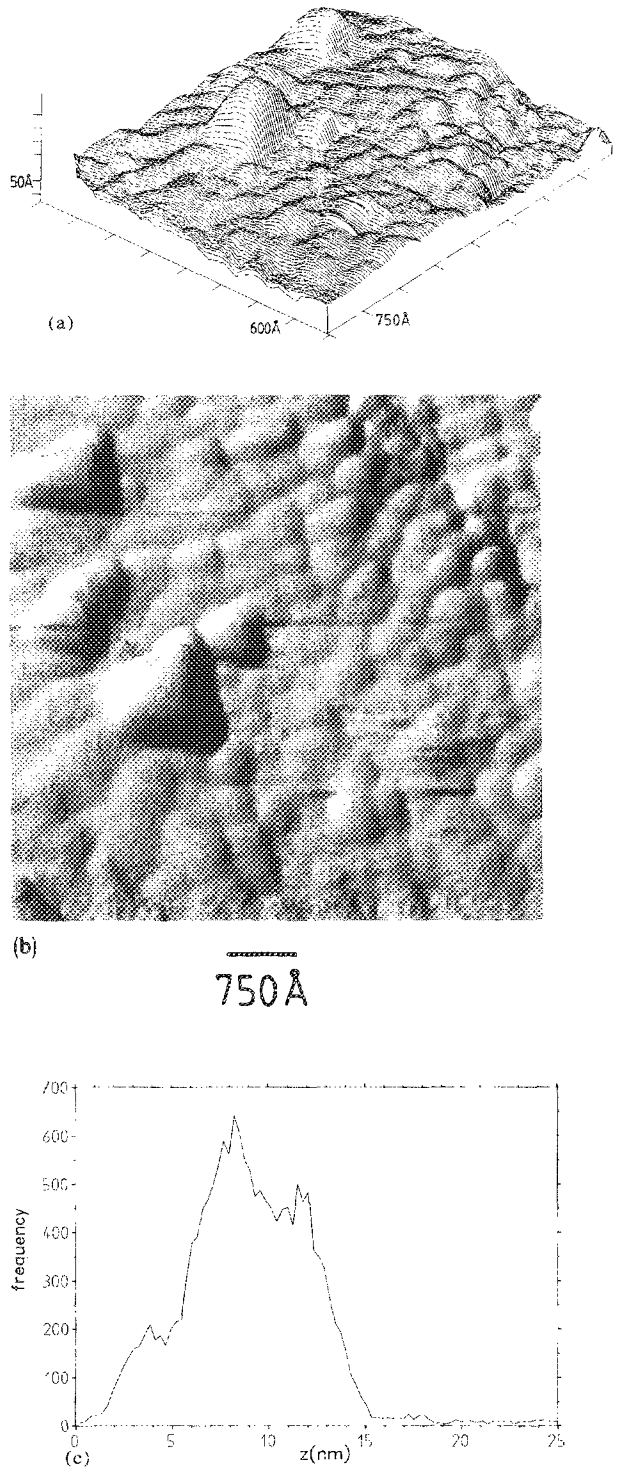

FIG. 1. (a) Hidden line presentation of a 4800×6000 Å^2 area of an a:C-H film of magnetic recording media. These are raw data. No data processing has been applied. (b) Bird view of the same image. An imaginary light source illuminates the surface. (c) Histogram of the height distribution. The rms value is 36 Å and the mean height is 90 Å.,

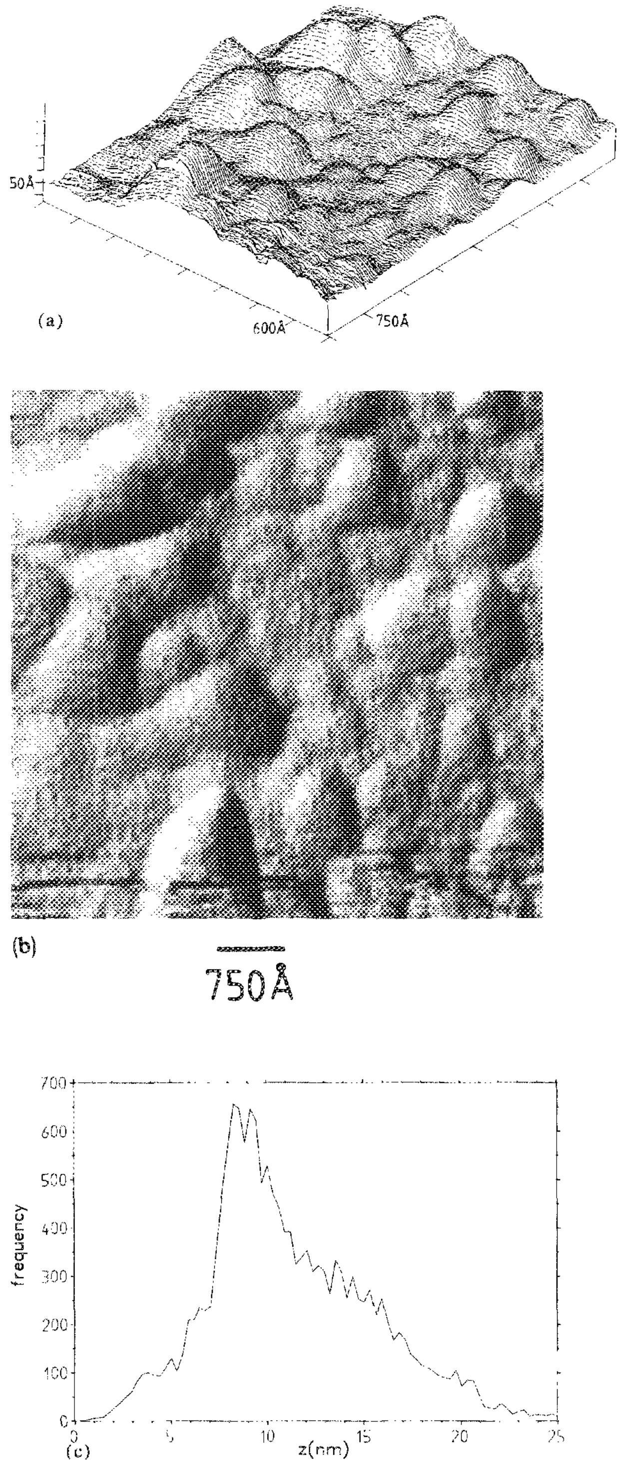

FIG. 2. (a) Hidden line presentation of a 4800×6000 Å^2 area of an a:C-H film of magnetic recording media; (b) bird view; and (c) histogram of the height distribution. The rms value is 45 Å and the mean height is 110 Å.

example of the other group. On the same scale the hillocks appear significantly bigger. The width ranges from 500 to 1500 Å and the height from 70 to 200 Å. The height distribution in Fig. 2(c) is broadened and the rms value raises to 45 Å. The same samples have been imaged on different places. The results were consistent and the rms value varied only within ± 3 Å. The samples from the other two disks showed the same behavior. The disks with low final friction exhibit a higher surface roughness compared to the disks with the high final friction.

For the first time we applied the AFM to a-C:H films, playing an important role in tribology as well as in the technology of recording media. With a lateral resolution of a few nanometers we could image hillocks of varying size. The differences in topography could be related to a different behavior in friction and wear. The question arises if the observed topography is an effect of the overcoat or a consequence of the roughness of the underlayer. Similar measurements on (a:C:H) films being deposited on single crystals showed no hillocks. We therefore assume that the observed roughness is mainly a consequence of the underlayer.

These investigations are only a first step in a new field of research. The microscopic view of friction and wear is a new approach, which promises to give a deeper insight into the physics of tribology. In addition to the mapping of topography it is possible to measure the interaction force law by $z_t(z_s)$ plots. In future work this will be a way to determine the adhesive forces and elastic properties of the samples and relate them to the macroscopic behavior.

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