RELATIVE WEAR DURABILITY OF ADVANCED SLIDER COATINGS ON CARBON COATED DISKS

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Abstract

A study of the effect of the adhesion layer of diamond like carbon (DLC) coatings on head-disk wear durability is presented. Al_2O_3-TiC sliders were coated with hydrogenated DLC protective thin films with and without the adhesion layer, and the wear durability was compared. It was found that DLC coatings without adhesion layers provided about 95% of the wear durability of those with adhesion layers on disks with 50Å DLC coatings. The absence of the adhesion layer reduces the magnetic spacing by 10% while maintaining comparable wear durability.

1 INTRODUCTION

Reducing the magnetic spacing is an important factor in improving areal density in disk drives. The deposition of protective thin film coatings has proven critical to the enhancement of wear durability at the head disk interface (HDI) and allows for minimum magnetic spacing. These coatings are deposited on the surface of the disk to protect the magnetic layer against corrosion and tribological wear from contact with the slider rails. Standard film thicknesses are on the order of 175Å when deposited on the disk. When deposited on slider rails the wear durability is further enhanced and the coefficient of friction between the head and disk is significantly reduced. Head coatings are on the order of 50Å. The challenge is to make the combination of films as thin as possible, minimizing the magnetic spacing, while maintaining the integrity of the HDI.

Protective thin films in hard disk drives are generally various forms of diamond like carbon (DLC). DLC is an amorphous form of carbon. It is neither entirely diamond nor graphite but sp^2 bonded regions linked together by sp^3 bonded carbon [1]. The structure can vary from predominantly sp^2 bonded unhydrogenated films to hydrogenated films with high sp^3 fractions. It exhibits many of the properties of diamond; it is chemically inert, very hard and characterized by high wear durability and a low friction coefficient. There are a variety of deposition procedures by which DLC is made. In all of these procedures control over the impacting ion energy is critical to the resulting properties of the DLC films. Adherence to the substrate is also a primary concern. An adhesion layer is deposited prior to the deposition of the DLC to increase the ability of carbon to adhere to the substrate. Adhesion layers typically are some form of Silicon, on the order of 20Å thick and are important as they reduce the likelihood of particle pullout. If DLC coatings could be deposited onto the surface of heads and disks without the adhesion layer while maintaining acceptable wear durability and coating adhesion, the magnetic spacing would be reduced by approximately 25% in current air bearing slider designs.

In this study two DLC protective thin films are deposited by direct ion beam deposition on to the surface of Seagate CUDA 4 50% Al_2O_3-TiC sliders. One coating, DLC, contains a 20Å adhesion layer, while the other, NILAD, does not. The NILAD coated sliders are found to exhibit approximately 95% of the wear durability of the DLC coated sliders.

2 EXPERIMENTAL METHOD

2.1 ACCELERATED WEAR TESTING

A Lotus Technologies 7000 Contact Start Stop Spin Stand was used to conduct contact start stop (CSS) accelerated wear tests. There are four spin stands that can be operated simultaneously. Each stand is equipped with a dual axis strain gage that can measure both horizontal and vertical forces exerted on the slider by the disk. In addition, they are fitted with acoustic emission, temperature and humidity sensors as well as digital micrometers for radial and lateral positioning.

During a CSS test the slider is mounted on its stage and then manually positioned at the desired radius. After calibration and zeroing of the strain gages the slider is lowered onto the surface of the disk until it is at the specified vertical suspension load. The data recorded are the stiction and the maximum value of friction for each cycle of the test. The real time behavior of the horizontal friction force is also recorded. It follows the Stribeck model of friction and can be divided into two regimes, that of static friction and dynamic friction. The horizontal force necessary to break the slider free is recorded and called stiction. The maximum value of friction is the maximum value of the horizontal force occurring during the period of intimate contact between the slider and the disk, before the slider reaches its take off velocity. Both of these values are recorded per cycle and then plotted versus the total number of cycles for the test.

The profile of a cycle is as follows: the spindle is accelerated from zero rpm to 7200 rpm in three seconds, maintained at 7200 rpm for one second and then decelerated to zero rpm in three seconds. The slider remains in the position where it comes to rest for a dwell period of six seconds before the cycle repeats itself. A complete test, in this study, consists of either 10,000 or 15,000 cycles.

A test failure is indicated by a breakdown of the protective coating on the disk surface. Wear debris collects in the interface causing abrasive wear of the disk coating. This process is marked by an increase in the maximum value of friction and a simultaneous decrease in the stiction values. The slider rails are forced to drag over the wear debris in the interface causing the maximum value of friction to increase. The stiction values decrease as the presence of the particles reduce the contact area between the slider rail surface and the disk surface which is directly proportional to the value of stiction. In a failed test there is a visible wear track on the surface of the disk and debris is visible on the slider rails when viewed under a microscope.

2.2 WHITE LIGHT INTERFEROMETRIC MICROSCOPY

The material surface characterization was completed in part using the Zygo NewView 100 System. The Zygo NewView 100 is a general purpose, three dimensional imaging surface structure analyzer. It uses coherence scanning white light interferometry to image and measure the micro-structure and topography of surfaces in three dimensions. A filtered white light source emits a beam, which is split with one portion reflected off of the test surface and the other off of an internal, high quality reference surface. Both portions of the beam are then directed onto a solid-state camera where the interference of the two light wavefronts results in fringes. The objective is moved vertically via a piezoelectric transducer capturing variations in the light intensities on the solid state camera. The intensities at each pixel are captured and converted into surface images. The vertical measurements are performed interferometrically using the variations in the light intensity. Lateral measurements, in the plane of the surface are performed by calculating the pixel size from the field of view of the objective in use. It is capable of imaging depths up to 100 micrometers, with 0.1 nanometer resolution and 0.3 nanometers RMS repeatability [2].

2.3 RAMAN SPECTROSCOPY

Raman Spectroscopy was used to characterize the wear mechanism at the head disk interface. Raman Spectroscopy is based upon the Raman Effect in which vibrational spectra are generated by inelastic collisions of incident photons and the sample molecules. These collisions create a quantized exchange of energy. Scattered light is emitted from this exchange that is different from the incident light by frequencies equal to those of the sample molecules [3]. Raman spectra are very sensitive to changes that disrupt the translational symmetry of materials and therefore are useful in the study of disorder and crystalline formation in thin carbon films. The spectra serve as fingerprints for DLC structures. Although they cannot directly quantify bonding information (e.g., sp^3 fractions), they can provide qualitative information regarding sp^3 content. The first order Raman spectrum of diamond consists of a single sharp peak at 1332 cm^{-1}. The spectrum of large single-crystal graphite is a single narrow peak at approximately 1580 cm^{-1} [4]. In many forms of carbon an additional broad D-peak occurs at approximately 1360 cm^{-1}. This D-peak is related to the disorder of the carbon structure. The Raman spectra of amorphous carbon films typically consist of two broad overlapping peaks between 1000 cm^{-1} and 1600 cm^{-1}. The spectra are well fit by the sum of these two Gaussian peaks G and D. The ratio of the integrated intensity of these two peaks is the I_D/I_G ratio. It has been shown that the position of the G-peak and the I_D/I_G ratio are directly correlated to the structure and mechanical properties of carbon films. The penetration depth of Raman Spectroscopy using radiation of approximately 2.6eV is on the order of 400 - 500Å and the spectra are sensitive down to a single carbon monolayer (~ 5Å). Raman spectra are therefore well suited for characterizing films on the order of 50 - 75Å [5].

2.4 DIRECT ION BEAM DEPOSITION

Diamonex Corporation prepared the slider coatings. Both coatings are hydrogenated DLC, one was a Si-doped DLC, Non-Interlayer Amorphous Diamond (NILAD) which contained no adhesion layer, and the other was a standard DLC coating which will be referred to as DLC. They were deposited by direct ion beam deposition using a filament Kaufman type ion source.

This is a high vacuum deposition process where a DC plasma is initiated in the source from which positive ions are electrostatically extracted to form a beam. The beam is directed at the substrate of interest, which is remote from the plasma to allow for low temperature deposition.

For any DLC deposition technique, the resulting material properties are functions of the ion energy distribution and the intensity of the ion specie striking the substrate. Direct ion beam deposition from a Kaufman source has the advantage that these parameters, along with the deposition rate are independent. A bias voltage on the plasma controls the ion energy distribution and the ion species are controlled by the gas composition feeding the plasma. The deposition rate is a function of the plasma density, which is metered by the flux of the electrons emitted from a hot cathode filament. In addition, studies by Agarwal and Li [6] show that films deposited on substrates at lower temperature have higher wear durability than those deposited at high temperature.

3 MATERIALS

The test matrix consisted of three different slider coatings on two types of disks. The sliders were Seagate CUDA 4 50% Al_2O_3-TiC coated with the following: Hydrogenated DLC of 75Å plus a Si adhesion layer of 20Å, NILAD of 75Å, and uncoated (Figure 1). The disks for this study were provided by Seagate Technologies. There were two sets of 95 mm disks one with 50Å DLC and the other with 175Å DLC; both sets were lubricated with 25Å of high molecular weight Z-dol lubricant.

Using the Zygo NewView 100 the disks coated with 50Å DLC had a measured average surface roughness of 30Å rms while those coated with 175Å had an average surface roughness of 25Å rms (Figures 3.1, 3.2). Measurements of the surface roughness on the sliders were taken at four points and those values were averaged. The measurements were taken from the inner and outer trailing edges and the inner and outer leading edges just behind the taper. The sliders coated with DLC had an average surface roughness of 8.44Å rms while the NILAD coated sliders had an average surface roughness of 7.54Å rms. The uncoated sliders were smooth with an average surface roughness of 3.51Å rms.

4 EXPERIMENTAL RESULTS AND DISCUSSION

CSS tests were run with each of the three slider types on both disks. The initial set of tests were run on the disks coated with 175Å as this is the standard thickness used on 95mm disks in disk drives. When an uncoated slider was tested on the 175Å DLC coated disk the test was able to complete the full set of 10K CSS cycles (Figure 4.1). Upon completion of the test there was no visible wear track on the surface of the disk nor was there any visible debris on the slider rails when examined under a microscope. The coefficient of friction was approximately 0.2 throughout the course of the test. The stiction force maintained an average value of 2.00 gram. This head-disk combination served as a standard against which the other combinations were measured.

DLC overcoats of 175Å provide substantial protection against tribological wear. The sliders coated with NILAD and DLC both successfully endured 10K CSS cycles without significant breakdown of the coatings on either the heads or the disks. The results of the DLC coated slider and the NILAD coated slider are seen in Figures 4.2 and 4.3. The coefficient of friction for the slider coated with DLC exhibited an unusual fluctuation between 5000 and 6000 cycles. The average value of the stiction force was 3 gram and exhibited a slight fluctuation between 5000 and 6000 cycles as well. Despite this slight variation the slider rails were free of debris after 10K cycles and there was no visible wear track on the surface of the disk. The NILAD coated slider experienced a steady increase in the coefficient of friction from approximately 0.16 to 0.2. The stiction forces also increased slightly but steadily throughout the test with an average value of 3.25 gram. 175Å of DLC on the disk surface protected the interface from significant wear for each of the three slider coatings. It has been shown that DLC coatings on slider rails enhance the wear durability beyond that of uncoated sliders [7]. Uncoated sliders are typically used on disks with 175Å DLC coatings. Therefore, sliders coated with DLC films would need to be examined on disks with thinner protective coats such that cycles to failure can be used as a reasonable metric. In order to more specifically investigate the contribution of the slider coating to the wear durability, disks coated with DLC overcoats of 50Å, approximately 30% as thick, were examined.

The uncoated slider tested on the 50Å DLC coated disk failed catastrophically after 1200 cycles (Figure 4.4). Uncoated sliders provide the least protection against tribological wear. In the tests with disks of 175Å DLC coating the protective film was thick enough to protect the interface despite the slider being uncoated. In this case the disk coating was thin enough that the head contribution to wear durability was easily seen. However, it was observed that both the DLC and NILAD coated sliders were able to protect the interface over CSS tests of 10K cycles.

In order to make a comparison between the NILAD and DLC coatings, an extended test was run to 15Kcycles. The DLC coated slider maintained a friction coefficient of approximately 0.25 throughout the course of the test (Figure 4.5). The stiction values increased steadily from approximately 1.7 gram load to 2.5 gram force. The NILAD coated slider failed at approximately 14K cycles (Figure 4.6). The sharp increase in the maximum value of friction there and the simultaneous decrease in the stiction force indicate failure. The cause of this failure is a critical question.

In order to determine the mechanism of failure the individual components must be examined for wear. The wear rate of the NILAD coating on the surface of the slider rails would indicate to what extent the failure was due to a breakdown of the coating on the disk or on the slider. In addition, the type of wear on the slider would indicate whether the failure was due to insufficient coating adhesion or due simply to poor mechanical properties of the film. If there were adhesion problems delamination of the coating would result in large particles of carbon being removed from the slider rail surface. If the problem is one of mechanical properties the wear rate may be more gradual as the wear debris collects in the interface and contributes to abrasive wear. The wear debris on the inner leading edge of the NILAD coated and DLC coated sliders are shown in Figure 4.7.

Raman Spectra were taken from the surfaces of both the heads and disks. Both of these spectra were necessary to identify the origin of the debris found on the surface of the slider rails and to identify the specific carbon structure of the deposited films. Spectra of the surface of the 50Å and 175Å DLC coated Seagate disk surfaces are shown in Figures 4.8 and 4.9 respectively. The spectra indicate the difference in the thickness and structure of the coatings. The 50Å coating has an I_D/I_G intensity ratio of 0.26. It has a single G-peak of 1530 cm^{-1} indicating that it is an amorphous carbon with a high sp^3 content. The spectrum of the 175Å coating resembles typical DLC coatings of amorphous hydrogenated carbon [8]. It has greater intensity as expected for a thicker coating. Its structure is different as it has a G-peak at 1570 cm^{-1} and a D-peak at approximately 1360 cm^{-1} with an I_D/I_G ratio of 0.58.

Raman spectra of the surface of the slider rails were taken to determine the structure of the different coatings. Figure 4.10 shows 3 spectra from different points on a virgin slider coated with 75Å DLC upon a 20Å adhesion layer. Three measurements were taken over the surface of the rails: the center of the leading edge, the inner leading edge and the inner trailing edge. The G-peak occurred at 1580 cm^{-1} for all three locations. The variation in intensity is possibly a function of the variation in the reflectivity of the substrate. The Al_2O_3 grains have a higher reflectivity than do the TiC grains. The spectra for a NILAD coated slider are seen in Figure 4.11. The measurements were taken on the inner leading and trailing edges. Here, a narrow G-peak occurred at 1586 cm^{-1} and a broad D-peak occurs at approximately 1475 cm^{-1}. This spectrum is quite different than the typical DLC coatings due in part to the presence of Si in the film.

To examine changes in the slider coatings, spectra were taken from the surfaces of the slider rails after they had been subjected to CSS accelerated wear tests. The surfaces of the slider rails were examined for the case where the HDI was worn but did not fail in addition to the case where there was catastrophic failure. Both the DLC and NILAD coated sliders were examined after being tested on 50Å DLC Seagate disks.

Figure 4.12 shows the changes in the DLC coating after being subjected to 15K CSS cycles without failure. There was no visible wear track on the surface of the disk and only a slight accumulation of debris on the slider rails. There was a significant downshift in the G-peak from 1580 cm^{-1} to 1553 cm^{-1} and the I_D/I_G ratio decreased to 0.41. A spectrum taken in the hogout section of the slider between the slider rails has a narrow graphitic feature occurring at 1580 cm^{-1} superimposed on the typical DLC spectrum. The spectra of the unworn DLC slider demonstrate this characteristic as well. On the surfaces that were exposed to contact with the disk this graphic feature is absent. It appears that there is localized and non-uniform deposition of graphitic material that the CSS cycles tend to remove. The intensity of the spectra decreased from the inner leading edge to the inner trailing edge. One possibility is that the coating on the trailing edge was thinner, confirming the notion that the trailing edge is subject to longer periods of intimate contact with the disk during take off and landing than the leading edge.

Figure 4.13 are spectra of a DLC coated slider that failed catastrophically. Spectra were taken of the spots on the slider rails with and without debris as well as on sections of thick black carbon accumulation. The spectra taken from the spots with and without debris are similar to those of the coating in Figure 4.12. In contrast, the G and D-peaks of the carbon spot indicate that it is chemically altered and its intensity suggests that it is possibly a combination of carbon from the disk as well as the head. The magnitude of the intensity could also be due to fluorescence caused by degradation of the lubricant, which is the only constituent of the HDI that contains fluorine. This could be confirmed by X-ray Photoelectron Spectroscopy (XPS) or Auger Electron Spectroscopy (AES). The results from the failed and worn DLC coated sliders indicate that the standard DLC coatings maintain their chemical structure well and exhibit good wear durability.

The NILAD coated sliders were examined after being worn for 10K CSS cycles without failure as well as a 14K CSS test with catastrophic failure. Figure 4.14 shows the Raman spectra of the coating after being worn with no failure. There are G and D peaks occurring at 1586 cm^{-1} and 1475 cm^{-1} respectively. These peaks are identical to those of the unworn slider indicating that the structure of the coating remained in tact exhibiting good wear durability and structural stability.

In the case where failure occurred the coating underwent significant structural changes. Figure 4.15 shows the spectra of a NILAD coated slider that failed after 14K CSS cycles. A measurement taken from inside the hogout section of the failed slider confirms that the material there is unaltered. The measurements taken on the slider rails indicate a transformation to a low sp^3 content graphitic material, identified by graphitic characteristics. There is a narrow G-peak occurring at approximately 1580 cm^{-1} with a D-peak at 1360 cm^{-1}. In addition, these peaks are well separated which is a particular characteristic of graphitic amorphous carbon. Spectra were taken from the exposed surface of the rail, in between the carbon debris spots, in order to identify the change in character or thickness of the coating. Had the coating been completely worn away there would have been no spectral results, therefore the results are of an altered carbon coating and not of exposed Al_2O_3-TiC. There is a sharp graphitic peak occurring at approximately 1580 cm^{-1} and a weak separated D-peak. The NILAD coating transformed to a graphitic carbon state. This measurement was taken from a clear spot on the rail that contained no debris. Another measurement was taken of the debris itself to determine its origin. The spectra taken from the debris spot itself matched those taken from the spot without debris in they also exhibited graphitic characteristics.

It is important to consider the possible wear mechanisms. The graphitic character of both the spots with and without visible debris could indicate the presence of a transfer film that coated the entire surface. This would be detectable by the superposition of graphitic spectra upon the spectra of the virgin NILAD coating. Raman spectroscopy is capable of providing information to make this determination provided there is spatial uniformity of the virgin NILAD coating over the surface of the rails. As the NILAD coating is carbon doped with Si, the chemical instability of SiC could have yielded graphitic characteristics under the high temperatures generated at the HDI. According to Tallant et al. [9], DLC begins to transform into nano-crystalline graphite at around 300ºC in ambient air. Allegedly, flash temperatures at the HDI can be as much as 125ºC higher than the nominal temperature and potentially much higher [10, 11]. Another possibility is that the coating wore off completely and was replaced by a graphitic transfer film from the disk.

Determining the wear mechanism is critically important as it allows for the development of improvement strategies. During catastrophic failure of the HDI the NILAD coating transformed its chemical structure. However, the results indicate that for considerable CSS cycles the coating remained structurally sound. The question then is whether a failed adhesion to Al_2O_3-TiC was the causal agent of failure or if it was due to a structural change in the coating in the immediate vicinity of failure.

5 CONCLUSIONS

Three different slider coatings were tested on 50Å and 175Å DLC coated disks. The distinction between the slider coatings was only seen on disks of 50Å DLC coatings. The HDI with the uncoated slider exhibited only 8% of the wear durability of the DLC coated slider. The HDI with the NILAD coated slider showed wear durability 93% that of the HDI with the DLC coated slider. The adhesionless NILAD coating provides comparable wear durability to the standard hydrogenated DLC coatings. The requirement of reduced magnetic spacing for increased areal density necessitates further study of doped carbon films that have desirable mechanical properties. The successful development of these films would significantly reduce the magnetic spacing and prove to be important as the HDI evolves into the use of picosliders.

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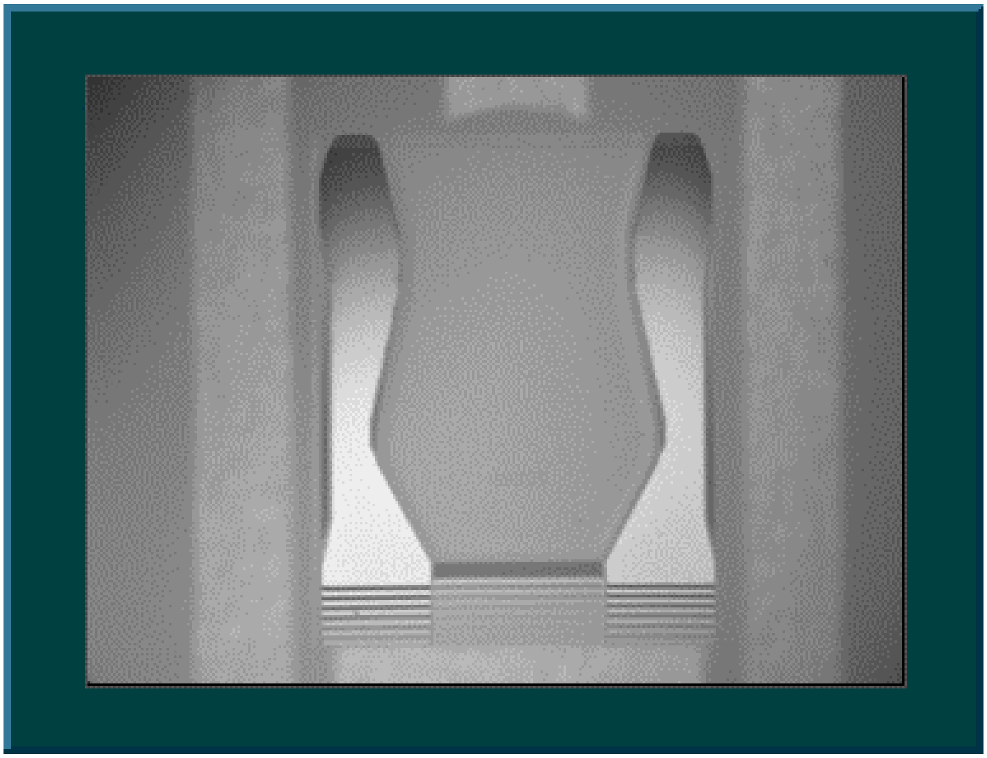
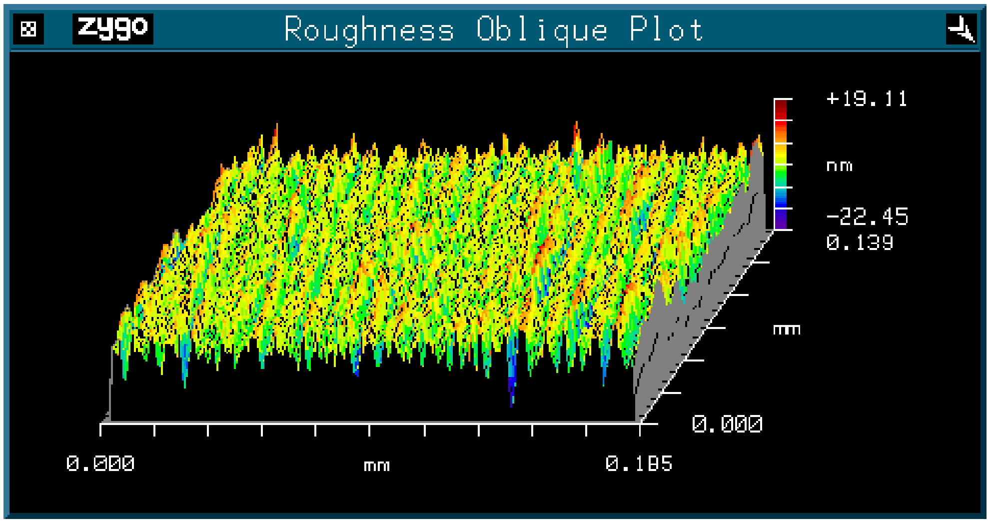


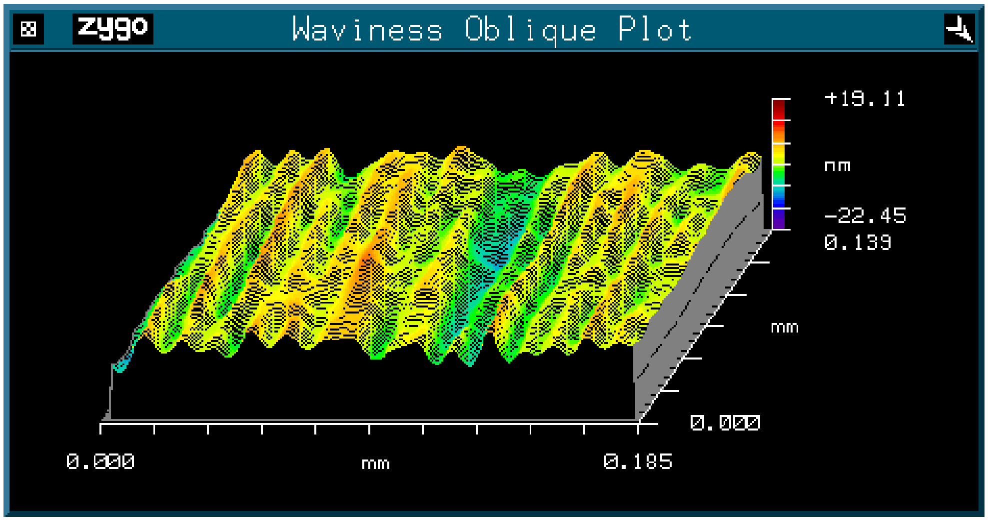
AVERAGE SURFACE ROUGHNESS (RMS)

Uncoated	**3.51Å**
NILAD	**7.54Å**
DLC	**8.44Å**

Figure 1 Seagate 50% Al_2O_3-TiC CUDA 4 Slider

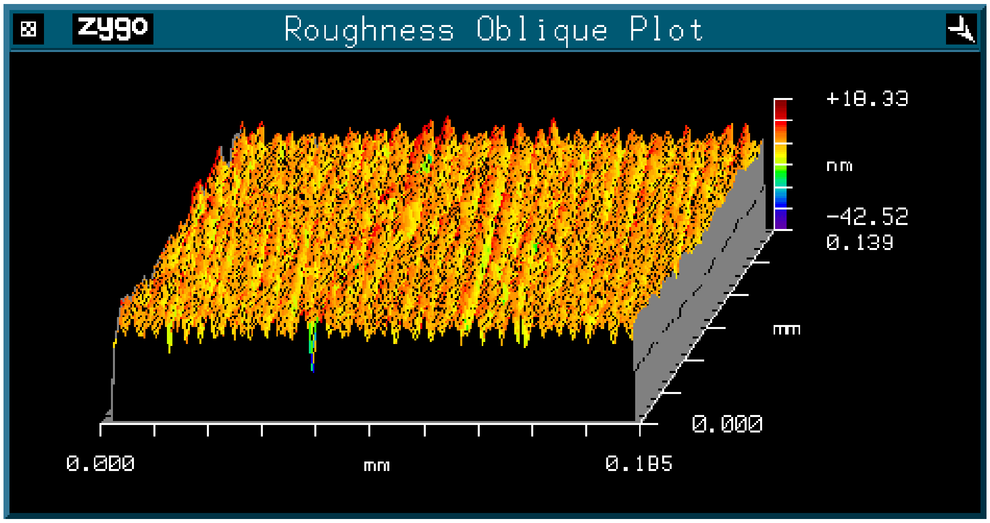


50Å DLC, roughness (rms) 32.26Å

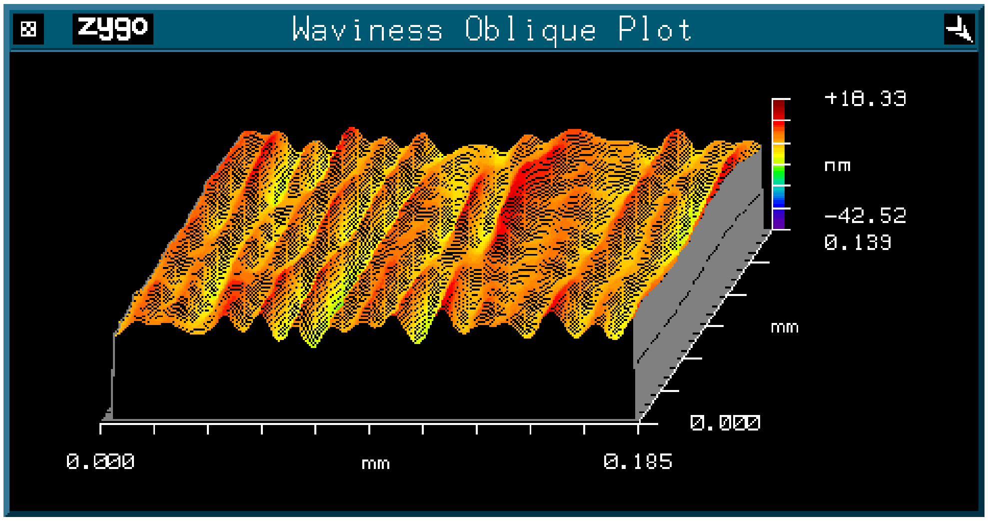


50Å DLC, waviness (rms) 28.18Å

Figure 3.1 50Å DLC disk surface characterization



175Å DLC, roughness (rms) 23.21Å



175Å DLC, waviness (rms) 27.63Å

Figure 3.2 175Å disk surface characterization

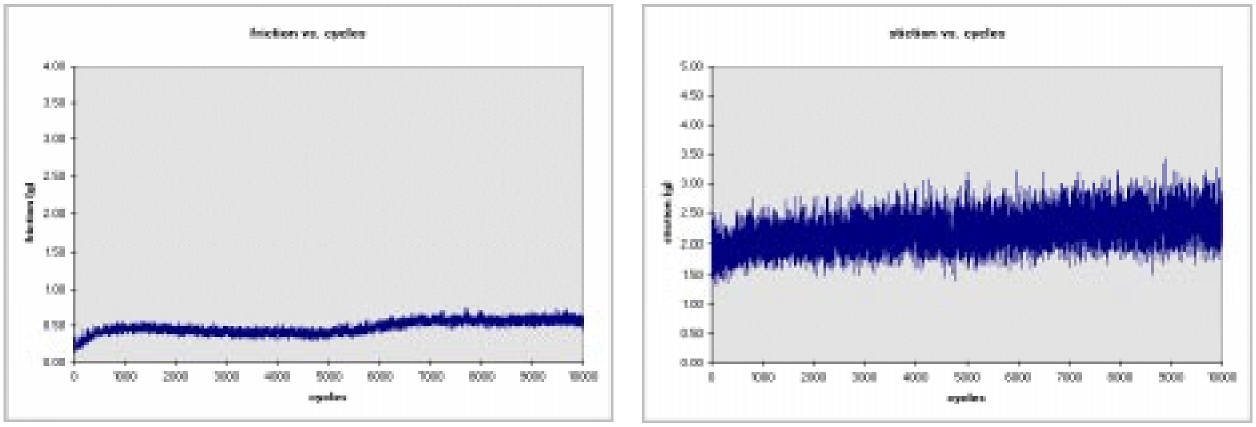


Figure 4.1 50% uncoated slider on 175Å DLC disk

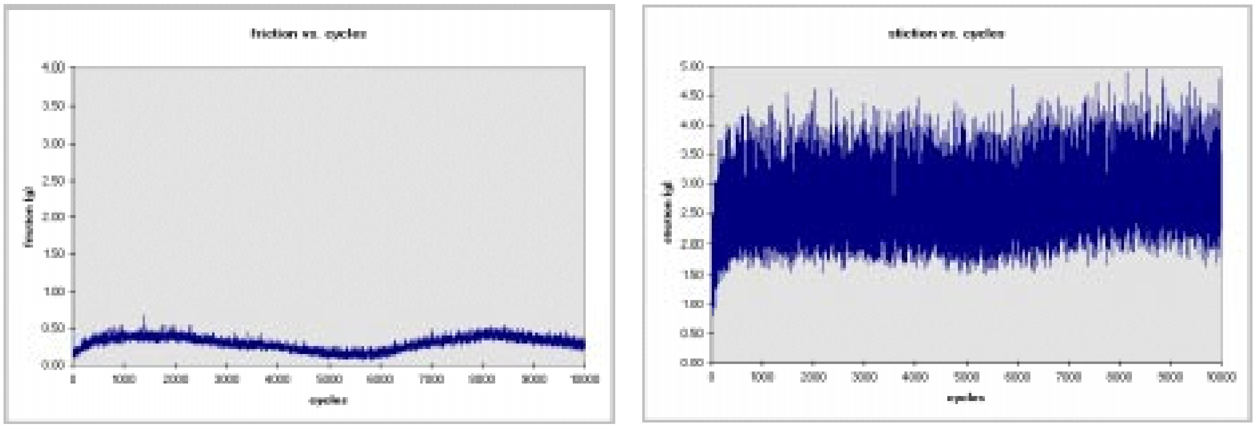


Figure 4.2 50% DLC coated slider on 175Å DLC disk

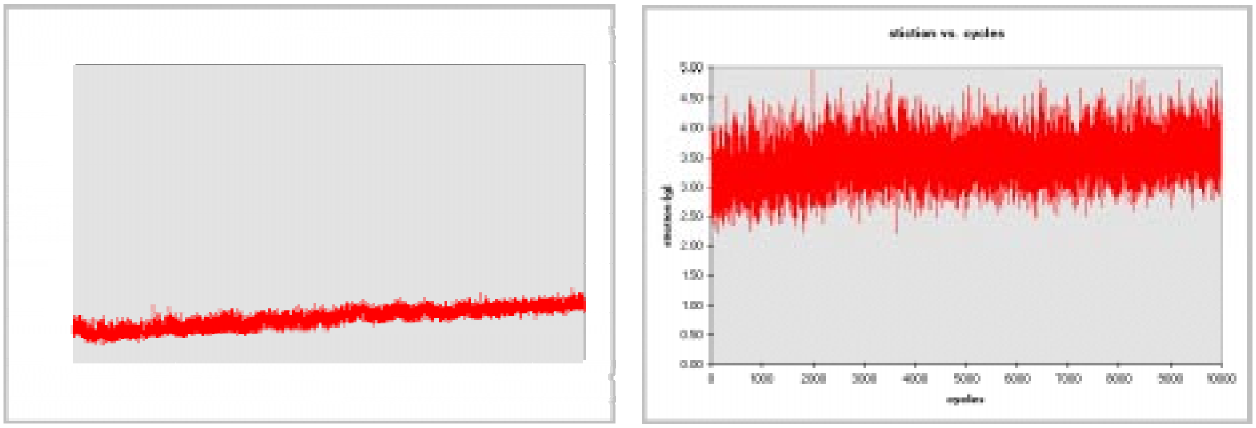


Figure 4.3 50% NILAD coated slider on 175Å DLC disk

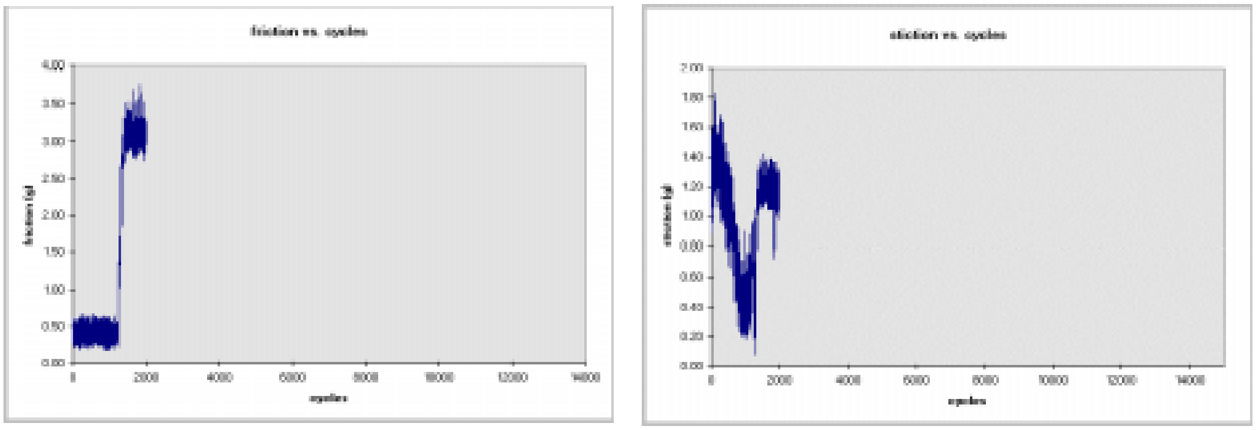


Figure 4.4 50% uncoated slider on 50Å DLC disk

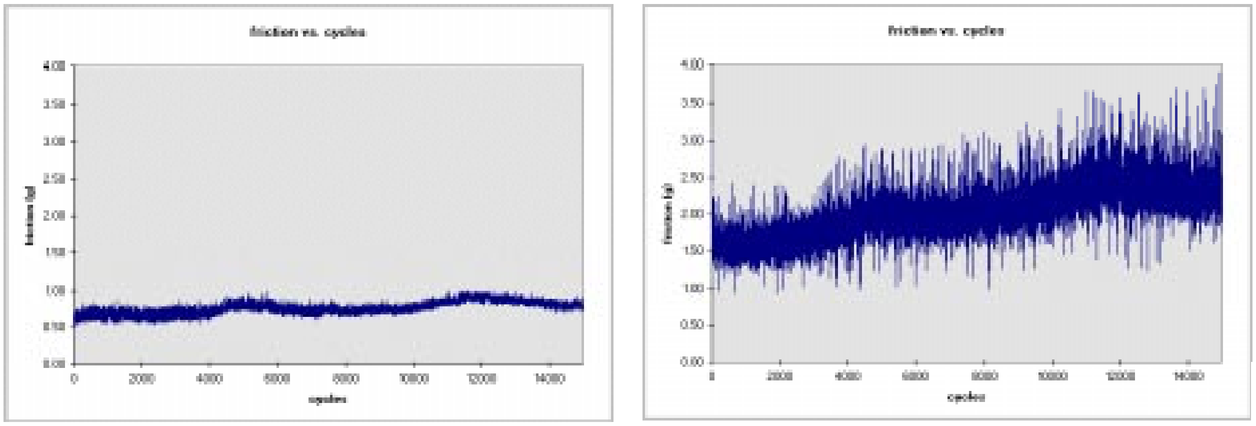


Figure 4.5 50% DLC coated slider on 50Å DLC disk

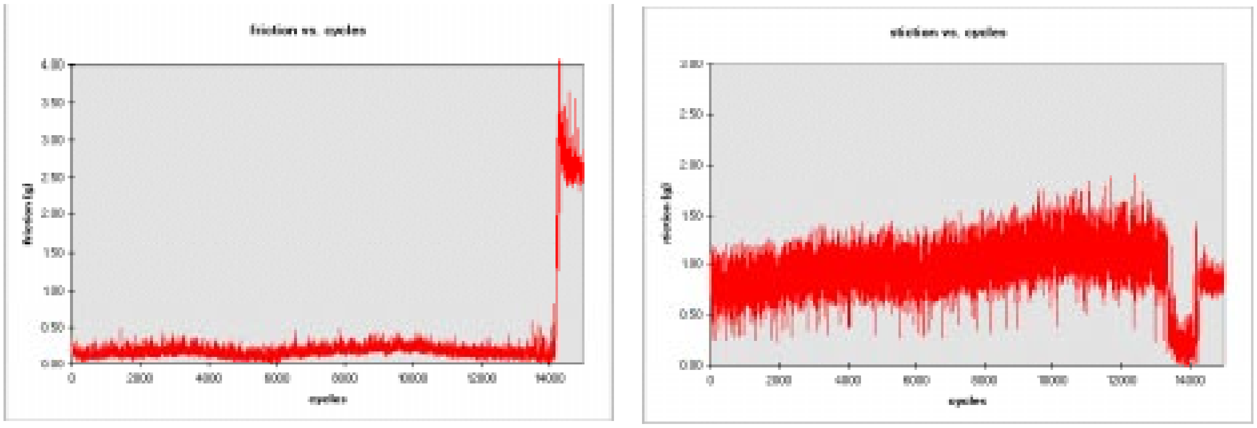
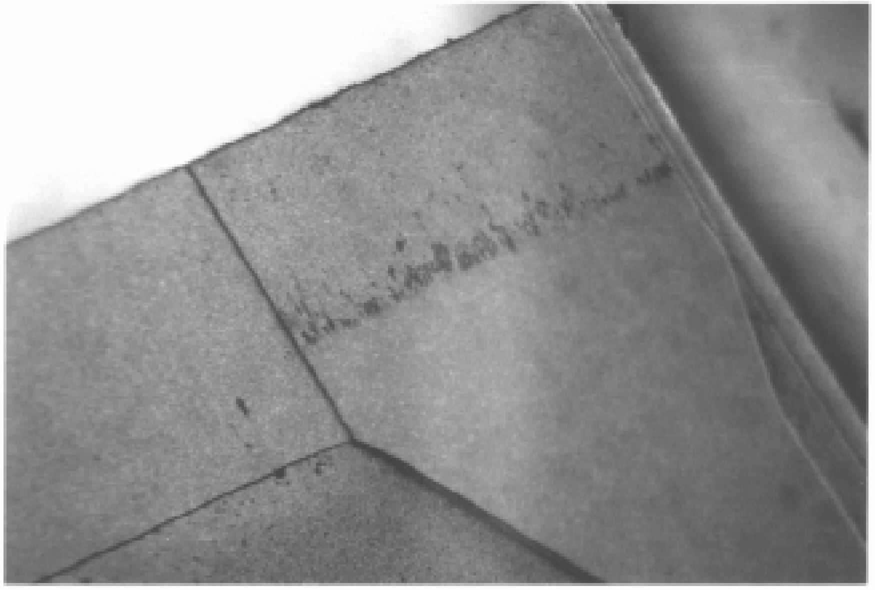
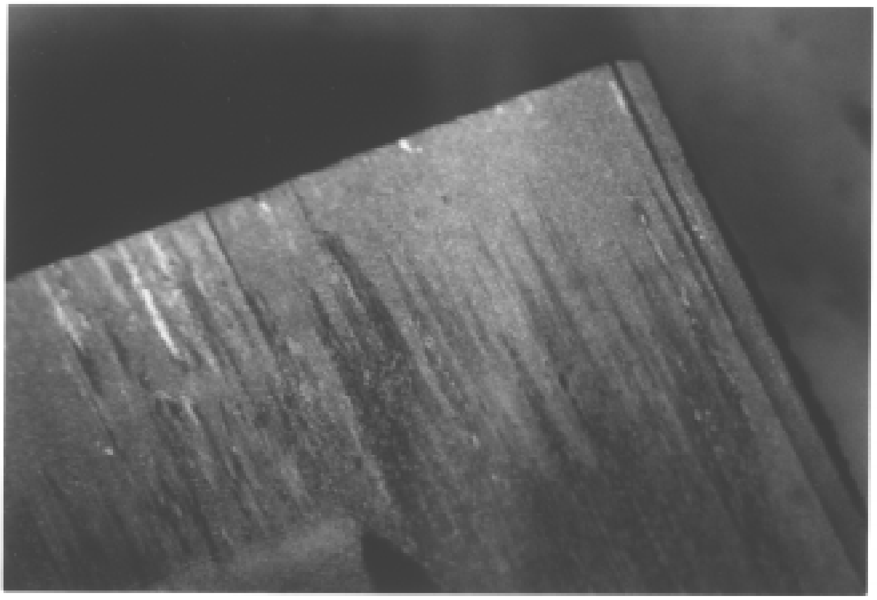


Figure 4.6 50% NILAD coated slider on 50Å DLC disk



DLC coated slider after 25000 cycles on 50Å DLC disk



NILAD coated slider after 24000 cycles on 50Å DLC disk

Figure 4.7 Wear debris on NILAD and DLC coated heads

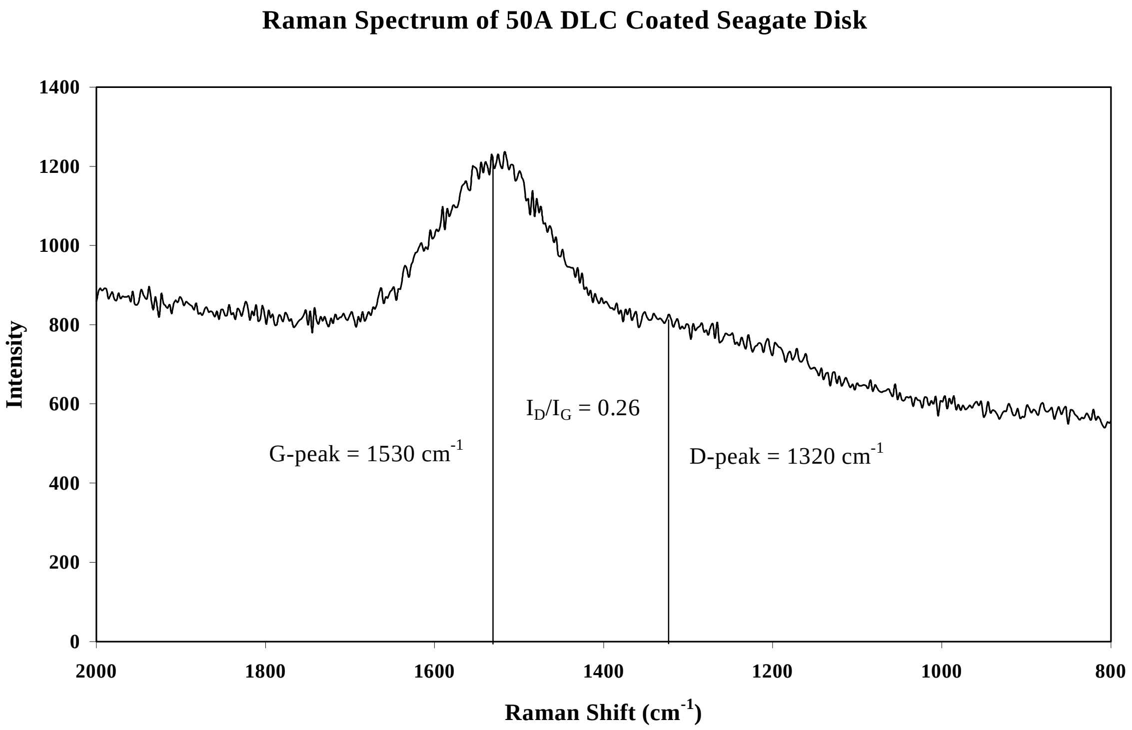


Figure 4.8 Raman Spectrum, 50Å DLC Coated Seagate Disk

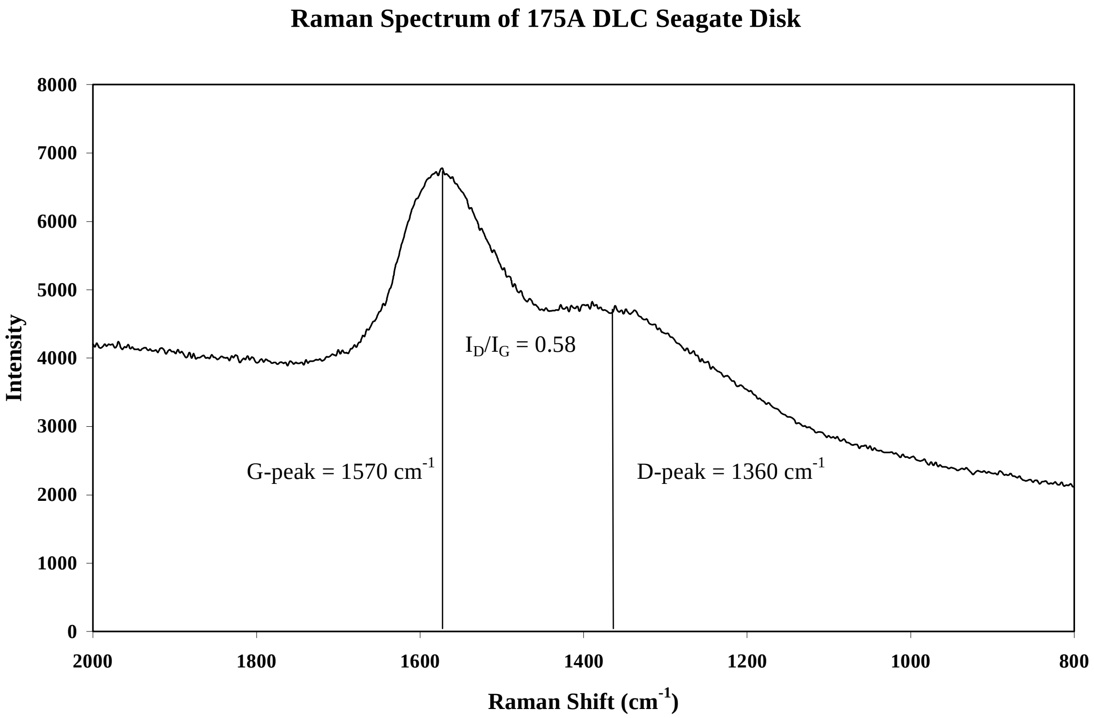


Figure 4.9 Raman Spectrum, 175Å DLC Coated Seagate Disk

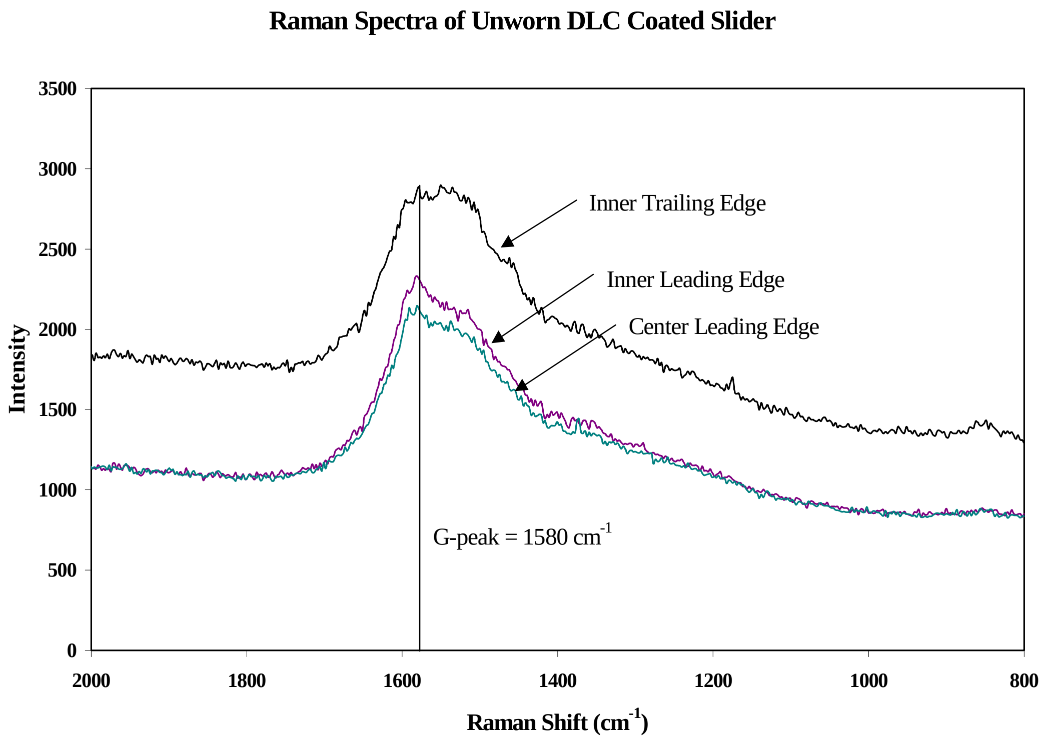


Figure 4.10 Raman Spectra, Unworn DLC Coated Slider

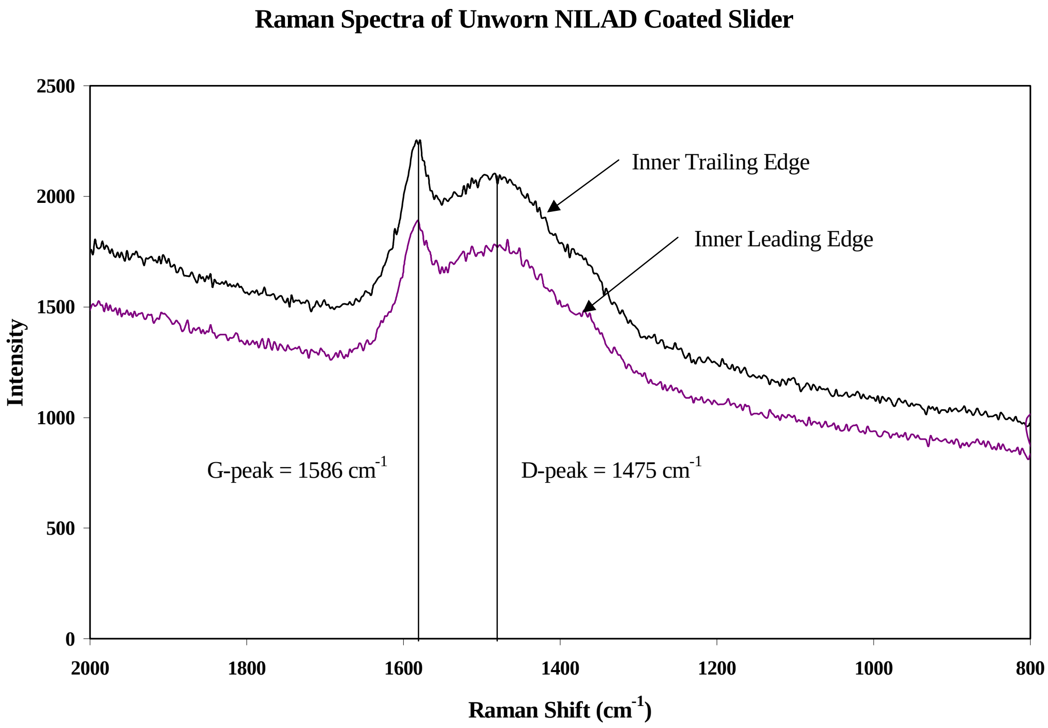


Figure 4.11 Raman Spectra, Unworn NILAD Coated Slider

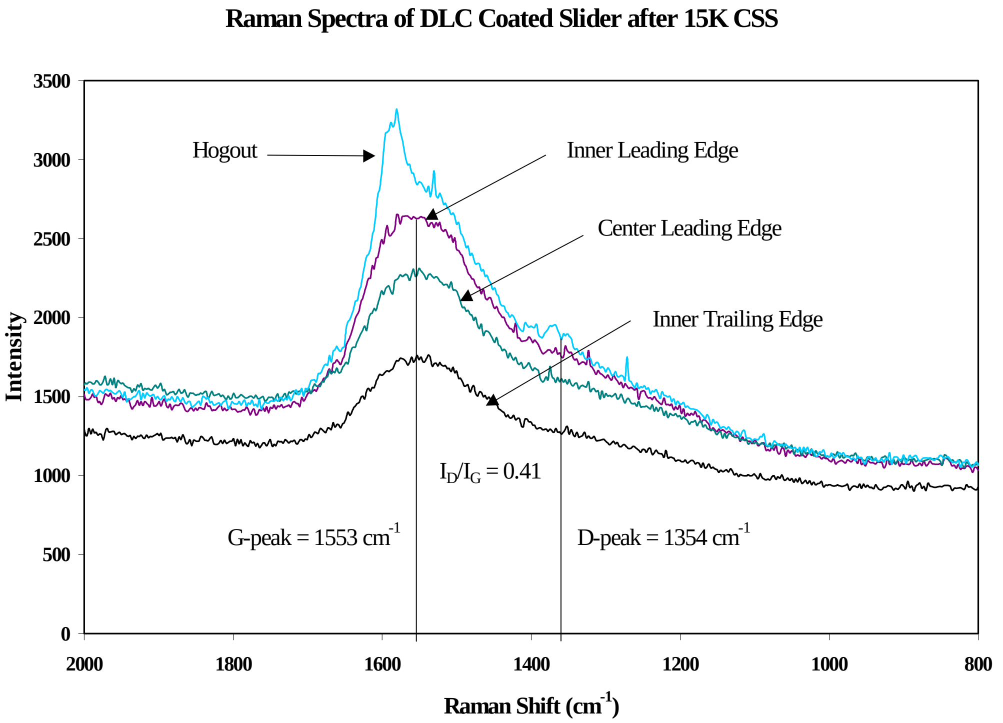


Figure 4.12 Raman Spectra, DLC Coated Slider after 10K CSS

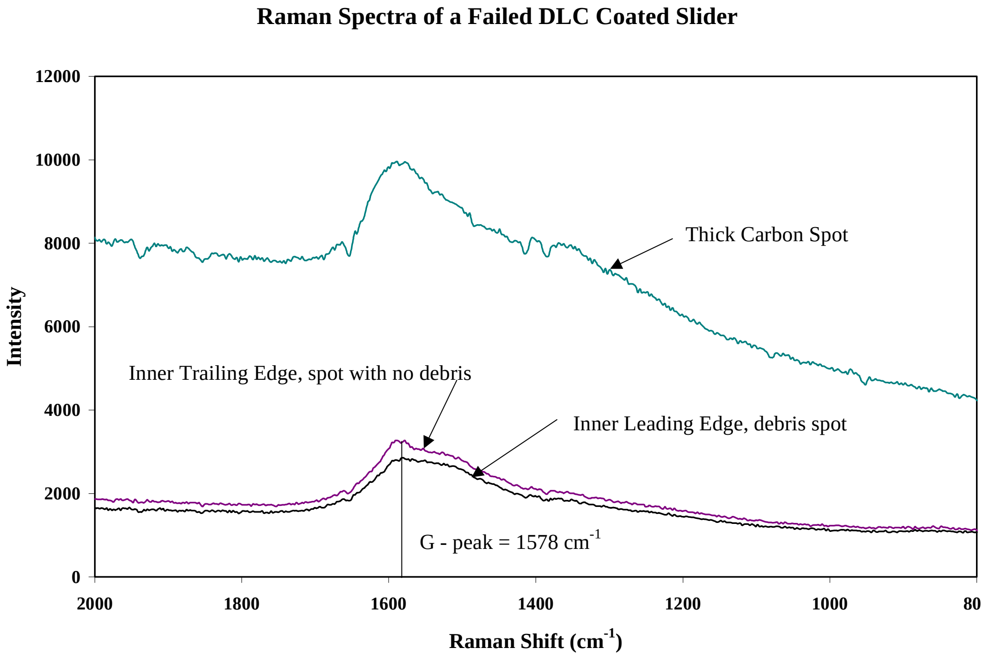


Figure 4.13 Raman Spectra, Failed DLC Coated Slider

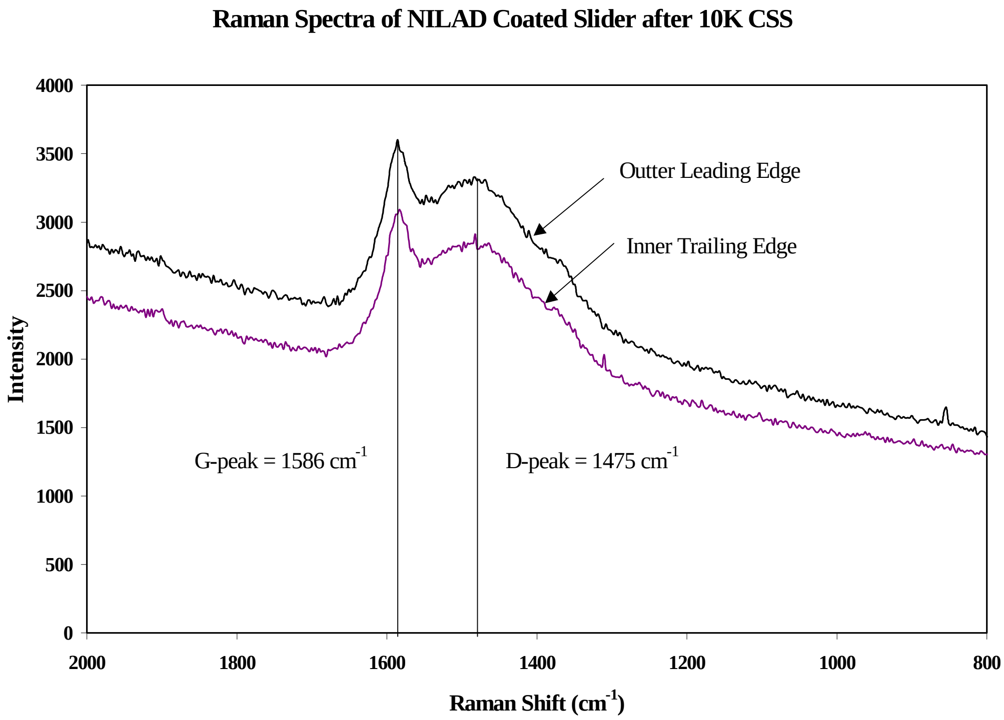


Figure 4.14 Raman Spectra, NILAD Coated Head after 10K CSS

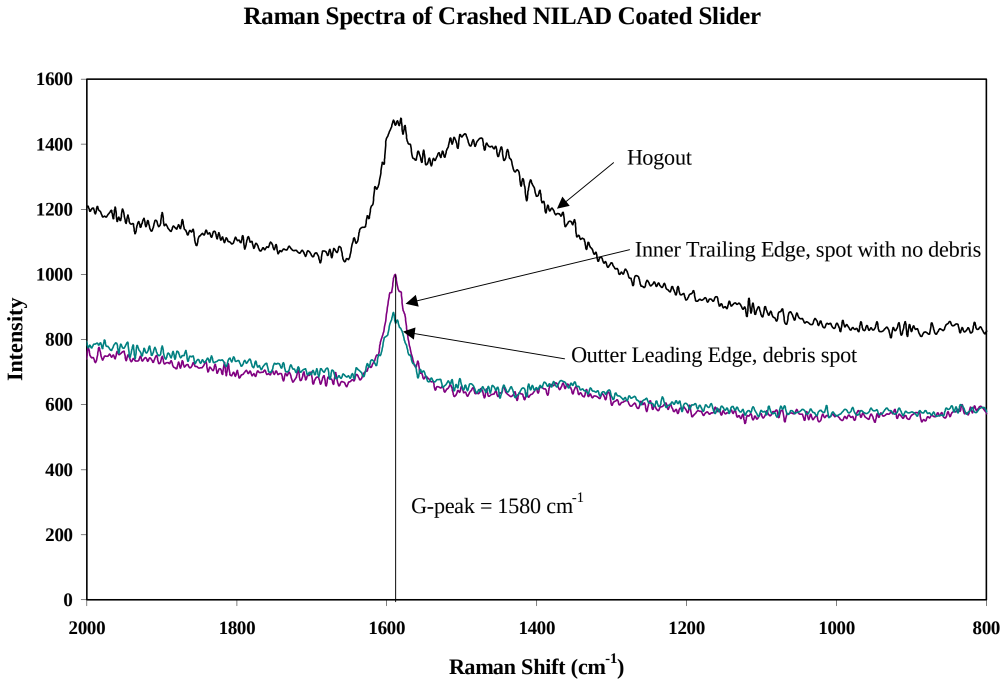


Figure 4.15 Raman Spectra, Failed NILAD Coated Slider