Surface Appearance of Highly Oriented Pyrolitic Graphite

Ștefan ȚĂLU¹,*, Rashid DALLAEV²,³ and Dinara SOBOLA²

¹Technical University of Cluj-Napoca, The Directorate of Research, Development and Innovation Management (DMCDI), Constantin Daicoviciu Street, no. 15, Cluj-Napoca, 400020, Cluj County, Romania
²Brno University of Technology, Faculty of Electrical Engineering and Communication, Physics Department, Technická 8, 616 00 Brno, Czech Republic
³Dagestan State University, Faculty of Physics, 367015 Makhachkala, M. Gadjieva 43-a, Dagestan Republic, Russia

*Corresponding authors

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Abstract. Due to a number of excellent electrical and optical properties highly oriented pyrolitic graphite (HOPG) is an attractive material to use for preparation of nanostructures. It has recommended itself as a calibration material for the methods of scanning probe microscopy. This study describes the mechanically processed surfaces of graphite for further use as substrates for depositing of thin films of semiconductor materials.

Introduction

There is a modification of carbon known as HOPG (highly oriented pyrolitic graphite) which finds a lot of applications in nano-technological calibration due to its well organized atomic positions [1-3].

An ideal combination of HOPG properties make it a perfect material for use in electronics and allow to recommend it as a substitution to currently used materials. The surface treatment method and mosaic spread (quality of HOPG) are crucial when it comes to surface texture, micro and macro-defects and roughness of obtained HOPG. Being a brittle material is another advantage of HOPG which allows processing it to meet the smoothness requirements of the substrate material.

Graphite material substrates may find their application in devices working under high temperatures. By using physical and chemical processing we can obtain the required surface roughness of HOPG. The average surface roughness for application in optics (from λ/10 down to λ/20) can be achieved. Therefore, such parameters as surface morphology are substantial when it comes to the quality of further structures design, and we should apply the dependable methods of measurement for characterization of surface [4-7].

Experimental Results

Such techniques as SEM (scanning electron microscopy) and AFM (atomic force microscopy) seem to be very promising for investigation of HOPG topography, and also can be applied in serial fabrication to achieve accurate surface control.

SEM and AFM techniques are powerful tools of nanotechnology that are capable of providing information on surface texturization at micro- and nano-scale [8-13].

These methods play a significant part in electronics and optoelectronics and are prevalent in industrial and scientific areas [14-17]. The controlling factor of performance is the surface condition of the substrate. It determines reliability of the device and also influences heterostructure properties. It is very important to seek minimization of defects in every manufacturing step. In certain situations the quality of the device can be improved by texturing. The processing and treatment of high-quality substrate are usually the first steps in preparation of heterostructures [18-21].
Figure 1 demonstrates the SEM image of HOPG after ordinary exfoliation by tape. There can also be seen the overlapping layers. Atomic smoothness of topography within one layer is expected.

![Figure 1. SEM image of HOPG surface after exfoliation by tape.](image)

AFM is a source of 3D data about topography; by using it we can implement numerical evaluation of correlation areas, sizes of grains and holes, and the nature of their distribution.

Height-height correlation function (Figure 3a) and fractal dimension (Figure 3b) for the topography of figure 2 is presented in figure 3.

![Figure 2. AFM images of HOPG surface a) 2D image; b) 3D topography, demonstrated the high of shreds.](image)
The fractal dimension $D$ (average ± standard deviation) of 3-D sample surfaces, as a measure of global scaling property determined by the cube counting method based on the linear interpolation type, is $(2.17 \pm 0.01)$. The basic properties of the height values distribution of the surface samples (including its variance, skewness and kurtosis), computed according the Ref. [22] are shown in Table 1.

Table 1. The basic properties of the height values distribution of the surface samples, for scanning square areas of $5.9 \mu m \times 5.9 \mu m$.

| The basic properties of the height values distribution of the surface samples | Values   |
|----------------------------------------------------------------------------|----------|
| $Ra$ (Sa) [nm]                                                              | 3.04     |
| $Rms$ (Sq) [nm]                                                            | 3.99     |
| Skew ($Ssk$) [-]                                                           | 0.377    |
| Kurtosis ($Sku$) [-]                                                        | 2.42     |
| Inclination $\theta$ [°]                                                   | 0.0      |
| Inclination $\varphi$ [°]                                                  | 178.7    |

The height and slope distribution functions (which belong to the first-order statistical quantities), computed as non-cumulative (i.e. densities) or cumulative, are graphically shown in Figure 4 (where $p$ is the corresponding quantity, height or slope; and abscissa is the tangent of the angle), according Ref. [22].
Summary

Quantitative and qualitative data about the surface (nano-scale optical properties, electrical properties of grain boundaries and morphology) can be also extracted from AFM images. The other parameters of importance are cleanliness and roughness. Which is why, the methods of processing of substrate materials are interesting and studying of results is helpful for obtaining better heterostructures. From both fundamental and practical points, gathering, studying and systematizing the information of surface condition seems to be useful. Parameters such as free energy, wettability are determined by estimation and measurement of nano- and micro-geometry of the surface and thus are of interest. Depending on required application the surface of HOPG can be modified (texturing). One of the ways to fabricate metamaterials with excellent properties is by nanoscale texturing of the surface.

Appendix

The basic properties of the height values distribution, including its variance, skewness and kurtosis, computed according the Ref. [22] is defined as follows:

- RMS value of the height irregularities: this quantity is computed from data variance.
- Ra value of the height irregularities: this quantity is similar to RMS value with the only difference in exponent (power) within the data variance sum. As for the RMS this exponent is q = 2, the Ra value is computed with exponent q = 1 and absolute values of the data (zero mean).
- Height distribution skewness: computed from 3rd central moment of data values.
- Height distribution kurtosis: computed from 4th central moment of data values.
- Mean inclination of facets in area: computed by averaging normalized facet direction vectors.

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