Assessment of surface roughness of substrates subjected to plasma-chemical etching

M S Glyanko¹, A V Volkov¹,² and S A Fomchenkov¹

¹Department of Nanoengineering, Samara State Aerospace University National Research University, 34 Moskovskoye shosse, Samara 443086, Russia
²Image Processing Systems Institution, 151 Molodogvardejskaya st., Samara 443001, Russia

E-mail: snake7732@yandex.ru

Abstract. The model based on fractional Brownian surface for substrate surface roughness assessment subjected to plasma-chemical etching is proposed.

1. Introduction

Surface roughness is an important factor to take into account in variety problems of science and technology, for instance, aerodynamic calculation of bodies moving in the rarefied gas or study of flows in channels and vessels. Roughness relates to such properties of a surface as microhardness, friction and aero- and hydrodynamic resistance.

Substrate surface roughness control is an important technological operation in the process of diffractive optical elements (DOE) microrelief formation. By a diffractive optical element we mean transmissive or reflective plate with a thin phase microrelief calculated within the theory of diffraction. A Diffraction grating and a zone plate are classical examples of DOE. Roughness item, even smaller than the smallest element of diffractive microrelief, can cause changes in DOE optical parameters. Thus, developing models and methods for the estimation of surface roughness of optical substrates is an actual problem.

There is a variety of models used to account for the roughness in applied and theoretical problems that can be divided into three main groups:
- regular model;
- probabilistic model;
- fractal models.

In the regular models roughness is considered as a set of elements of identical size and shape. But due to its physical features real roughness has the property of irregularity, that makes its mathematical description considerably complicated [1]. So, probabilistic models of roughness were developed, for instance, Greenwood-Williamson model that is widely used in contact mechanics to study friction between two surfaces. In this model, surface roughness is modeled by hemispheres with the same radii of curvature. The distribution of roughness height relative to the plane of contact follows the Gaussian distribution function. However, the statistical approach has its own drawbacks due to the great complexity of calculations with the need to calculate continual integrals, which are approximated by...
integrals of high multiplicity. At present fractal models of surface roughness are used increasingly. The advantage of this group of models is the relative simplicity of calculations and the possibility of accounting for nanoscale roughness [2].

2. Real surface roughness modelling using fractals

Various factors influence on the process of optical substrates surface roughness formation. These are surface treatment methods such as mechanical, chemical, plasma and plasma-chemical etching and others. Generally, the methods are independent of each other and have approximately the same scales. This fact allows us to apply to the process of surface roughness formation probability theory Central limit theorem according to which the resulting distribution is close to normal. Therefore, in this work we proposed a model for the simulation of surface roughness based on the fractional Brownian surface.

By definition, a Gaussian process \( Z(x, y) \) is called a two-dimensional fractal Brownian motion with parameter \( H \), where \( 0 < H < 1 \), if meet the following conditions:

- the function \( Z(x, y) \) is almost always continuous;
- the random variable \( Z(x + \Delta x, y + \Delta y) - Z(x, y) \) has a Gaussian distribution with zero mean and variance \( \sigma^2 (\Delta x^2 + \Delta y^2)^{2H} \), where \( t_2 > t_1 \) and \( \sigma \) is a positive constant.

The most accurate simulation of the Brownian surface is achieved by the Fourier transform of spectral density. In figure 1 and 2 you can see the simulation results of the algorithm for the Hurst parameter values \( H = 0.2 \) and \( H = 0.5 \).

![Figure 1. Fractional Brownian surface for Hurst parameter value H = 0.2.](image1)

![Figure 2. Fractional Brownian surface for Hurst parameter value H = 0.5.](image2)

Considering the problem of the difference between the real surface and a perfect fractal surface we use a structural function (1) [3]:

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\[ S_I = \frac{I}{(K - I)^2} \sum_{i=1}^{K-1} \sum_{j=1}^{K-1} \left( |X_{i+1,j} - X_{i,j}| + |X_{i,j+1} - X_{i,j}| \right) \]  

The graph of \( S_I \) against \( I \) for a perfect fractal while built in the double logarithmic scale will represent a straight line. Hurst parameter may be determined by the tangent of the angle of line slope. The wider the scope of \( I \) changes where the graph is well approximated by a straight line, the stronger fractal properties of the surface exhibits.

3. Experiments

In our study we used optical glass substrate with copper coating subjected to the procedure of plasma-chemical etching (figures 3 and 4). The elevation map of surface irregularities was obtained using three-dimensional surface structure analyzer NewView Zygo 7300, scan size – 140 μm × 110 μm.

![Image](Figure 3. The substrate surface subjected to plasma-chemical etching. The etching process durability is 3 minutes.)

4. Conclusion

The effectiveness analysis of proposed model for roughness estimation of the surfaces subjected to the operation of plasma-chemical etching proves that it is in accordance with real data obtained from the chosen type substrate and treatment method. According to the research results plasma-chemical etching operation forms the surface roughness whose height distribution can be considered Gaussian with a high confidence. It allows us to use the model for estimating of the roughness parameters of substrates subjected to the operation of plasma-chemical etching. It also can be used to determine optimal values of plasma-chemical etching parameters that lead to increase the percentage of work diffractive optical elements.
Figure 4. The substrate surface subjected to plasma-chemical etching. The etching process durability is 5 minutes.

References

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